THE RADIO HANDBOOK

Including Television and Sound Motion Pictures

BY

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PREFACE

Accumulated information on any subject, to be generally available, requires from time to time a detailed compilation. Experience shows that the most convenient form for such reference material is a handbook, arranged with a suitably complete index, making it possible to find definitions, formulas, tables, and methods of practice more quickly than by referring to textbooks and treatises on special subjects, which are usually inadequately indexed. This point of view has been constantly in mind in the preparation of the sections and the index of this handbook. For the further assistance of the reader, numerous cross references have been inserted wherever technical terms could not be adequately discussed.

The applications of formulas are clearly explained, special attention being given to the statement of the units represented by the symbols. Nothing is more discouraging when referring to a handbook or textbook than to discover that the symbols are not fully explained or that they require for their understanding the careful reading of a number of preceding pages.

During the next few years there are likely to be many new and epoch-making applications of vacuum tubes. For this reason, electrical designers and electrical engineers generally must consider that they have now at hand a unique device which has innumerable possibilities of utilization. In fact, the future development of the electrical industry is likely to depend on the relative success attained in the application of the various types of vacuum tubes in radio circuits.

Probably no other industry uses a greater variety of indicating and recording instruments than the modern power plant. For this reason, the development of radio equipment for use in such plants has brought about the introduction of control instruments which are directly related to the radio field. The extreme sensitiveness which is obtainable with various radio devices suggests the possibility of numerous untried applications in this mechanical field.

The photo-electric cell in combination with radio amplifiers is a new device which promises to be of almost as much importance in our industrial, business, and social relations as the incandescent lamp; one of the fields of this application most recently developed is in making and reproducing "talking" motion pictures. The vacuum tube, the photo-electric cell, the grid-glow tube, and the power pentode have made possible the development of a large number of devices which have apparently unlimited possibilities.

The authors are especially indebted in the preparation of this volume to the radio engineers of the Radio Corporation of America, Western Electric Company, General Electric Company, Westinghouse Electric and Manufacturing Company, American Telephone and Telegraph Company, and General Radio Company. Frequent references have been made to the files of *Journal of the American Institute of Electrical Engineers*, *Transactions of the Institute of Radio Engineers*, *Electronics*, *Electrical Journal*, *General Electric Review*, *The Bell System Technical Journal*, *Q.S.T.*, *Radio Engineering*, *Radio Broadcast*, and *Popular Science Monthly*.

Completeness and perfect accuracy are obviously difficult of attainment in a first edition of a volume covering as many subjects as are included in this one. The authors, therefore, are glad to answer inquiries regarding the accuracy of the subjects discussed, and suggestions for improvement are welcomed.

THE AUTHORS.

STATE HOUSE,
BOSTON, MASS.,
January, 1931.

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THE RADIO HANDBOOK

INTRODUCTION

RADIO COMMUNICATION

A stone thrown into smooth water starts a series of waves which spread out with a speed of a fraction of an inch per second. In a similar manner an electrical disturbance may be made to start *electric waves* which spread out in all directions with the velocity of light, or about 186,300 miles per second. Such electric waves are utilized in radio communication. The use of these waves in practice requires (1) a device to produce regular electric disturbances which cause the waves; (2) an apparatus to get the waves out into space; (3) a receiving device which is acted on by these waves in such a way as to set up electric currents in the device; (4) the transformation of these electric currents into a form which may be detected by electrical instruments.

An explanation of radio communication, then, must include the following subjects: direct currents, alternating currents, power-generating machinery, action of electric current in a vacuum, electric waves, and the apparatus used for producing and receiving electric waves.

A mechanically vibrating body such as a violin string when in motion radiates *sound waves.* Similarly, as an iron bar is heated, its molecules vibrate more and more rapidly and radiate *heat waves*, and finally, when the bar is heated to incandescence, *light waves* also are radiated.

The limits of the response of the human ear to sound waves lie between a frequency of about 18 to 20,000, where the *frequency* is the number of waves radiated per second. The eye, just as the ear, is subject to certain limitations of response. The "flicker range" of the human eye is from a frequency of below 1 to 30 per second. Thus, the heat wave from a heated bar is perceptible before a change in color is noticed. Color as detected by the eye is the effect of a light wave of a certain length.

The colors of the rainbow—red, orange, yellow, green, blue, and violet—range successively in wave length from 0.00075 to about 0.00038 millimeter. The heat wave noticed before an iron bar changes color, from black or gray to red, is called an *infra-red wave*, its wave length being longer than that of red. Similarly, above the upper limit of frequency of visible light waves, there are radiations having wave lengths which are shorter than that of violet. These waves, called *ultra-violet*, which are the shortest known, are radiated by the sun, electric arcs, radio-active substances and *X*-ray tubes.

Of longer wave length than the infra-red waves are the *electromagnetic waves*, sometimes called *Hertzian electric waves*, which are used in radio communication. The range of frequency of waves used for radio communication is from about 10,000 to 100,000,000 per second. According to the theory proposed by Maxwell in 1865, the radio, heat, light, and ultra-violet waves are all electric waves of different wave length or frequency of vibration, all of which travel through the ether (see page 36) at the rate of 186,300 miles or 300,000,000 meters per second. A chart of vibratory phenomena is shown in Fig. 1.

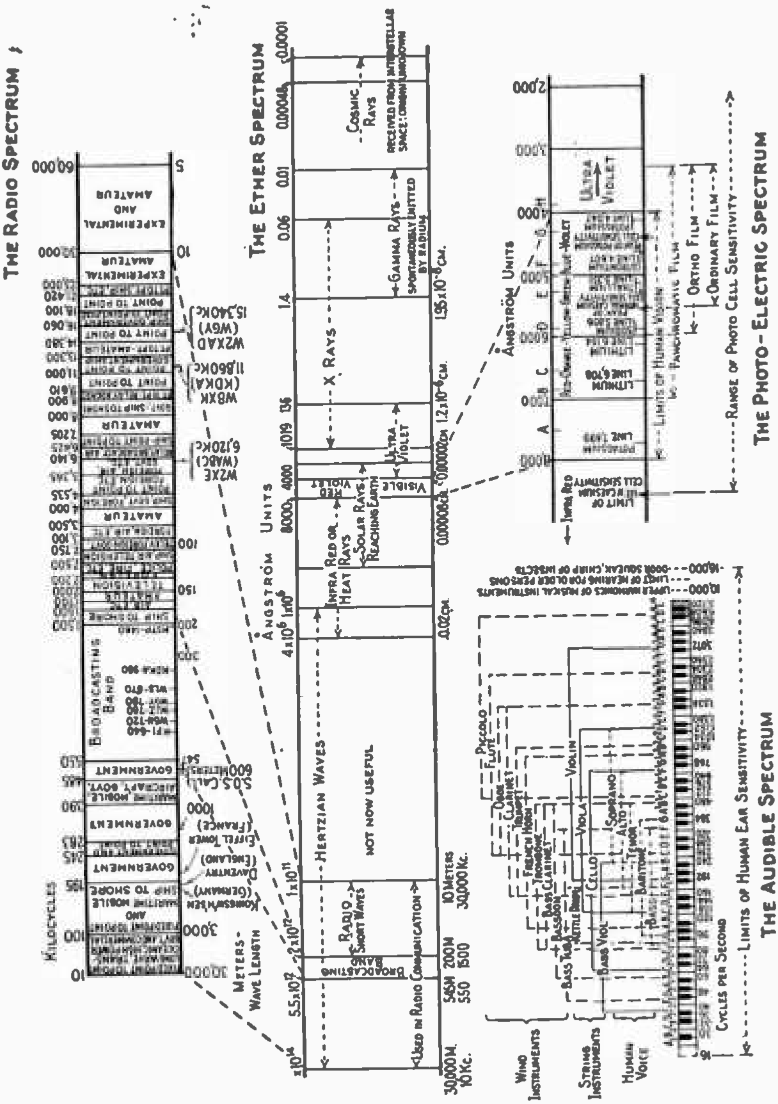

THE RADIO SPECTRUM
KILOCYCLES
METERS-WAVE LENGTH
BROADCASTING BAND
AMATEUR
EXPERIMENTAL AND AMATEUR
GOVERNMENT
POINT TO POINT
S.O.S. CALL
600 METERS
EIFFEL TOWER (FRANCE)
DAVENTRY (ENGLAND)
KONIGSWUSTERHAUSEN (GERMANY)
W2XE (WABC) 6,120KC
W8XK (KDKA) 11,860KC
W2XAD (WGY) 15,340KC
THE ETHER SPECTRUM
ANGSTROM UNITS
COSMIC RAYS
RECEIVED FROM INTERSTELLAR SPACE: ORIGIN UNKNOWN
GAMMA RAYS
SPONTANEOUSLY EMITTED BY RADIUM
X RAYS
ULTRA-VIOLET
VISIBLE
RED VIOLET
INFRA RED OR HEAT RAYS
SOLAR RAYS REACHING EARTH
HERTZIAN WAVES
NOT NOW USEFUL
RADIO SHORT WAVES
BROADCASTING WAVES
USED IN RADIO COMMUNICATION
10 METERS 30,000 KC.
200M 1500
545M 550
30,000M 10KC.
THE PHOTO-ELECTRIC SPECTRUM
ANGSTROM UNITS
INFRA RED
ULTRA VIOLET
LIMIT OF CELL SENSITIVITY
POTASSIUM LINE 7,665
LITHIUM LINE 6,708
LIMITS OF HUMAN VISION
PANCHROMATIC FILM
ORTHO FILM
ORDINARY FILM
RANGE OF PHOTO CELL SENSITIVITY
THE AUDIBLE SPECTRUM
WIND INSTRUMENTS
STRING INSTRUMENTS
HUMAN VOICE
PICCOLO
FLUTE
OBOE
CLARINET
TRUMPET
FRENCH HORN
TROMBONE
BASS CLARINET
BASSOON
BASS TUBA
KETTLE DRUMS
VIOLIN
VIOLA
CELLO
BASS VIOL
SOPRANO
ALTO
TENOR
BARITONE
BASS
CYCLES PER SECOND
LIMITS OF HUMAN EAR SENSITIVITY
10,000 UPPER HARMONICS OF MUSICAL INSTRUMENTS
LIMIT OF HEARING FOR OLDER PERSONS
16,000 DOOR SQUEAK, CHIRP OF INSECTS

FIG. 1.

SECTION I

FUNDAMENTAL UNITS AND RADIO GLOSSARY

Part 1

FUNDAMENTAL UNITS

(Arranged According to Sequence of Subjects)

Length.—In the United States the measures of length commonly employed are identical with the corresponding units used in England. The ancient fundamental unit of length was the *yard*. The *meter* has been standardized as an *international* unit of length. In 1893, what is now the Bureau of Standards fixed the value of the yard in the United States as 3,600/3,937 meters.

Table I.—Metric Prefixes

Mega-	= 1,000,000	= 10^6	Greek for "great"
Myria-	= 10,000	= 10^4	Greek for 10,000 as in word "myriad"
Kilo-	= 1,000	= 10^3	Greek for 1,000
Hecto-	= 100	= 10^2	Greek for 100
Deka-	= 01	= 10^1	Greek for 10
Deci-	$= \frac{1}{10}$	= 10^{-1}	= Latin for 10 as in U. S. dime
Centi-	$= \frac{1}{100}$	= 10^{-2}	= Latin for 100 as in U. S. cent
Milli-	$= \frac{1}{1,000}$	= 10^{-3}	= Latin for 1,000 as in U. S. mill
Micro-	$= \frac{1}{1,000,000}$	= 10^{-6}	= Greek for "small"

The *foot* is one-third of a yard; and 5,280 feet are a mile. In the international metric system the prefixes to the word "meter" indicate decimal or factorial derivatives. These same prefixes apply also to all the metric units of *weight* and *volume* as well as to *electric* and *magnetic* units. The mile is expressed in the metric system as 1,609.33 meters. One thousand meters is called a *kilometer*, so that a mile is 1.609 kilometers. Since one yard is equal to 36 inches, the length of a meter is 39.37 inches (U. S.) or approximately 3 feet 3 inches. A kilometer is approximately 0.625 mile, a centimeter (cm.) is roughly 0.4 inch, and a millimeter (mm.) may be taken without appreciable error as 0.04 inch.

It is interesting to know that the meter is approximately equal to the ten millionth part of the northern quadrant of the earth (distance from the north pole to the equator at the meridian of Paris).

Weight.—The unit of weight most commonly used in electrical work is the *gram*, which is an international unit and which was originally defined as the mass of a cubic centimeter of distilled water at 0°C. A weight of 1,000 grams is called a *kilogram*, and the *pound* in the United States has been fixed by the U. S. Bureau of Standards as 453.59 grams or 0.45359 kilogram. In terms of pounds, one kilogram is 2.205 pounds.

Area.—Space occupied in two dimensions is called an area. In the metric system the primary unit is the *square meter*. In the English system the units of area most commonly used are the *square inch* and the *square foot*. One square foot is equal to 0.0929 square meter; and one square inch equals 6.452 square centimeters, a square centimeter being 0.0001 square meter. Conversely, one square meter is 10.76 square feet and a square centimeter is 0.1550 square inch.

Volume.—Space occupied in three dimensions is called volume. In the metric system the primary unit of volume is the *cubic meter;* but the cubic decimeter or *liter* is also used. The most commonly used units of volume in the United States are the cubic inch, the cubic foot, and the gallon. In terms of the metric system one cubic foot is 0.02832 cubic meter and one cubic inch is 16.39 cubic centimeters. Conversely, one cubic meter is 35.31 cubic feet and one cubic centimeter is 0.06102 cubic inch. One cubic foot is 28.32 liters, and, conversely, one liter is 0.0353 cubic foot or 61.02 cubic inches. One gallon (4 quarts or 8 pints) in the United States is defined as 231 cubic inches, which is equal to 4.546 liters. Conversely, one liter is equal to 0.220 gallon. The British or "Imperial" gallon is 277.274 cubic inches.

Pressure.—Intensity of pressure is the ratio of the pressure exerted to the surface area over which it is applied, or it is the pressure per unit of area. The so-called "metric" unit of pressure is the *dyne* per square centimeter. The standard atmospheric pressure is 760 millimeters of mercury at the sea level and at the temperature of 0°C. Pressures are frequently calculated in atmospheres. In the United States, unit pressures are usually expressed in pounds per square inch and in most other countries in kilograms per square centimeter. Since the weight of a cubic inch of mercury at 0°C. is 0.4906 pound and the weight of a cubic inch of water is 0.0360 pound, pressure in inches of mercury can be reduced to pounds per square inch by multiplying by 0.4906 or by dividing by 2.035. Pressures in centimeters of mercury are reduced to pounds per square inch by multiplying by 0.1903. Kilograms per square centimeter are reduced to pounds per square inch by multiplying the kilograms per square centimeter by 14.223; and pounds per square inch can be expressed in kilograms per square centimeter by multiplying the pounds per square inch by 0.0703.

The pressure as measured by a suitable instrument in pounds per square inch, kilograms per square centimeter or millimeters of mercury, when added to the pressure of the atmosphere is called the *absolute pressure.*

Weight of Water.—A cubic foot of water at 70°F. weighs 62.3 pounds.

Heat.—The unit of heat commonly used is the quantity required to raise the temperature of one pound of water one degree Fahrenheit, this quantity of heat being called a *British thermal unit* (B.t.u.). In the metric system of units the unit of heat is defined as the quantity required to raise the temperature of one gram of water one degree Centigrade, this quantity being called a *gram calorie* (small calorie). Another unit, which is one thousand times as large, is called the *kilogram calorie* (large calorie). It is also called, in German texts, the *wärme-einheit* (W.E.). One British thermal unit is equal to 0.252 kilogram calorie.

Mechanical Equivalent of Heat.—The equivalent of heat in terms of mechanical units as accepted in America is that one British thermal unit (B.t.u.) is equivalent to 777.5 foot-pounds. The U. S. Bureau of Standards, however, uses in its work the value represented by 778.2 foot-pounds at 59°F. and 777.5 foot-pounds at 68°F.

Work.—The energy expended by a force of one pound acting through a distance of one foot in the line of action of the force is called a *foot-pound.* In other words, work in foot-pounds is equal to the force in pounds multiplied by the distance in feet.

Mechanical Power.—The rate of performing work is called *power.* The unit of mechanical power is *horsepower* (hp.), which is defined as the performance of 33,000 foot-pounds of work in a minute or 550 foot-pounds in a second. A mechanical unit of power exerted continuously for one hour is called a *horsepower-hour.*

Temperature.—In America, temperatures in ordinary practice are measured in Fahrenheit units. In the *Fahrenheit* scale of temperature the melting point of ice is 32° and the temperature of boiling water (at atmospheric pressure) is 212°. The difference, therefore, between the boiling temperature of water and the melting temperature of ice is 180°. In electrical work another scale of temperatures is frequently used, and in fact in nearly all exact work this other scale is the one most used. This other scale, known as *Centigrade*, has its zero temperature at the melting point of ice and the boiling temperature of water is 100°. The difference, therefore, between the boiling temperature of water and the melting temperature of ice is 100° on the Centigrade scale. The following equations are used to convert temperatures from one scale to the other:

$$\text{Fahrenheit degrees} = \tfrac{9}{5}\ \text{Centigrade degrees plus } 32.$$
$$\text{Centigrade degrees} = \tfrac{5}{9}\ (\text{Fahrenheit degrees minus } 32).$$

Torque.—The moment of a twisting couple usually exerted about a shaft as an axis is the *torque*. It is measured by a unit of force (a dyne or a pound) acting at right angles to a radius arm of one unit of length (a centimeter or a foot).

Electromotive Force (e.m.f.)—A difference of electrical potential is necessary to establish an electromotive force. The practical unit of electromotive force or difference of potential (electric pressure) is called a *volt*. See also page 46.

Electric Current.—The practical unit of current is the *ampere*. It is the current which flows through a wire or other conductor having a resistance of one ohm (see below) when there is a difference of potential of one volt between its ends.

Electrical Power.—The unit of electrical pressure or *difference in potential*, a volt, when multiplied by the unit of electrical current, an ampere, is the electrical power, which is called a *watt*. The kilowatt, a larger unit of electrical power, is 1,000 watts. A kilowatt of power delivered continuously for one hour is a *kilowatt-hour*.

Quantity of Electricity.—The unit of quantity of electricity is called a *coulomb*, which is the quantity of electricity which passes a cross-section of wire or other conductor in one second when the *rate of flow* is one ampere.

Electrical Resistance.—The unit used to designate an obstruction to the flow of electric current is called an *ohm*. The ratio of the difference of potential in volts to the current in amperes in a wire or other conductor is expressed in ohms. The *specific resistance* of a metal or other substance is equal to the resistance offered by a unit cube of the substance as measured between a pair of parallel sides. See also page 48.

Electric Capacity or Capacitance.—The power of a circuit to store or hold an electric charge is called its electric capacity. The ratio of an electric charge (in coulombs) on a conductor to the electric potential difference (in volts) producing that charge is called the *farad*. As the farad is too large a unit for practical purposes, the *microfarad* (mf.), which is one millionth of a farad, is generally used. For condensers such as are used for radio purposes the micromicrofarad (mmf.) or 10^{-12} (see page 12) farad is a more suitable unit.

Dielectric Constant.—The ratio of the capacity (capacitance) of a condenser with coatings which are separated by a given substance to the capacity (capacitance) of a similar condenser with plates separated by air is the *dielectric constant* of the condenser with the coatings. See also page 55.

Frequency (f.).—In a simple alternating-current circuit, the number of cycles (waves) produced by the current in a second is the *frequency*. The practical unit is a *cycle per second*. The frequency required for radio purposes is usually stated in kilocycles per second, a *kilocycle* being 1,000 cycles.

Dyne.—The force acting upon a mass of one gram during one second giving this mass a velocity of one centimeter per second is a *dyne*.

Magnetic Pole.—The portion of the surface of a magnet where the magnetic lines enter or leave the surface is a magnetic pole.

Unit Magnetic Pole.—When one magnetic pole repels an equal and like magnetic pole with a force of one dyne at a distance of one centimeter, it is a unit magnetic pole.

Flux (ϕ).—The flow of magnetic lines that passes through any magnetic circuit is called the *magnetic flux*. See also page 59.

Flux Density (V).—The ratio of the magnetic flux in any cross-section of a magnetic circuit to the area of that cross-section is the magnetic flux density, which is measured by a unit called a *gauss*.

Magnetomotive Force (m.m.f.).—The force which produces the magnetic flux is the magnetomotive force in a magnetic circuit. It corresponds to the electromotive force in an electric circuit. The unit of magnetomotive force is the *gilbert*. A more convenient practical unit, however, is the *ampere-turn* which is 1.257 gilberts. See also page 63.

Reluctance.—The obstruction in a magnetic circuit to the flow of the flux is the reluctance. It is the ratio of the magnetomotive force to the magnetic flux.

Magnetic Field Intensity (H).—The force in dynes exerted on a unit magnetic pole is the magnetic field intensity.

Permeability (μ).—The ratio of the magnetic flux density to the magnetizing force is the permeability ($\phi:H$). It is actually the ratio of the magnetic flux in any cross-section to the flux which would exist if the cross-section were replaced with air, the magnetomotive force remaining unchanged. See also page 64.

Reluctivity.—The reciprocal of permeability is the reluctivity.

Power Conversion.—One kilowatt is equal to 1.34 horsepower; or, in other words, one horsepower is almost exactly 0.75 kilowatt (actually 746 watts). One kilowatt-hour is 3.412 B.t.u. or 1.34 horsepower-hours.

Apparent Power.—In an alternating-current circuit, the apparent power is obtained by multiplying together the volts and amperes to obtain *apparent watts.* The true power or *true watts* in an alternating-current circuit is found by multiplying together the volts, the amperes, and the cosine (page 12) of the angle of the phase difference (see below) or the power factor.

Power Factor (p.f.).—In an alternating-current circuit, the true power is the product of the square of the current I and the effective resistance $\acute{R}$. The apparent power is the voltage E times the current I. Then, if the true power is represented by P, the ratio of P to E times I (volt-amperes) is the *power factor.*

Root-mean-square (r.m.s.) **Value.**—The square root of the mean of the squares of the instantaneous values for one complete cycle is called the root-mean-square value. Unless otherwise specified the numerical value of an alternating current refers to its root-mean-square value. In the case of a sine wave (page 72) the root-mean-square value is equal to its maximum or crest value $\div \sqrt{2}$.

Form Factor.—The ratio of the root-mean-square value to the algebraic mean of the ordinates taken over a half cycle beginning with the zero value is the *form factor.* The form factor of a sine wave is 1.11.

Vector Diagram.—A quantity which possesses both numerical magnitude and direction, as, for example, an alternating current, may be represented by a line called a *vector.* Sine waves of voltage and current can be represented by vectors, that is, the vectors being proportional in magnitude to the waves which they represent. The angle between the vectors is always equal to the angle between the sine waves of voltage and current which they represent.

Vectors may be combined as forces are combined in mechanics, preferably by the graphical methods. Impedances (page 37) and admittances (page 33) may be similarly combined. In the latter case, the usual method is to resolve the impedances into their component resistances and reactances (page 39), then combine all resistances and all reactances, from which the resultant impedance Z is obtained.
Thus,

$$Z_1^2 + Z_2^2 = (R_1 + R_2)^2 + (X_1 + X_2)^2,$$ where R_1 and X_1 are the components of Z_1, and R_2 and X_2 are the components of Z_2.

Phase Differences.—When there is only resistance (and no reactance) in an alternating-current circuit, the current and the voltage are *in phase* with each other. When there is inductance only in an alternating-current circuit, the current *lags* behind the voltage by 90 degrees; and when there is capacity (capacitance) only in an alternating-current circuit, the current *leads* the voltage by 90 degrees.

Resonance.—In an alternating-current circuit which contains both inductive and capacity reactances in series, it is possible to obtain an enormous rise in electromotive force by adjusting the reactances or the frequency. At the maximum value there is the so-called "series resonance."

When an inductive reactance and a capacity reactance are joined in parallel, it is possible to obtain a very large increase in the current by adjusting the reactances or the frequency. At the maximum value "current resonance" will take place. The condition of resonance, except in tuned circuits (see below) where it is especially desired as for radio purposes, is otherwise to be avoided.

Series Resonance.—In a circuit in which a resistance, an inductance, and a capacity are in *series*, the total reactance will be zero at a frequency (page 9) at which the inductive reactance is equal to the capacity reactance.

Coupling.—When one part or portion of a circuit is connected with another, they are coupled.

Tuned Circuit.—When the inductive reactance and the capacity reactance in a circuit are equal (inductance, capacity, and resistance in series), the circuit is said to be in *resonance*, meaning that it is "tuned" to the operating frequency of the circuit.

Eddy Current.—Secondary or parasitic currents in those parts of a circuit which are interlinked with alternating or pulsating magnetic flux are *eddy currents* (also called *Foucault currents*). The eddy currents can be greatly reduced by laminating the circuit, that is, by making it of the thin sheets, each insulated from each other.

Hysteresis.—When iron or steel is subjected to alternating magnetization, a phenomenon which may be called *magnetic friction* between the molecules of the material produces values of magnetization (magnetic flux) which are different for *increasing* and *decreasing* values of magnetic intensity.

Skin Effect.—An alternating-current phenomenon which materially affects conductors of large cross-section is produced by electric currents passing through the strands of a cable around the outer surface where they encounter less inductance and impedance than in the strands near the center, thus causing the outer strands of a cable to carry more current than the inner strands.

Magnetic Saturation.—When the intensity of magnetization is increased beyond a limiting value, there is practically no increase in the magnetic flux. In other words, at this limiting value of magnetization, the iron or steel becomes magnetically *saturated*.

Exponential Term.—When the exponent used with a number or symbol is a positive whole number, it means that the number or symbol is to be raised to the *power* indicated by the exponent; thus, a^2 means that the symbol a is to be multiplied by itself once ($a \times a$). When the exponent is a positive fraction, it means that the corresponding root of the number or symbol is to be taken; thus, $a^{1/2}$ means that the square root is to be taken of a ($\sqrt{a}$). Similarly, $a^{1/4}$ is the fourth root of a. When the exponent is a negative number or a negative fraction it means that the numerical exponent refers to the "power" or "root" indicated by the number or fraction; thus, a^{-2} is $1/a^2$, $a^{-1/2}$ is $1/a^{1/2}$ or $1 \div \sqrt{a}$.

Wire Gages.—The American wire gage (A.W.G.), also called "B. & S." (Brown & Sharpe), is based on a constant ratio between diameters of successive gage numbers. The ratio of any diameter to the next smaller being 1.123, the corresponding ratio of cross-sections is approximately 1.25 or $5/4$. See tables II and III.

Mil.—One-thousandth (0.001) of an inch is called a *mil.*

Circular Mil.—The area of a circular wire which is one mil (0.001 inch) in diameter is a *circular mil.* The square of the diameter of a circle in mils is the area in circular mils.

Trigonometric Functions.—The relations of *sine* (sin), *cosine* (cos), *tangent* (tan), and *cotangent* (cot) of a unit circle are simply expressed by the equations, $\sin^2 A + \cos^2 A = 1$, $\tan A = \sin A \div \cos A$, and $\cot A = 1 \div \tan A$, where A is the angle of which these relations are required. These trigonometric functions are given for various angles in table XI.

Natural (or *Naperian*) *logarithms* of numbers can be calculated from the corresponding common logarithms as given on pages 26 and 27 by multiplying the logarithm (characteristic and mantissa) by 2.3. For example, the common logarithm of 84.4 is 1.9263. The natural logarithm of this number is, therefore, 1.9263×2.3 or 4.431.

TABLE II.—ALLOWABLE CARRYING CAPACITIES OF COPPER WIRES

Number of wire American (B.& S.) gage	Diameter of solid wires, mils[1]	Area, circular mils	*A* Rubber insulation, amperes	*B* Varnished cambric-cloth insulation, amperes	*C* Other insulation, amperes
18	40.3	1,624	3	.....	5
16	50.8	2,583	6	.....	10
14	64.1	4,107	15	18	20
12	80.8	6,530	20	25	25
10	101.9	10,380	25	30	30
8	128.5	16,510	35	40	50
6	162.0	26,250	50	60	70
5	181.9	33,100	55	65	80
4	204.3	41,740	70	85	90
3	229.4	52,630	80	95	100
2	257.6	66,370	90	110	125
1	289.3	83,690	100	120	150
0	324.9	105,500	125	150	200
00	364.8	133,100	150	180	225
000	409.6	167,800	175	210	275
		200,000	200	240	300
0000	460.	211,600	225	270	325
		250,000	250	300	350
		300,000	275	330	400
		350,000	300	360	450
		400,000	325	390	500
		500,000	400	480	600
		600,000	450	540	680
		700,000	500	600	760
		800,000	550	660	840
		900,000	600	720	920
		1,000,000	650	780	1,000
		1,100,000	690	830	1,080
		1,200,000	730	880	1,150
		1,300,000	770	920	1,220
		1,400,000	810	970	1,290
		1,500,000	850	1,020	1,360
		1,600,000	890	1,070	1,430
		1,700,000	930	1,120	1,490
		1,800,000	970	1,160	1,550
		1,900,000	1,010	1,210	1,610
		2,000,000	1,050	1,260	1,670

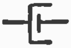
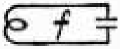
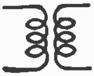
[1] 1 mil = 0.001 inch.

TABLE III.—STANDARDIZED STRANDING OF WIRES

Strands			Cable		Allowable carrying capacities, amperes		
Number of strands	Diameter, mils	Number of wire American (B. & S.) gage	Area, circular mils	Outside diameter over copper, inches	*A* Rubber insulation	*B* Varnished cambric-cloth insulation	*C* Other insulation
7	25	22	4,490	0.075	15	18	20
7	32	20	7,150	0.096	20	25	25
7	40	18	11,370	0.120	25	30	35
7	51	16	18,080	0.153	35	40	50
7	64	14	28,740	0.192	50	60	70
7	81	12	45,710	0.253	70	85	90
7	91	11	58,000	0.273	80	95	110
7	102	10	72,680	0.306	90	110	130
19	64	14	78,030	0.320	100	120	150
19	72	13	98,380	0.360	125	150	175
19	81	12	124,900	0.405	150	180	210
19	91	11	157,300	0.455	175	210	250
19	107	[1]	217,500	0.540	225	270	325
19	114	9	248,700	0.570	250	300	350
37	91	11	306,400	0.637	275	330	400
37	97	[1]	347,500	0.679	300	360	450
37	102	10	381,200	0.714	325	390	500
37	116	[1]	484,300	0.798	400	480	600
61	102	10	633,300	0.918	475	565	700
61	107	[1]	698,000	0.963	500	600	750
61	114	9	798,300	1.030	550	660	825
61	121	[1]	893,100	1.090	600	720	900
61	128	8	1,007,000	1.150	650	780	1,000
91	114	9	1,191,000	1.250	725	870	1,125
91	128	8	1,502,000	1.410	850	1,020	1,350
127	114	9	1,660,000	1.480	900	1,100	1,460
127	128	8	2,097,000	1.660	1,100	1,300	1,700

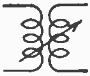
[1] These individual strands are odd sizes not listed in the American or B. & S. Wire Tables.

TABLE IV.—GRAPHIC SYMBOLS USED IN RADIO COMMUNICATION
Proposed American Tentative Standard

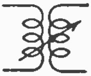
1. Aerial (antenna)		19. Inductor, iron core	
2. Ammeter		20. Inductor, variable	
3. Arc		21 Jack	
4. Battery (the positive electrode is indicated by the long line)		22. Key	
5. Coil antenna		23. Lightning arrester	
6. Condenser fixed		24. Loud-speaker	
7. Condenser, fixed, shielded		25. Microphone (telephone transmitter)	
8. Condenser, variable		26. Photoelectric cell	
9. Condenser, variable (with moving plate indicated)		27. Piezo-electric plate	
10. Condenser, variable, shielded		28. Resistor	
11. Counterpoise		29. Resistor, adjustable	
12. Crystal detector		30. Resistor, variable	
13. Frequency meter (wavemeter)		31. Spark gap, rotary	
14. Galvanometer		32. Spark gap, plain	
15. Glow lamp		33. Spark gap, quenced	
16. Ground		34. Telephone receiver	
17. Inductor		35. Thermoelement	
18. Inductor, adjustable		36. Transformer, air core	

37. Transformer, iron core

38. Transformer with variable coupling



39. Transformer, with variable coupling (with moving coil indicated



40. Voltmeter

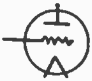
41. Wires, joined

42. Wires, crossed, not joined

Vacuum Tubes

43. Diode (or half-wave rectifier)

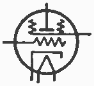
44. Triode (with directly heated cathode)



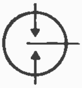
45. Triode (with indirectly heated cathode)

46. Screen-grid tube (with directly heated cathode)

47. Screen-grid tube (with indirectly heated cathode)



48. Rectifier tube, full wave (filamentless)



49. Rectifier tube, full wave (with directly heated cathode)

50. Rectifier tube, half wave (filamentless)

TABLE V.—RELATION OF WAVE LENGTH, FREQUENCY, AND THE PRODUCT OF CAPACITY AND INDUCTANCE IN OSCILLATORY CIRCUITS

Wave length, meters W	Frequency, multiply values below by 1,000	$2\pi f$ Multiply values below by 1,000	$C \times L$ C in microfarads L in cm.[1]
1	300,000	1,884,000	0.0003
2	150,000	942,000	0.0011
3	100,000	628,000	0.0018
4	75,000	471,000	0.0045
5	60,000	377,000	0.0057
6	50,000	314,200	0.0101
7	42,900	269,000	0.0138
8	37,500	235,500	0.0180
9	33,330	209,400	0.0228
10	30,000	188,400	0.0282
15	20,000	125,600	0.0635
20	15,000	94,200	0.1129
25	12,000	75,400	0.1755
30	10,000	62,800	0.2530
35	8,570	53,800	0.3446
40	7,500	47,100	0.450
45	6,670	41,900	0.570
50	6,000	37,700	0.704
55	5,450	34,220	0.852
60	5,000	31,420	1.014
65	4,620	28,970	1.188
70	4,290	26,900	1.378
75	4,000	25,120	1.583
80	3,750	23,520	1.801
85	3,529	22,120	2.034
90	3,333	20,920	2.280
95	3,158	19,830	2.541
100	3,000	18,840	2.816
105	2,857	17,940	3.105
110	2,727	17,130	3.404
115	2,609	16,380	3.721
120	2,500	15,710	4.05
125	2,400	15,070	4.40
130	2,308	14,480	4.76
135	2,222	13,950	5.13
140	2,144	13,450	5.52
145	2,069	12,980	5.92
150	2,000	12,560	6.34
155	1,935	12,150	6.76
160	1,875	11,770	7.20
165	1,818	11,410	7.66
170	1,765	11,080	8.13
175	1,714	10,760	8.62
180	1,667	10,470	9.12
185	1,622	10,180	9.63
190	1,579	9,910	10.16
195	1,538	9,660	10.71
200	1,500	9,420	11.26
205	1,463	9,190	11.83

Wave length, meters W	Frequency, multiply values below by 1,000	$2\pi f$ Multiply values below by 1,000	$C \times L$ C in microfarads L in cm.
210	1,429	8,970	12.41
215	1,395	8,760	13.01
220	1,364	8,560	13.62
225	1,333	8,370	14.25
230	1,304	8,190	14.89
235	1,277	8,020	15.55
240	1,250	7,850	16.22
245	1,225	7,690	16.90
250	1,200	7,540	17.60
255	1,177	7,390	18.31
260	1,154	7,250	19.03
265	1,132	7,110	19.77
270	1,111	6,980	20.52
275	1,091	6,860	21.29
280	1,071	6,740	22.07
285	1,053	6,620	22.87
290	1,035	6,500	23.68
295	1,017	6,380	24.50
300	1,000	6,280	25.33
310	968	6,080	27.05
320	938	5,890	28.83
330	909	5,700	30.66
340	882	5,540	32.55
350	857	5,380	34.48
360	833	5,230	36.48
370	811	5,090	38.54
380	790	4,953	40.7
390	769	4,830	42.8
400	750	4,710	45.0
410	732	4,590	47.3
420	714	4,480	49.7
430	698	4,380	52.0
440	682	4,280	54.5
450	667	4,190	57.0
460	652	4,100	59.6
470	638	4,010	62.3
480	625	3,920	64.8
490	612	3,842	67.6
500	600	3,766	70.4
510	588	3,692	73.2
520	577	3,620	76.0
530	566	3,552	79.0
540	556	3,485	82.1
550	545	3,422	85.2
560	536	3,361	88.3
570	526	3,302	91.5
580	517	3,246	94.7
590	509	3,193	98.0

TABLE V.—RELATION OF WAVE LENGTH, FREQUENCY, AND THE PRODUCT OF CAPACITY AND INDUCTANCE IN OSCILLATORY CIRCUITS.—(*Continued*)

Wave length, meters W	Frequency, multiply values below by 1,000	$2\pi f$ Multiply values below by 1,000	$C \times L$ C in microfarads L in cm.[1]	Wave length, meters W	Frequency, multiply values below by 1,000	$2\pi f$ Multiply values below by 1,000	$C \times L$ C in microfarads L in cm.[1]
600	500	3,140	101.4	1,550	193.5	1,215	676
610	492	3,088	104.7	1,600	187.5	1,177	720
620	484	3,038	108.2	1,650	181.8	1,142	766
630	476	2,990	111.7	1,700	176.5	1,108	813
640	469	2,942	115.4	1,750	171.4	1,076	862
650	462	2,896	118.8	1,800	166.7	1,046	912
660	455	2,852	122.5	1,850	162.2	1,017	963
670	448	2,810	126.3	1,900	157.9	990	1,016
680	441	2,768	130.2	1,950	153.8	965	1,071
690	435	2,730	134.1				
				2,000	150.0	942	1,126
700	429	2,692	137.8	2,050	146.3	920	1,183
710	423	2,654	141.9	2,100	142.9	898	1,241
720	417	2,616	145.9	2,150	139.5	876	1,301
730	411	2,580	150.0	2,200	136.4	856	1,362
740	405	2,544	154.0	2,250	133.3	838	1,425
750	400	2,510	158.3	2,300	130.4	819	1,489
760	394.8	2,476	162.6	2,350	127.7	801	1,555
770	389.6	2,443	166.8	2,400	125.0	784	1,622
780	384.6	2,412	171.4	2,450	122.5	768	1,690
790	379.8	2,382	175.6				
				2,500	120.0	753	1,760
800	375.0	2,353	180.1	2,550	117.7	738	1,831
810	370.4	2,325	184.7	2,600	115.4	724	1,903
820	365.9	2,297	189.3	2,650	113.2	710	1,977
830	361.4	2,270	194.0	2,700	111.1	697	2,052
840	357.1	2,242	198.5	2,750	109.1	684	2,129
850	352.9	2,214	203.4	2,800	107.1	672	2,207
860	348.8	2,188	208.2	2,850	105.3	660	2,287
870	344.8	2,162	213.2	2,900	103.5	648	2,366
880	340.9	2,138	217.9	2,950	101.7	638	2,450
890	337.1	2,115	222.9				
				3,000	100.0	628	2,533
900	333.3	2,092	228.0	3,500	85.7	538	3,448
910	329.7	2,070	233.2	4,000	75.0	471	4,500
920	326.1	2,047	238.1	4,500	66.7	418	5,700
930	322.6	2,024	243.4	5,000	60.0	377.0	7,040
940	319.1	2,003	248.7	5,500	54.5	342.2	8,520
950	315.8	1,982	254.1	6,000	50.0	314.2	10,140
960	312.5	1,962	259.5	6,500	46.2	289.8	11,880
970	309.3	1,942	264.9	7,000	42.9	268.8	13,780
980	306.1	1,922	270.4	7,500	40.0	251.0	15,830
990	303.0	1,902	275.9				
				8,000	37.50	235.2	18,010
1,000	300.0	1,884	281.6	8,500	35.29	221.4	20,340
1,050	285.7	1,794	310.5	9,000	33.33	209.2	22,800
1,100	272.7	1,712	340.4	9,500	31.58	198.2	25,410
1,150	260.9	1,637	372.1	10,000	30.00	188.4	28,160
1,200	250.0	1,570	405	15,000	20.00	125.7	63,400
1,250	240.0	1,506	440	20,000	15.00	94.2	112,600
1,300	230.8	1,448	476	25,000	12.00	75.4	176,000
1,350	222.2	1,395	513	30,000	10.00	62.8	253,300
1,400	214.4	1,346	552	35,000	8.57	53.8	344,800
1,450	206.9	1,298	592	40,000	7.50	47.1	450,000
				45,000	6.67	41.8	570,000
1,500	200.0	1,256	634	50,000	6.00	37.7	704,000

[1] One thousand centimeters of inductance is equal to one microhenry.

TABLE VI.—WEIGHT OF BARE AND INSULATED COPPER WIRE

In pounds per 1,000 feet at 68°F. The sizes shown are American wire gage (Brown & Sharpe). Data on insulated wires supplied by Belden Manufacturing Co.

Size	Bare	Enamel	Single cotton	Double cotton	Single silk	Double silk
8	50.0	50.55	50.60	51.15		
9	39.63	40.15	40.15	40.60		
10	31.43	31.80	31.85	32.18		
11	24.92	25.25	25.30	25.60		
12	19.77	20.05	20.10	20.40		
13	15.68	15.90	15.99	16.20		
14	12.43	12.60	12.73	12.91		
15	9.858	10.00	10.10	10.33		
16	7.818	7.930	8.025	8.210	7.890	7.955
17	6.200	6.275	6.395	6.540	6.260	6.315
18	4.917	4.980	5.080	5.235	4.970	5.015
19	3.899	3.955	4.035	4.220	3.940	3.990
20	3.092	3.135	3.218	3.373	3.132	3.173
21	2.452	2.490	2.561	2.685	2.488	2.520
22	1.945	1.970	2.048	2.168	1.976	2.006
23	1.542	1.565	1.635	1.727	1.570	1.593
24	1.223	1.245	1.304	1.398	1.247	1.272
25	0.9699	0.988	1.039	1.129	0.994	1.018
26	0.7692	0.7845	0.8335	0.9140	0.7905	0.8100
27	0.6100	0.6220	0.6660	0.7560	0.6280	0.6450
28	0.4837	0.4940	0.5325	0.6075	0.4980	0.5140
29	0.3836	0.3915	0.4255	0.4890	0.3970	0.4130
30	0.3042	0.3105	0.3400	0.3955	0.3160	0.3330
31	0.2413	0.2465	0.2762	0.3257	0.2157	0.2678
32	0.1913	0.1960	0.2230	0.2700	0.2100	0.2170
33	0.1517	0.1550	0.1816	0.2270	0.1611	0.1750
34	0.1203	0.1230	0.1478	0.1928	0.1290	0.1412
35	0.09542	0.0980	0.1202	0.1600	0.1035	0.1130
36	0.07568	0.0776	0.0994	0.1361	0.0823	0.0920
37	0.0601	0.0616	0.0822	0.1204	0.0663	0.0740
38	0.04579	0.0488	0.0702	0.1049	0.0534	0.0623
39	0.03774	0.0387	0.0602	0.0937	0.0424	0.0504
40	0.02990	0.0307	0.0519	0.0838	0.0345	0.0429

TABLE VII.—PROPERTIES OF COPPER WIRE

The resistance given in the table is that of pure copper wire; ordinary commercial copper has a resistance from 3 to 5 per cent greater

American or B. & S. Gage

Gage No.	Diameter in mils (page 12)	Area in circular mils	Weight in pounds per 1,000 feet	Feet per pound	Resistance of pure copper in international ohms at 20°C. or 68°F.		
					Ohms per foot	Feet per ohm	Ohms per pound
0000	460.0	211,600	640.5	1.56	0.0000489	20,440	0.00007639
00	409.6	167,800	508.0	1.97	0.0000617	16,210	0.0001215
00	364.8	133,100	402.8	2.49	0.0000778	12,850	0.0001931
0	324.9	105,600	319.5	3.13	0.0000981	10,190	0.0003071
1	289.3	83,690	253.3	3.95	0.0001237	8,083	0.0004883
2	257.6	66,370	200.9	4.98	0.0001560	6,410	0.0007763
3	229.4	52,630	159.3	6.28	0.0001967	5,084	0.001235
4	204.3	41,740	126.4	7.91	0.0002480	4,031	0.001963
5	181.9	33,100	100.2	9.98	0.0003128	3,197	0.003122
6	162.0	26,250	79.46	12.58	0.0003944	2,535	0.004963
7	144.3	20,820	63.02	15.87	0.0004973	2,011	0.007892
8	128.5	16,510	49.98	20.01	0.0006271	1,595	0.01255
9	114.4	13,090	39.63	25.23	0.0007908	1,265	0.01995
10	101.9	10,380	31.43	31.85	0.0009972	1.003	0.03173
11	90.74	8,234	24.93	40.12	0.001257	795.5	0.05045
12	80.81	6,530	19.77	50.58	0.001586	630.5	0.08022
13	71.96	5,178	15.68	63.78	0.001999	500.1	0.1276
14	64.08	4,107	12.43	80.45	0.002521	396.6	0.2028
15	57.07	3.257	9.86	101.4	0.003179	314.5	0.3225
16	50.82	2,583	7.82	127.9	0.004009	249.4	0.5128
17	45.26	2,048	6.20	161.3	0.005055	197.8	0.8153
18	40.30	1,624	4.92	203.4	0.006374	156.9	1.296
19	35.89	1,288	3.90	256.5	0.008038	124.4	2.061
20	31.96	1,022	3.09	323.4	0.01014	98.62	3.278
21	28.46	810.1	2.45	407.8	0.01278	78.24	5.212
22	25.35	642.6	1.95	514.2	0.01612	62.05	8.287
23	22.57	509.5	1.54	648.4	0.02032	49.21	13.18
24	20.10	404.0	1.22	817.6	0.02563	39.02	20.95
25	17.90	320.4	0.97	1,031	0.03231	30.95	33.32
26	15.94	254.1	0.77	1,300	0.04075	24.54	52.97
27	14.20	201.5	0.61	1,639	0.05138	19.46	84.23
28	12.64	159.8	0.48	2,067	0.06479	15.43	133.9
29	11.26	126.7	0.38	2,607	0.08170	12.24	213.0
30	10.03	100.5	0.30	3,287	0.1030	9.707	338.6
31	8.928	79.71	0.24	4,145	0.1299	7.698	538.4
32	7.950	63.20	0.19	5,227	0.1638	6.105	856.2
33	7.080	50.13	0.15	6,591	0.2066	4.841	1,361
34	6.305	39.75	0.12	8,311	0.2605	3.839	2,165
35	5.615	31.52	0.10	10,840	0.3284	3.045	3,441
36	5.000	25.00	0.08	13,210	0.4142	2.414	5,473
37	4.453	19.83	0.06	16,660	0.5222	1.915	8,702
38	3.965	15.72	0.05	21,010	0.6585	1.519	13,870
39	3.531	12.47	0.04	26,500	0.8304	1.204	22,000
40	3.145	9.89	0.03	33,410	1.047	0.955	34,980

TABLE VIII.—DIAMETERS OF BARE COPPER WIRE AND OUTSIDE DIAMETERS OF INSULATED WIRE

Sizes of wire are American wire or Brown & Sharpe gage

Gage No.	Bare, mils (page 12)	Enamel, mils	Single cotton, mils	Double cotton, mils	Single silk, mils	Double silk, mils
8	128.5	130.60	135.5	141.5		
9	114.4	116.50	121.4	127.4		
10	101.9	104.00	107.9	112.9		
11	90.74	92.70	96.7	101.7		
12	80.81	82.80	86.8	91.8		
13	71.96	74.00	78.0	83.0		
14	64.08	66.10	70.1	75.1		
15	57.07	59.10	63.1	68.1		
16	50.82	52.80	55.8	60.8	52.8	54.6
17	45.26	47.00	50.3	55.3	47.3	49.1
18	40.30	42.10	45.3	50.3	42.3	44.1
19	35.89	37.70	40.9	45.9	37.9	39.7
20	31.96	33.70	37.0	42.0	34.0	35.8
21	28.46	30.20	33.5	38.5	30.5	32.3
22	25.35	26.90	29.3	33.3	27.3	29.1
23	22.57	24.10	26.6	30.6	24.6	26.4
24	20.10	21.50	24.1	28.1	22.1	23.9
25	17.90	19.20	21.9	25.9	19.9	21.7
26	15.94	17.10	19.9	23.9	17.9	19.7
27	14.20	15.30	18.2	22.2	16.2	18.0
28	12.64	13.60	16.6	20.6	14.6	16.4
29	11.26	12.20	15.3	19.3	13.3	15.1
30	10.03	10.90	14.0	18.0	12.0	13.8
31	8.928	9.70	12.9	16.9	10.9	12.7
32	7.950	8.70	11.95	15.95	9.95	11.75
33	7.080	7.70	11.08	15.08	9.08	10.88
34	6.305	6.90	10.30	14.30	8.30	10.10
35	5.615	6.20	9.61	13.61	7.61	9.41
36	5.000	5.50	9.00	13.00	7.00	8.80
37	4.453	4.90	8.45	12.45	6.45	8.25
38	3.965	4.40	7.96	11.96	5.96	7.76
39	3.531	3.90	7.53	11.53	5.53	7.33
40	3.145	3.50	7.14	11.14	5.14	6.94

TABLE IX.—FOR SELECTING WIRE AND FUSE SIZES FOR MOTOR-BRANCH CIRCUITS

Full-load current rating of motor, amperes	Minimum allowable size of copper wire, American (B. & S.) gage or circular mils			For running protection of motors		Maximum allowable rating of branch-circuit fuses			
	Rubber	Varnished cambric	Slow burning	Maximum rating of N.E.C. fuses, amperes	Maximum setting of time-limit protective device, amperes	Squirrel cage, full-voltage starting, single-phase repulsion or split-phase, amperes	Squirrel cage, reduced voltage starting, high-reactance[1] squirrel cage (up to 30), amperes	Squirrel cage, reduced voltage starting, high-reactance[1] squirrel cage (above 30) amperes	Slip-ring alternating current and direct current, amperes
1	2	3	4	5	6	7	8	9	10
1	14	14	14	2[2]	1.25[2]	15	15	...	15
2	14	14	14	3[2]	2.50[2]	15	15	...	15
3	14	14	14	4[2]	3.75[2]	15	15	...	15
4	14	14	14	6[2]	5.0 [2]	15	15	...	15
5	14	14	14	8[2]	6.25[2]	15	15	...	15
6	14	14	14	8[2]	7.50[2]	20	15	...	15
7	14	14	14	10[2]	8.75[2]	25	20	...	15
8	14	14	14	10[2]	10.0 [2]	25	20	...	15
9	14	14	14	12[2]	11.25[2]	30	25	...	15
10	14	14	14	15[2]	12.50[2]	30	25	...	15
11	14	14	14	15[2]	13.75[2]	35	30	...	20
12	14	14	14	15[2]	15.00[2]	40	30	...	20
13	12	14	14	20[2]	16.25[2]	40	35	...	20
14	12	14	14	20[2]	17.50[2]	45	35	...	25
15	12	12	14	20[2]	18.75[2]	45	40	...	25
16	12	12	14	20[2]	20.00[2]	50	40	...	25
17	10	12	12	25[2]	21.25[2]	60	45	...	30
18	10	12	12	25[2]	22.50[2]	60	45	...	30
19	10	12	12	25[2]	23.75[2]	60	50	...	30
20	10	12	12	25[2]	25.0 [2]	60	50	...	30
22	8	10	10	30	27.50	70	60	...	35
24	8	10	10	30	30.00	80	60	...	40
26	8	8	8	35	32.50	80	70	...	40
28	8	8	8	35	35.00	90	70	...	45
30	6	8	8	40	37.50	90	80	...	45
32	6	8	8	40	40.00	100	..	70	50
34	6	6	8	45	42.50	110	..	70	60
36	6	6	8	45	45.00	110	..	80	60

TABLE IX.—FOR SELECTING WIRE AND FUSE SIZES FOR MOTOR-BRANCH CIRCUIT.—(*Continued*)

Full-load current rating of motor, amperes	Minimum allowable size of copper wire, American (B. & S.) gage or circular mils			For running protection of motors		Maximum allowable rating of branch-circuit fuses			
	Rubber	Varnished cambric	Slow burning	Maximum rating of N.E.C. fuses, amperes	Maximum setting of time-limit protective device, amperes	Squirrel cage, full-voltage starting, single-phase repulsion or split-phase, amperes	Squirrel cage, reduced voltage starting, high-reactance[1] squirrel cage (up to 30), amperes	Squirrel cage, reduced voltage starting, high-reactance[1] squirrel cage (above 30) amperes	Slip-ring alternating current and direct current, amperes
1	2	3	4	5	6	7	8	9	10
38	6	6	8	50	47.50	125	..	80	60
40	6	6	8	50	50.00	125	..	80	60
42	5	6	6	50	52.50	125	..	90	70
44	5	6	6	60	55.0	125	..	90	70
46	4	6	6	60	57.50	150	..	100	70
48	4	6	6	60	60.0	150	..	100	80
50	4	5	6	60	62.50	150	..	100	80
52	4	5	6	70	65.0	175	..	110	80
54	4	4	6	70	67.50	175	..	110	90
56	4	4	6	70	70.00	175	..	120	90
58	3	4	5	70	72.50	175	..	120	90
60	3	4	5	80	75.00	200	..	120	90
62	3	4	5	80	77.50	200	..	125	100
64	3	4	5	80	80.00	200	..	150	100
66	2	4	4	80	82.50	200	..	150	100
68	2	4	4	90	85.00	225	..	150	110
70	2	3	4	90	87.50	225	..	150	110
72	2	3	4	90	90.00	225	..	150	110
74	1	3	3	90	92.50	225	..	150	125
76	1	3	3	100	95.00	250	..	175	125
78	1	2	3	100	97.50	250	..	175	125
80	1	2	3	100	100.00	250	..	175	125
82	0	2	2	110	102.50	250	..	175	125
84	0	2	2	110	105.00	250	..	175	150
86	0	2	2	110	107.50	300	..	175	150
88	0	2	2	110	110.00	300	..	200	150
90	0	1	2	110	112.50	300	..	200	150
92	0	1	2	125	115.00	300	..	200	150
94	0	1	2	125	117.50	300	..	200	150

TABLE IX.—FOR SELECTING WIRE AND FUSE SIZES FOR MOTOR-BRANCH CIRCUITS.—(*Continued*)

Full-load current rating of motor, amperes	Minimum allowable size of copper wire, American (B. & S.) gage or circular mils			For running protection of motors		Maximum allowable rating of branch-circuit fuses			
	Rubber	Varnished cambric	Slow burning	Maximum rating of N.E.C. fuses, amperes	Maximum setting of time-limit protective device, amperes	Squirrel cage, full-voltage starting, single-phase repulsion or split-phase, amperes	Squirrel cage, reduced voltage starting, high-reactance[1] squirrel cage (up to 30), amperes	Squirrel cage, reduced voltage starting, high-reactance[1] squirrel cage (above 30) amperes	Slip-ring alternating current and direct current, amperes
1	2	3	4	5	6	7	8	9	10
96	0	1	2	125	120.00	300	..	200	150
98	0	0	2	125	122.50	300	..	200	150
100	0	0	2	125	125.00	300	..	200	150
105	00	0	1	150	131.5	350	..	225	175
110	00	0	1	150	137.5	350	..	225	175
115	00	0	1	150	144.0	350	..	250	175
120	00	0	1	150	150.0	400	..	250	200
125	000	00	0	175	156.5	400	..	250	200
130	000	00	0	175	162.5	400	..	300	200
135	000	00	0	175	169.0	450	..	300	225
140	000	00	0	175	175.0	450	..	300	225
145	200,000	000	0	200	181.5	450	..	300	225
150	200,000	000	0	200	187.5	450	..	300	225
155	200,000	000	0	200	194.0	500	..	350	250
160	200,000	000	0	200	200.0	500	..	350	250
165	0,000	000	00	225	206.	500	..	350	250
170	0,000	200,000	00	225	213.	500	..	350	300
175	200,000	200,000	00	225	219.	600	..	350	300
180	200,000	200,000	00	225	225.	600	..	400	300
185	250,000	200,000	000	250	231.	600	..	400	300
190	250,000	200,000	000	250	238.	600	..	400	300
195	250,000	0,000	000	250	244.	600	..	400	300
200	250,000	0,000	000	250	250.	600	..	400	300
210	300,000	0,000	000	250	263.	...	..	450	350
220	300,000	250,000	000	300	275.	...	..	450	350
230	350,000	250,000	200,000	300	288.	...	..	500	350
240	350,000	250,000	200,000	300	300.	...	..	500	400
250	400,000	300,000	200,000	300	313.	...	..	500	400
260	400,000	300,000	200,000	350	325.	...	..	600	400

TABLE IX.—FOR SELECTING WIRE AND FUSE SIZES FOR MOTOR-BRANCH CIRCUIT.—(*Continued*)

Full-load current rating of motor, amperes	Minimum allowable size of copper wire, American (B. & S.) gage or circular mils			For running protection of motors		Maximum allowable rating of branch-circuit fuses			
	Rubber	Varnished cambric	Slow burning	Maximum rating of N.E.C. fuses, amperes	Maximum setting of time-limit protective device, amperes	Squirrel cage, full-voltage starting, single-phase repulsion or split-phase, amperes	Squirrel cage, reduced voltage starting, high-reactance[1] squirrel cage (up to 30), amperes	Squirrel cage, reduced voltage starting, high-reactance[1] squirrel cage (above 30) amperes	Slip-ring alternating current and direct current, amperes
1	2	3	4	5	6	7	8	9	10
270	500,000	350,000	250,000	350	338.	. . .	. .	600	450
280	500,000	350,000	250,000	350	350.	. . .	. .	600	450
290	500,000	350,000	300,000	350	363.	. . .	. .	600	450
300	500,000	400,000	300,000	400	375.	. . .	. .	600	450
320	500,000	500,000	300,000	400	400.	. . .	. .	. . .	500
340	600,000	500,000	350,000	450	425.	. . .	. .	. . .	600
360	600,000	500,000	350,000	450	450.	. . .	. .	. . .	600
380	700,000	500,000	400,000	500	475.	. . .	. .	. . .	600
400	700,000	600,000	400,000	500	500.	. . .	. .	. . .	600
420	800,000	600,000	500,000	600	525.				
440	800,000	700,000	500,000	600	550.				
460	900,000	700,000	500,000	600	575.				
480	900,000	700,000	500,000	600	600.				
500	1,000,000	800,000	600,000	. . .	625.				
520	1,000,000	800,000	600,000	. . .	650.				
540	1,100,000	900,000	600,000	. . .	675.				
560	1,200,000	900,000	700,000	. . .	700.				
580	1,200,000	1,000,000	700,000	. . .	725.				
600	1,300,000	1,000,000	700,000	. . .	750.				
625	1,400,000	1,000,000	800,000	. . .	782.				

NOTE.—For motors having larger full-load current rating than those given in this table, calculations for the sizes of wires (and other conductors) and the rating of protection devices are to be made on the same basis.

[1] High-reactance, squirrel-cage motors are those designed to limit the starting current by means of deep-slot or double-wound secondaries.

[2] Motors of two horsepower or less are considered to be sufficiently protected by the automatic overload protective devices used to protect the wires as specified in the foregoing tables. It is recommended that the running protection specified in the tables be provided for all such small motors when they are located out of sight of the operator.

TABLE X.—COMMON LOGARITHMS

N.	0	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396
N.	0	1	2	3	4	5	6	7	8	9

TABLE X.—COMMON LOGARITHMS.—(*Continued*)

N.	0	1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996
N.	0	1	2	3	4	5	6	7	8	9

TABLE XI.—TRIGONOMETRIC FUNCTIONS

Angles	Sines		Cosines		Tangents		Cotangents		Angles
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
0° 00′	.0000	∞	1.0000	0.0000	.0000	∞	∞	∞	90° 00′
10	.0029	7.4637	1.0000	0000	.0029	7.4637	343.77	2.5363	50
20	.0058	7648	1.0000	0000	.0058	7648	171.89	2352	40
30	.0087	9408	1.0000	0000	.0087	9409	114.59	0591	30
40	.0116	8.0658	.9999	0000	.0116	8.0658	85.940	1.9342	20
50	.0145	1627	.9999	0000	.0145	1627	68.750	8373	10
1° 00′	.0175	8.2419	.9998	9.9999	.0175	8.2419	57.290	1.7581	89° 00′
10	.0204	3088	.9998	9999	.0204	3089	49.104	6911	50
20	.0233	3668	.9997	9999	.0233	3669	42.964	6331	40
30	.0262	4179	.9997	9999	.0262	4181	38.188	5819	30
40	.0291	4637	.9996	9998	.0291	4638	34.368	5362	20
50	.0320	5050	.9995	9998	.0320	5053	31.242	4947	10
2° 00′	.0349	8.5428	.9994	9.9997	.0349	8.5431	28.636	1.4569	88° 00′
10	.0378	5776	.9993	9997	.0378	5779	26.432	4221	50
20	.0407	6097	.9992	9996	.0407	6101	24.542	3899	40
30	.0436	6397	.9990	9996	.0437	6401	22.904	3599	30
40	.0465	6677	.9989	9995	.0466	6682	21.470	3318	20
50	.0494	6940	.9988	9995	.0495	6945	20.206	3055	10
3° 00′	.0523	8.7188	.9986	9.9994	.0524	8.7194	19.081	1.2806	87° 00′
10	.0552	7423	.9985	9993	.0553	7429	18.075	2571	50
20	.0581	7645	.9983	9993	.0582	7652	17.169	2348	40
30	.0610	7857	.9981	9992	.0612	7865	16.350	2135	30
40	.0640	8059	.9980	9991	.0641	8067	15.605	1933	20
50	.0669	8251	.9978	9990	.0670	8261	14.924	1739	10
4° 00′	.0698	8.8436	.9976	9.9989	.0699	8.8446	14.301	1.1554	86° 00′
10	.0727	8613	.9974	9989	.0729	8624	13.727	1376	50
20	.0756	8783	.9971	9988	.0758	8795	13.197	1205	40
30	.0785	8946	.9969	9987	.0787	8960	12.706	1040	30
40	.0814	9104	.9967	9986	.0816	9118	12.251	0882	20
50	.0843	9256	.9964	9985	.0846	9272	11.826	0728	10
5° 00′	.0872	8.9403	.9962	9.9983	.0875	8.9420	11.430	1.0580	85° 00′
10	.0901	9545	.9959	9982	.0904	9563	11.059	0437	50
20	.0929	9682	.9957	9981	.0934	9701	10.712	0299	40
30	.0958	9816	.9954	9980	.0963	9836	10.385	0164	30
40	.0987	9945	.9951	9979	.0992	9966	10.078	0034	20
50	.1016	9.0070	.9948	9977	.1022	9.0093	9.7882	0.9907	10
6° 00′	.1045	9.0192	.9945	9.9976	.1051	9.0216	9.5144	0.9784	84° 00′
10	.1074	0311	.9942	9975	.1080	0336	9.2553	9664	50
20	.1103	0426	.9939	9973	.1110	0453	9.0098	9547	40
30	.1132	0539	.9936	9972	.1139	0567	8.7769	9433	30
40	.1161	0648	.9932	9971	.1169	0678	8.5555	9322	20
50	.1190	0755	.9929	9969	.1198	0786	8.3450	9214	10
7° 00′	.1219	9.0859	.9925	9.9968	.1228	9.0891	8.1443	0.9109	83° 00′
10	.1248	0961	.9922	9966	.1257	0995	7.9530	9005	50
20	.1276	1060	.9918	9964	.1287	1096	7.7704	8904	40
30	.1305	1157	.9914	9963	.1317	1194	7.5958	8806	30
40	.1334	1252	.9911	9961	.1346	1291	7.4287	8709	20
50	.1363	1345	.9907	9959	.1376	1385	7.2687	8615	10
8° 00′	.1392	9.1436	.9903	9.9958	.1405	9.1478	7.1154	0.8522	82° 00′
10	.1421	1525	.9899	9956	.1435	1569	6.9682	8431	50
20	.1449	1612	.9894	9954	.1465	1658	6.8269	8342	40
30	.1478	1697	.9890	9952	.1495	1745	6.6912	8255	30
40	.1507	1781	.9886	9950	.1524	1831	6.5606	8169	20
50	.1536	1863	.9881	9948	.1554	1915	6.4348	8085	10
9° 00′	.1564	9.1943	.9877	9.9946	.1584	9.1997	6.3138	0.8003	81° 00′
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
Angles	Cosines		Sines		Cotangents		Tangents		Angles

TABLE XI.—TRIGONOMETRIC FUNCTIONS.—*(Continued)*

Angles	Sines		Cosines		Tangents		Cotangents		Angles
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
9° 00′	.1564	9.1943	.9877	9.9946	.1584	9.1997	6.3138	0.8003	81° 00′
10	.1593	2022	.9872	9944	.1614	2078	6.1970	7922	50
20	.1622	2100	.9868	9942	.1644	2158	6.0844	7842	40
30	.1650	2176	.9863	9940	.1673	2236	5.9758	7764	30
40	.1679	2251	.9858	9938	.1703	2313	5.8708	7687	20
50	.1708	2324	.9853	9936	.1733	2389	5.7694	7611	10
10° 00′	.1736	9.2397	.9848	9.9934	.1763	9.2463	5.6713	0.7537	80° 00′
10	.1765	2468	.9843	9931	.1793	2536	5.5764	7464	50
20	.1794	2538	.9838	9929	.1823	2609	5.4845	7391	40
30	.1822	2606	.9833	9927	.1853	2680	5.3955	7320	30
40	.1851	2674	.9827	9924	.1883	2750	5.3093	7250	20
50	.1880	2740	.9822	9922	.1914	2819	5.2257	7181	10
11° 00′	.1908	9.2806	.9816	9.9919	.1944	9.2887	5.1446	0.7113	79° 00′
10	.1937	2870	.9811	9917	.1974	2953	5.0658	7047	50
20	.1965	2934	.9805	9914	.2004	3020	4.9894	6980	40
30	.1994	2997	.9799	9912	.2035	3085	4.9152	6915	30
40	.2022	3058	.9793	9909	.2065	3149	4.8430	6851	20
50	.2051	3119	.9787	9907	.2095	3212	4.7729	6788	10
12° 00′	.2079	9.3179	.9781	9.9904	.2126	9.3275	4.7046	0.6725	78° 00′
10	.2108	3238	.9775	9901	.2156	3336	4.6382	6664	50
20	.2136	3296	.9769	9899	.2186	3397	4.5736	6603	40
30	.2164	3353	.9763	9896	.2217	3458	4.5107	6542	30
40	.2193	3410	.9757	9893	.2247	3517	4.4494	6483	20
50	.2221	3466	.9750	9890	.2278	3576	4.3897	6424	10
13° 00′	.2250	9.3521	.9744	9.9887	.2309	9.3634	4.3315	0.6366	77° 00′
10	.2278	3575	.9737	9884	.2339	3691	4.2747	6309	50
20	.2306	3629	.9730	9881	.2370	3748	4.2193	6252	40
30	.2334	3682	.9724	9878	.2401	3804	4.1653	6196	30
40	.2363	3734	.9717	9875	.2432	3859	4.1126	6141	20
50	.2391	3786	.9710	9872	.2462	3914	4.0611	6086	10
14° 00′	.2419	9.3837	.9703	9.9869	.2493	9.3968	4.0108	0.6032	76° 00′
10	.2447	3887	.9696	9866	.2524	4021	3.9617	5979	50
20	.2476	3937	.9689	9863	.2555	4074	3.9136	5926	40
30	.2504	3986	.9681	9859	.2586	4127	3.8667	5873	30
40	.2532	4035	.9674	9856	.2617	4178	3.8208	5822	20
50	.2560	4083	.9667	9853	.2648	4230	3.7760	5770	10
15° 00′	.2588	9.4130	.9659	9.9849	.2679	9.4281	3.7321	0.5719	75° 90′
10	.2616	4177	.9652	9846	.2711	4331	3.6891	5669	50
20	.2644	4223	.9644	9843	.2742	4381	3.6470	5619	40
30	.2672	4269	.9636	9839	.2773	4430	3.6059	5570	30
40	.2700	4314	.9628	9836	.2805	4479	3.5656	5521	20
50	.2728	4359	.9621	9832	.2836	4527	3.5261	5473	10
16° 00′	.2756	9.4403	.9613	9.9828	.2867	9.4575	3.4874	0.5425	74° 00′
10	.2784	4447	.9605	9825	.2899	4622	3.4495	5378	50
20	.2812	4491	.9596	9821	.2931	4669	3.4124	5331	40
30	.2840	4533	.9588	9817	.2962	4716	3.3759	5284	30
40	.2868	4576	.9580	9814	.2994	4762	3.3402	5238	20
50	.2896	4618	.9572	9810	.3026	4808	3.3052	5192	10
17° 00′	.2924	9.4659	.9563	9.9806	.3057	9.4853	3.2709	0.5147	73° 00′
10	.2952	4700	.9555	9802	.3089	4898	3.2371	5102	50
20	.2979	4741	.9546	9798	.3121	4943	3.2041	5057	40
30	.3007	4781	.9537	9794	.3153	4987	3.1716	5013	30
40	.3035	4821	.9528	9790	.3185	5031	3.1397	4969	20
50	.3062	4861	.9520	9786	.3217	5075	3.1084	4925	10
18° 00′	.3090	9.4900	.9511	9.9782	.3249	9.5118	3.0777	0.4882	72° 00′
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
Angles	Cosines		Sines		Cotangents		Tangents		Angles

TABLE XI.—TRIGONOMETRIC FUNCTIONS.—*(Continued)*

Angles	Sines		Cosines		Tangents		Cotangents		Angles
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
18° 00′	.3090	9.4900	.9511	9.9782	.3249	9.5118	3.0777	0.4882	72° 00′
10	.3118	4939	.9502	9778	.3281	5161	3.0475	4839	50
20	.3145	4977	.9492	9774	.3314	5203	3.0178	4797	40
30	.3173	5015	.9483	9770	.3346	5245	2.9887	4755	30
40	.3201	5052	.9474	9765	.3378	5287	2.9600	4713	20
50	.3228	5090	.9465	9761	.3411	5329	2.9319	4671	10
19° 00′	.3256	9.5126	.9455	9.9757	.3443	9.5370	2.9042	0.4630	71° 00′
10	.3283	5163	.9446	9752	.3476	5411	2.8770	4589	50
20	.3311	5199	.9436	9748	.3508	5451	2.8502	4549	40
30	.3338	5235	.9426	9743	.3541	5491	2.8239	4509	30
40	.3365	5270	.9417	9739	.3574	5531	2.7980	4469	20
50	.3393	5306	.9407	9734	.3607	5571	2.7725	4429	10
20° 00′	.3420	9.5341	.9397	9.9730	.3640	9.5611	2.7475	0.4389	70° 00′
10	.3448	5375	.9387	9725	.3673	5650	2.7228	4350	50
20	.3475	5409	.9377	9721	.3706	5689	2.6985	4311	40
30	.3502	5443	.9367	9716	.3739	5727	2.6746	4273	30
40	.3529	5477	.9356	9711	.3772	5766	2.6511	4234	20
50	.3557	5510	.9346	9706	.3805	5804	2.6279	4196	10
21° 00′	.3584	9.5543	.9336	9.9702	.3839	9.5842	2.6051	0.4158	69° 00′
10	.3611	5576	.9325	9697	.3872	5879	2.5826	4121	50
20	.3638	5609	.9315	9692	.3906	5917	2.5605	4083	40
30	.3665	5641	.9304	9687	.3939	5954	2.5386	4046	30
40	.3692	5673	.9293	9682	.3973	5991	2.5172	4009	20
50	.3719	5704	.9283	9677	.4006	6028	2.4960	3972	10
22° 00′	.3746	9.5736	.9272	9.9672	.4040	9.6064	2.4751	0.3936	68° 00′
10	.3773	5767	.9261	9667	.4074	6100	2.4545	3900	50
20	.3800	5798	.9250	9661	.4108	6136	2.4342	3864	40
30	.3827	5828	.9239	9656	.4142	6172	2.4142	3828	30
40	.3854	5859	.9228	9651	.4176	6208	2.3945	3792	20
50	.3881	5889	.9216	9646	.4210	6243	2.3750	3757	10
23° 00′	.3907	9.5919	.9205	9.9640	.4245	9.6279	2.3559	0.3721	67° 00′
10	.3934	5948	.9194	9635	.4279	6314	2.3369	3686	50
20	.3961	5978	.9182	9629	.4314	6348	2.3183	3652	40
30	.3987	6007	.9171	9624	.4348	6383	2.2998	3617	30
40	.4014	6036	.9159	9618	.4383	6417	2.2817	3583	20
50	.4041	6065	.9147	9613	.4417	6452	2.2637	3548	10
24° 00′	.4067	9.6093	.9135	9.9607	.4452	9.6486	2.2460	0.3514	66° 00′
10	.4094	6121	.9124	9602	.4487	6520	2.2286	3480	50
20	.4120	6149	.9112	9596	.4522	6553	2.2113	3447	40
30	.4147	6177	.9100	9590	.4557	6587	2.1943	3413	30
40	.4173	6205	.9088	9584	.4592	6620	2.1775	3380	20
50	.4200	6232	.9075	9579	.4628	6654	2.1609	3346	10
25° 00′	.4226	9.6259	.9063	9.9573	.4663	9.6687	2.1445	0.3313	65° 00′
10	.4253	6286	.9051	9567	.4699	6720	2.1283	3280	50
20	.4279	6313	.9038	9561	.4734	6752	2.1123	3248	40
30	.4305	6340	.9026	9555	.4770	6785	2.0965	3215	30
40	.4331	6366	.9013	9549	.4806	6817	2.0809	3183	20
50	.4358	6392	.9001	9543	.4841	6850	2.0655	3150	10
26° 00′	.4384	9.6418	.8988	9.9537	.4877	9.6882	2.0503	0.3118	64° 00′
10	.4410	6444	.8975	9530	.4913	6914	2.0353	3086	50
20	.4436	6470	.8962	9524	.4950	6946	2.0204	3054	40
30	.4462	6495	.8949	9518	.4986	6977	2.0057	3023	30′
40	.4488	6521	.8936	9512	.5022	7009	1.9912	2991	20
50	.4514	6546	.8923	9505	.5059	7040	1.9768	2960	10
27° 00′	.4540	9.6570	.8910	9.9499	.5095	9.7072	1.9626	0.2928	63° 00′
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
Angles	Cosines		Sines		Cotangents		Tangents		Angles

TABLE XI.—TRIGONOMETRIC FUNCTIONS.—(*Continued*)

Angles	Sines		Cosines		Tangents		Cotangents		Angles
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
27° 00′	.4540	9.6570	.8910	9.9499	.5095	9.7072	1.9626	0.2928	63° 00′
10	.4566	6595	.8897	9492	.5132	7103	1.9486	2897	50
20	.4592	6620	.8884	9486	.5169	7134	1.9347	2866	40
30	.4617	6644	.8870	9479	.5206	7165	1.9210	2835	30
40	.4643	6668	.8857	9473	.5243	7196	1.9074	2804	20
50	.4669	6692	.8843	9466	.5280	7226	1.8940	2774	10
28° 00′	.4695	9.6716	.8829	9.9459	.5317	9.7257	1.8807	0.2743	62° 00′
10	.4720	6740	.8816	9453	.5354	7287	1.8676	2713	50
20	.4746	6763	.8802	9446	.5392	7317	1.8546	2683	40
30	.4772	6787	.8788	9439	.5430	7348	1.8418	2652	30
40	.4797	6810	.8774	9432	.5467	7378	1.8291	2622	20
50	.4823	6833	.8760	9425	.5505	7408	1.8165	2592	10
29° 00′	.4848	9.6856	.8746	9.9418	.5543	9.7438	1.8040	0.2562	61° 00′
10	.4874	6878	.8732	9411	.5581	7467	1.7917	2533	50
20	.4899	6901	.8718	9404	.5619	7497	1.7796	2503	40
30	.4924	6923	.8704	9397	.5658	7526	1.7675	2474	30
40	.4950	6946	.8689	9390	.5696	7556	1.7556	2444	20
50	.4975	6968	.8675	9383	.5735	7585	1.7437	2415	10
30° 00′	.5000	9.6990	.8660	9.9375	.5774	9.7614	1.7321	0.2386	60° 00′
10	.5025	7012	.8646	9368	.5812	7644	1.7205	2356	50
20	.5050	7033	.8631	9361	.5851	7673	1.7090	2327	40
30	.5075	7055	.8616	9353	.5890	7701	1.6977	2299	30
40	.5100	7076	.8601	9346	.5930	7730	1.6864	2270	20
50	.5125	7097	.8587	9338	.5969	7759	1.6753	2241	10
31° 00′	.5150	9.7118	.8572	9.9331	.6009	9.7788	1.6643	0.2212	59° 00′
10	.5175	7139	.8557	9323	.6048	7816	1.6534	2184	50
20	.5200	7160	.8542	9315	.6088	7845	1.6426	2155	40
30	.5225	7181	.8526	9308	.6128	7873	1.6319	2127	30
40	.5250	7201	.8511	9300	.6168	7902	1.6212	2098	20
50	.5275	7222	.8496	9292	.6208	7930	1.6107	2070	10
32° 00′	.5299	9.7242	.8480	9.9284	.6249	9.7958	1.6003	0.2042	58° 00′
10	.5324	7262	.8465	9276	.6289	7986	1.5900	2014	50
20	.5348	7282	.8450	9268	.6330	8014	1.5798	1986	40
30	.5373	7302	.8434	9260	.6371	8042	1.5697	1958	30
40	.5398	7322	.8418	9252	.6412	8070	1.5597	1930	20
50	.5422	7342	.8403	9244	.6453	8097	1.5497	1903	10
33° 00′	.5446	9.7361	.8387	9.9236	.6494	9.8125	1.5399	0.1875	57° 00′
10	.5471	7380	.8371	9228	.6536	8153	1.5301	1847	50
20	.5495	7400	.8355	9219	.6577	8180	1.5204	1820	40
30	.5519	7419	.8339	9211	.6619	8208	1.5108	1792	30
40	.5544	7438	.8323	9203	.6661	8235	1.5013	1765	20
50	.5568	7457	.8307	9194	.6703	8263	1.4919	1737	10
34° 00′	.5592	9.7476	.8290	9.9186	.6745	9.8290	1.4826	0.1710	56° 00′
10	.5616	7494	.8274	9177	.6787	8317	1.4733	1683	50
20	.5640	7513	.8258	9169	.6830	8344	1.4641	1656	40
30	.5664	7531	.8241	9160	.6873	8371	1.4550	1629	30
40	.5688	7550	.8225	9151	.6916	8398	1.4460	1602	20
50	.5712	7568	.8208	9142	.6959	8425	1.4370	1575	10
35° 00′	.5736	9.7586	.8192	9.9134	.7002	9.8452	1.4281	0.1548	55° 00′
10	.5760	7604	.8175	9125	.7046	8479	1.4193	1521	50
20	.5783	7622	.8158	9116	.7089	8506	1.4106	1494	40
30	.5807	7640	.8141	9107	.7133	8533	1.4019	1467	30
40	.5831	7657	.8124	9098	.7177	8559	1.3934	1441	20
50	.5854	7675	.8107	9089	.7221	8586	1.3848	1414	10
36° 00′	.5878	9.7692	.8090	9.9080	.7265	9.8613	1.3764	0.1387	54° 00′
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
Angles	Cosines		Sines		Cotangents		Tangents		Angles

TABLE XI.—TRIGONOMETRIC FUNCTIONS.—(*Continued*)

Angles	Sines		Cosines		Tangents		Cotangents		Angles
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
36° 00′	.5878	9.7692	.8090	9.9080	.7265	9.8613	1.3764	0.1387	54° 00′
10	.5901	7710	.8073	9070	.7310	8639	1.3680	1361	50
20	.5925	7727	.8056	9061	.7355	8666	1.3597	1334	40
30	.5948	7744	.8039	9052	.7400	8692	1.3514	1308	30
40	.5972	7761	.8021	9042	.7445	8718	1.3432	1282	20
50	.5995	7778	.8004	9033	.7490	8745	1.3351	1255	10
37° 00′	.6018	9.7795	.7986	9.9023	.7536	9.8771	1.3270	0.1229	53° 00′
10	.6041	7811	.7969	9014	.7581	8797	1.3190	1203	50
20	.6065	7828	.7951	9004	.7627	8824	1.3111	1176	40
30	.6088	7844	.7934	8995	.7673	8850	1.3032	1150	30
40	.6111	7861	.7916	8985	.7720	8876	1.2954	1124	20
50	.6134	7877	.7898	8975	.7766	8902	1.2876	1098	10
38° 00′	.6157	9.7893	.7880	9.8965	.7813	9.8928	1.2799	0.1072	52° 00′
10	.6180	7910	.7862	8955	.7860	8954	1.2723	1046	50
20	.6202	7926	.7844	8945	.7907	8980	1.2647	1020	40
30	.6225	7941	.7826	8935	.7954	9006	1.2572	0994	30
40	.6248	7957	.7808	8925	.8002	9032	1.2497	0968	20
50	.6271	7973	.7790	8915	.8050	9058	1.2423	0942	10
39° 00′	.6293	9.7989	.7771	9.8905	.8098	9.9084	1.2349	0.0916	51° 00′
10	.6316	8004	.7753	8895	.8146	9110	1.2276	0890	50
20	.6338	8020	.7735	8884	.8195	9135	1.2203	0865	40
30	.6361	8035	.7716	8874	.8243	9161	1.2131	0839	30
40	.6383	8050	.7698	8864	.8292	9187	1.2059	0813	20
50	.6406	8066	.7679	8853	.8342	9212	1.1988	0788	10
40° 00′	.6428	9.8081	.7660	9.8843	.8391	9.9238	1.1918	0.0762	50° 00′
10	.6450	8096	.7642	8832	.8441	9264	1.1847	0736	50
20	.6472	8111	.7623	8821	.8491	9289	1.1778	0711	40
30	.6494	8125	.7604	8810	.8541	9315	1.1708	0685	30
40	.6517	8140	.7585	8800	.8591	9341	1.1640	0659	20
50	.6539	8155	.7566	8789	.8642	9366	1.1571	0634	10
41° 00′	.6561	9.8169	.7547	9.8778	.8693	9.9392	1.1504	0.0608	49° 00′
10	.6583	8184	.7528	8767	.8744	9417	1.1436	0583	50
20	.6604	8198	.7509	8756	.8796	9443	1.1369	0557	40
30	.6626	8213	.7490	8745	.8847	9468	1.1303	0532	30
40	.6648	8227	.7470	8733	.8899	9494	1.1237	0506	20
50	.6670	8241	.7451	8722	.8952	9519	1.1171	0481	10
42° 00′	.6691	9.8255	.7431	9.8711	.9004	9.9544	1.1106	0.0456	48° 00′
10	.6713	8269	.7412	8699	.9057	9570	1.1041	0430	50
20	.6734	8283	.7392	8688	.9110	9595	1.0977	0405	40
30	.6756	8297	.7373	8676	.9163	9621	1.0913	0379	30
40	.6777	8311	.7353	8665	.9217	9646	1.0850	0354	20
50	.6799	8324	.7333	8653	.9271	9671	1.0786	0329	10
43° 00′	.6820	9.8338	.7314	9.8641	.9325	9.9697	1.0724	0.0303	47° 00′
10	.6841	8351	.7294	8629	.9380	9722	1.0661	0278	50
20	.6862	8365	.7274	8618	.9435	9747	1.0599	0253	40
30	.6884	8378	.7254	8606	.9490	9772	1.0538	0228	30
40	.6905	8391	.7234	8594	.9545	9798	1.0477	0202	20
50	.6926	8405	.7214	8582	.9601	9823	1.0416	0177	10
44° 00′	.6947	9.8418	.7193	9.8569	.9657	9.9848	1.0355	0.0152	46° 00′
10	.6967	8431	.7173	8557	.9713	9874	1.0295	0126	50
20	.6988	8444	.7153	8545	.9770	9899	1.0235	0101	40
30	.7009	8457	.7133	8532	.9827	9924	1.0176	0076	30
40	.7030	8469	.7112	8520	.9884	9949	1.0117	0051	20
50	.7050	8482	.7092	8507	.9942	9975	1.0058	0025	10
45° 00′	.7071	9.8495	.7071	9.8495	1.0000	0.0000	1.0000	0.0000	45° 00′
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
Angles	Cosines		Sines		Cotangents		Tangents		Angles

Part 2

RADIO GLOSSARY

(Arranged Alphabetically)

Admittance.—The reciprocal of the impedance of an alternating-current circuit is called the admittance.

Ampere-turns.—See pages 9 and 63.

Amplification Constant.—This is the ratio of the change in plate voltage which is necessary to change the plate current a given amount to the change in grid voltage which will produce the same variation in the plate current. This constant is conveniently obtained from the plate current-grid voltage curve of a vacuum tube. It is valuable for determining the qualities of a vacuum tube as an amplifier.

Amplifier.—A device included in or attached to a receiving set which increases the magnitude of radio waves or sound waves. This name is used to refer either to an amplifying vacuum tube or to an amplifying unit consisting of several vacuum tubes.

Armature (in radio).—A short, thin iron bar located in a magnetic field.

Audio Frequencies.—These are frequencies of radio currents corresponding to variations which are audible to the human ear. All frequencies less than about 10,000 cycles (10 kilocycles) per second are easily heard and are called audio frequencies.

Audio Oscillator.—An oscillating tube in an audio-frequency circuit.

Audion.—Another name for a radio vacuum tube, consisting of the three usual elements, filament, grid, and plate.

B Battery.—A battery of which one terminal is intended to be connected directly or indirectly to the plate of a vacuum tube and the other to the grid.

Beats.—Regularly increasing and decreasing intensity in radio currents. Beats are produced by the interaction of two similar wave motions having only slightly different frequencies.

Bias.—The means of variating the effect of the grid in a vacuum tube. A small-capacity, low-voltage battery, when connected in the circuit of a radio receiving set so that a negative voltage is applied to the grid of a vacuum tube, is called a *biasing battery* or a *C battery.*

Biasing Battery.—This is another term sometimes used to designate a C battery.

Binding Post.—A means of connecting mechanically the wires outside a receiving set to the instruments in the set.

Blocking Condenser.—A small-capacity condenser inserted in one of the circuits of a receiving set in order to separate that circuit from another.

It is sometimes called a "stop" condenser and, in that sense, may be used to allow an alternating current to flow in a circuit but "block" a direct current.

Bus (Busbar).—A conducting bare bar installed on a switchboard or other structure in which there is an adequate protection from accidental short circuits and grounding. Frequently, buses are used in large generating stations for connecting generators and switchboards. In that case they are installed in suitable channels in the floor. Bare buses have an advantage over the insulated kind for the reason that they radiate heat more readily.

Buzzer.—A magnetic device having a vibrating armature which is used to interrupt an electric current. The making and breaking of the current vibrates the armature and thus produces a "buzzing" sound.

By-pass Condenser.—A condenser having sufficient capacity to offer low impedance to radio-frequency currents but having much higher impedance to audio-frequency currents.

C Battery.—A small low-voltage battery usually of the dry-cell type intended to be connected in the circuit of a radio vacuum tube so that a negative voltage is applied to the grid of the tube.

Cage Antenna.—An antenna usually intended for outdoors in which the wires are arranged to form the outline of a cylinder.

Capacity.—This is the property of a device temporarily to store electric energy. Capacity as well as inductance controls the cyclic frequency or wave length of a radio circuit.

Carrier Wave.—The primary oscillation sent out from a transmitter. This carrier wave provides the means for carrying the audio-frequency wave which is the electrical equivalent of the sound to be transmitted.

Cascade Amplification.—This means a high degree of amplification of the radio currents in a receiving set, amplification being accomplished by several vacuum tubes arranged in cascade (in series).

Choke Coil.—A coil of wire wound so that it has a large amount of induction or choking effect on the flow of an alternating electric current.

Chopper.—A device consisting of a commutator wheel with segments connected to a central ring and having two brushes which are so adjusted that both make contact at regular intervals during rotation with the connected segments.

Close Coupling.—A transformer or a tuning coil is said to have close coupling when the primary and the secondary winding are very close together.

Condenser.—This consists of at least two but usually a very large number of sheets of metal each of which is separated from the one adjoining by a sheet insulator called a *dielectric*. Besides being used for the temporary storage of electric currents, a condenser is also used in radio work for "tuning" circuits, thus bringing the circuits into resonance.

Conductance.—The conducting "power" of a wire or other conductor of electricity is generally expressed by the unit *mho.*

Continuous Wave (C. W.).—This is a type of radio wave which has a constant amplitude or which, in other words, is undamped. This form of radio wave is to be distinguished from the discontinuous, damped radio wave which is produced by a spark transmitter.

Core.—This consists usually of iron wire or strips placed so that they are in the center of an electromagnet. The core of a transformer is inside the primary and secondary windings.

Counterpoise.—This is an artificial ground system for either a radio receiving or transmitting outfit which consists of one or more wires stretched close to the ground but carefully insulated from it. A counterpoise is usually placed directly below the antenna.

Coupling.—This is the connecting or linking together of apparatus or instruments so that radio currents may be transferred between the connected or linked circuits.

Crystal Detector.—Some metallic crystals have the property of rectifying small alternating currents, especially radio currents, so that the alternating current after passing through the crystal becomes an intermittent, or a pulsating, direct current.

Damping.—Changing the intensity of a radio wave is called damping.

Decibel.—This is the transmission unit (T.U.) used to express the amplification in terms of the power, instead of the voltage as in usual practice.

Decade Bridge.—A "bridge" arrangement of wire resistance for the measurement and comparison of voltage drop with marks corresponding to the decimal system.

Detector.—This is a device for rectifying the incoming radio (alternating) currents so that they may be used to operate a telephone receiver or a loudspeaker. This device uses only one-half of the radio wave.

Dynamic Characteristic.—The ordinary characteristic curve of a vacuum tube is a "static" characteristic, having a constant grid voltage. A dynamic characteristic curve has a variable grid voltage.

Electron.—This is a very small electric charge which passes from the negative to the positive parts of a circuit. See also page 43.

Elements of Vacuum Tubes.—Vacuum tubes may have two, three, four, or five elements. In the two-element tube the elements are the filament and the plate. In the three-element tube they are the filament, plate, and grid. In the screen grid tube there are four elements, namely, filament, plate, grid, and screen.

Ether.—The "substance" which is supposed to occupy all space as well as the interior of solid bodies. Through it heat, light, and radio waves are transmitted.

Fading.—The fluctuation in the intensity of radio waves at a radio receiving set. Fading is usually caused by atmospheric conditions.

Filament.—A fine metallic wire in a vacuum tube which glows when an electric current of suitable voltages passes through it. The filament in a vacuum tube is intended primarily to send out electrons and not to produce light.

Filter.—A combination of coils and condensers which offers low impedance to some radio frequencies but high impedance to other frequencies.

Grid.—This is the controlling element of a vacuum tube. Usually it consists of a frame of perforated metal which is placed between and is insulated from both the plate and the filament of a vacuum tube.

Grid Bias.—This refers to the negative voltage applied to the grid of a vacuum tube. In a battery-operated set this voltage is obtained usually by means of a small, low-voltage battery connected in the circuit.

Grid Leak.—A non-inductive resistance which is used to permit excessive electric charges to leak from the grid of a vacuum tube. By this leakage method, it is possible to control accurately the operating conditions of the tube. The detector circuit is a rectifier which uses only one half of the radio wave. The other half of the wave is wasted, and the grid leak serves as a path leading the wasted energy away from the vacuum tube.

Grid Return.—One end of the grid circuit common to each vacuum tube is connected to the grid of the tube. The other end of this circuit is known as the grid return. It is connected to A minus, A plus, or C minus, depending upon the design of the circuit.

Hard Tube.—A vacuum tube especially suited for use as an amplifier. It differs from a soft tube in that it is more highly exhausted of gas.

Harmonics.—Radio waves which differ in length and therefore also in frequency from the natural wave of the transmitted station. When a harmonic has a lower frequency than that of the transmitting station, it is called a *wave-length harmonic*, and when its frequency is higher than the natural frequency of the transmitting station, it is called a *frequency harmonic*.

Henry.—The unit of inductance.

Heterodyne.—A radio receiving system which depends for its operation primarily on the utilization of beats which are produced by the interaction of two radio-frequency currents, one external and the other internal to the receiving set.

Hook-up.—A diagrammatic representation of the relative positions of instruments in a circuit and the wiring connecting them.

Impedance.—The property of a circuit that tends to hold back or "impede" the flow of alternating current. An inductance, a condenser, or a resistance may impede an alternating electric current.

Impedance Coupling.—A method of connecting or linking an inductance, a condenser, or a resistance so as to offer impedance to an alternating electric current through the circuit.

Inductance.—This tends to check any change in the flow of current through a coil of wire. Inductance may be either of two kinds: (1) *self-inductance* or (2) *mutual inductance.* The practical unit of both kinds of inductance is the *henry.*

Induction.—The action of the lines of force in a magnetic field which produces an electric current in a conductor which is in its field. By induction there is a transfer of electric energy, for example, from the primary to the secondary circuit of a transformer.

Input Circuit.—This is a circuit through which electric power is brought to an instrument or device.

Input Transformer.—This is a transformer in the input circuit of a radio tube including amplifying tubes.

Jack.—A device used to complete one or more circuits by means of a spring contact arrangement into which a plug may be inserted.

Kilocycle.—One thousand cycles.

Kilowatt.—One thousand watts.

Lead-in.—The wire connecting the antenna to the receiving set.

Loading Coil.—This is a coil of wire placed in series with the antenna so that the input circuit in the receiving set can be tuned to higher wave lengths than may be done normally.

Loop Antenna.—A number of turns of suitable wire wound on an insulated frame. One end of the loop is to be connected to the antenna terminal of the receiving set and the other end to the ground terminal.

Loose Coupler.—This is a device for tuning which consists of a primary coil into which is fitted a secondary coil which slides in and out, thereby changing the coupling.

Loud-speaker.—A device for reproducing sounds so that they will be loud enough to be heard without the use of telephone receivers (head sets).

Magnetic Field.—The region around a magnet in which there are magnetic lines of force. See Flux (page 59).

Megohm.—One million ohms.

Mho.—This is a unit of electrical conductance. It is the reciprocal of the ohm.

Microampere.—One-millionth of an ampere.

Microfarad.—One-millionth of a farad (unit of capacity).

Microhenry.—One-millionth of a henry.

Micromho.—This is one-millionth of a mho.

Microphone.—An instrument used to vary the electric current in a transmitting circuit by means of sound.

Microphone Buzzer.—A device for producing a sound for comparison with other sounds of unknown intensity.

Milliampere.—One-thousandth of an ampere.

Millihenry.—One-thousandth of a henry or one thousand microhenrys.

Modulation.—The method of impressing a sound wave upon a radio-frequency carrier wave at the transmitting station.

Mutual Inductance.—The electromotive force inducted by one electric circuit in another.

Natural Frequency.—The frequency of a radio circuit corresponding to its inductance and capacity. It is also called *fundamental frequency.*

Negative Bias.—The negative voltage applied to the grid of a vacuum tube through the connection of the grid return (page 36).

Neutrodyne Circuit.—A tuned radio-frequency amplifier in which the capacity couplings between the tubes are neutralized by small condensers called *neutrodons.*

Ohm.—The unit of electric resistance.

Oscillating Circuit.—A circuit which contains inductance and capacity and has such a low resistance that it oscillates when a suitable voltage is impressed.

Oscillator.—A vacuum tube which is designed for operation in an oscillating circuit.

Oscillograph.—This is an instrument for observing (and photographing usually) alternating-current waves. It is especially useful for wave-form analysis.

Output Circuit.—A circuit into which an instrument or device delivers electric power.

Output Impedance.—A combination of inductance and capacity used between the plate circuit of the last tube in an audio amplifier and the loud-speaker.

Output Transformer.—A special transformer used to transfer the electrical energy from the last audio stage to the loud-speaker.

Pentode.—A five-element power-output vacuum tube.

Pitch (sound).—The intensity of a tone depending upon the rate of the vibrations producing the tone.

Plate.—The output terminal or element of a radio vacuum tube.

Plate Circuit.—That section of the wiring in a receiving set which is connected between the plate of a vacuum tube and the positive terminal of the B battery.

Plate Current.—The current which flows in the circuit connected to the plate of a vacuum tube.

Plug-and-jack Device.—A connecting device consisting of a jack and a plug for rapidly connecting and disconnecting electric circuits.

Potentiometer.—A resistance unit which is used for varying the voltage applied to a circuit. It consists essentially of a variable resistance of high value.

Power Amplifier.—Two radio vacuum tubes connected into one stage of a receiving set so that a balancing effect is secured between them with the object of obtaining more energy for each tube without distortion. It is also called the *push-pull circuit.*

Power-output Tube.—The vacuum tube supplying the loud-speaker.

Primary Circuit.—The input coil of a transformer.

Push-pull Circuit.—See Power Amplifier above.

Radiation.—Transmission of energy by means of radio and other electromagnet waves.

Radio Frequency.—This is the frequency of variation above the range of the human ear (between 16,000 and 300,000,000 cycles per second).

Radiotron.—A trade name for a particular make of radio vacuum tubes.

Reactance.—The opposition to the flow of a variable current which is produced by a condenser (*capacity reactance*) or by a coil of wire (*inductive reactance*). The practical unit of reactance is the *ohm.*

Rectifier.—A device for changing alternating electric current into direct current.

Reflex Circuit.—A circuit in which radio currents of different frequencies are superimposed upon each other without interference. Because the two superimposed currents are of different frequencies, neither of the currents loses its identity.

Regenerative Circuit.—A circuit in which a radio vacuum tube is connected so that, after detection, the radio signal introduced in the plate circuit is led back to the grid circuit of the tube. By this means the original strength of the signal received by the grid is very much increased.

Resistance Coupling.—The method of linking two circuits together by means of a resistance which is common to both.

Resonance.—A circuit is in resonance when its natural frequency is the same as the frequency of the radio current passing through it.

Resonance Curve.—A chart showing the change in volts, amperes, or watts in a circuit at about the condition of resonance.

Rheostat.—A variable resistance used for controlling the amount of current in a circuit.

Rotary Converter.—A machine employing mechanical rotation in changing electrical energy from one form into another. Converters, as commonly used, may be for changing alternating current to direct current or for changing alternating current from one frequency to another without changing the number of phases.

Secondary Circuit.—The output coil of a transformer.

Selectivity.—This is the ability of a radio receiving set to select any particular wave length and exclude others.

Sharp Tuning.—This is the condition when a small change in the position of the tuning device will produce a marked effect in the strength of signals.

Shield.—A metal plate or casing usually connected to the ground which is intended to prevent effects from changes in capacity.

Slope of a Line.—This refers to the slant of a line or curve, or its inclination with reference to an arbitrary axis.

Soft Tube.—A radio vacuum tube which is not thoroughly exhausted of air and gases.

Spark Transmitter.—A radio transmitter which operates by sending telegraph code signals by making and interrupting a high-voltage spark.

Static.—Natural electric discharges occurring in the air.

Static Level.—Reception becomes impractical when the intensity of static disturbance reaches a certain strength or level. Broadcasting which is received at an intensity below this level is not intelligible.

Stopping Condenser.—See Blocking Condenser.

Susceptance.—The reactive component of the admittance of an alternating-current circuit is the susceptance, the practical unit being the *mho.*

Tickler.—A coil which is used to feed back electric current from the plate to the grid circuit of a radio vacuum tube.

Tuner.—The part of a receiving set which is used to adjust it to resonance or to adjust the receiving circuit so that it will be in tune.

Tuning.—Changing the capacity or inductance in a radio receiving circuit so that the circuit will be in resonance with the frequency of a transmitted radio current.

Variometer.—A device consisting of two coils connected in series which are arranged so that the mutual inductance between them may be varied.

Vernier Condenser.—A variable condenser with vernier device for very accurate setting of the dial.

Volt.—The unit of electric pressure.

Watt.—The unit of electric power, also one-thousandth of a kilowatt.

Wave Meter.—A device for measuring the wave length of radio electric currents.

ABBREVIATIONS

a.c. = alternating current.
A.C.W. = attenuated continuous (radio) wave.

A.F. = audio frequency.
antilog = antilogarithm.
A.W.G. = American wire gage (same as B. & S.).
B.P. = binding post.
cos = cosine of angle.
C.W. = continuous (radio) wave.
d.c. = direct current.
D.S.C. = double silk covered.
D.C.C. = double cotton covered.
E.C. = enamel covered.
I.C.W. = interrupted continuous (radio) wave.
log = logarithm.
M.U. = amplification constant.
m.f. = microfarad.
R.F. = radio frequency.
tan = tangent of angle.
T.U. = transmission unit.
π = 3.1416.

SECTION II

ELECTRICITY IN RADIO

Part 1

ELECTRICAL THEORY

Simple Circuits.—It is well known that many forms of matter can be made to show evidences of the phenomenon which is called "electricity"; thus, if a piece of hard wax is rubbed with a cloth which is then taken away, both the wax and the cloth will attract light bits of paper. The wax is said to have a *negative charge* of electricity, and the cloth a *positive charge.* It can be shown that "like" charges repel each other while "unlike" charges attract. When equal unlike charges *come into contact* they neutralize each other.

Electrons.—Every substance consists of a large number of particles called *molecules*, which, for a given substance, are assumed to be alike. Molecules, in turn, are composed of atoms which are the smallest particles of matter that can be obtained by chemical action. In order to account for the presence and behavior of electricity in matter, it is considered that the atom has a central charge of positive electricity and that a number of charges of negative electricity rotate at great speeds around this center. Normally, the sum of the negative charges balances the positive charge. The negative charges, which are all equal, are called *electrons* and represent the smallest amounts of electricity which can be conceived. The arrangement and number of moving electrons belonging to an atom determine whether the atom is copper, or silver, or hydrogen, and so on.

The electron is assumed to be spherical in shape and to have a diameter of one-fifth of a trillionth $\left(\frac{1}{5\times 10^{12}}\right)$ of a centimeter. It has been calculated that the average velocity of a "free" electron at 0°C. is about 100 kilometers or 62 miles per second. An idea of the extremely small size of the electron may be obtained from the estimate that in a tiny sphere of copper having a diameter of 0.00001 inch there are about 20,000,000,000 electrons. The atom formerly was regarded as the smallest particle of matter which could exist; something like 250,000 hydrogen atoms placed in a row would have a length of 0.00001 inch. The weight of an electron is only about one two-thousandths of the weight of a hydrogen atom.

Some of the electrons, in moving about, may escape from one atom and get into the atomic system of another. If an atom loses an electron the balance between positive and negative charges is destroyed and the atom is left positively charged. In the same way, a negatively charged body is one which has obtained more than its normal number of electrons.

Electric Current.—The "free" atoms may be acted on by an electric charge outside the body in such a way that they travel in a common direction and constitute what is called an *electric current* in the body. Hence the flow of an electric current in a wire or other conductor is considered to consist of the motion of an immense number of electrons. According to another theory, it is held that an electric current or the process of conduction is brought about by the spontaneous discharge of electrons from one molecule to another. The external electric charge in this case influences the direction of the discharge, which, in its absence, would be at random. When the external distorting force is removed, the original condition of the structure of the atom is restored. The progressive velocity, or drift, of the electrons in a wire or other conductor carrying a current is, however, very slow and may be only a small fraction of an inch per second.

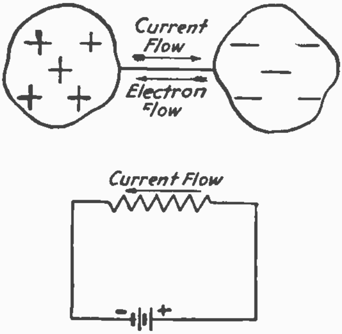


Fig. 1.—Assumed direction of electric current.

Ampere.—The intensity of an electric current, that is, the unit quantity of electricity flowing in a wire during a unit of time, is called an *ampere.* This intensity has the same value at all points along the wire.

Direction of Flow of Current.—The flow of current as to direction is defined arbitrarily as taking place from the positive to the negative end of a wire; that is, in a wire connecting the terminals of a battery the direction of the flow of current is assumed to be from the positive terminal of the battery to the negative. *Electrons, however, being negative charges, move from negative to positive.* Hence it must be remembered that the direction of electron flow is opposite to the assumed direction of current flow as represented, for example, in Fig. 1.

Electrolysis and Electric Heating.—The amount and rate of flow of electricity can be detected by the chemical, heating, and magnetic effects which it produces. A familiar example of chemical action is the process of electrolysis used in electrotyping, electroplating, and in the refining of metals. The heating effect of electricity depends on the quantity of current flowing and varies as the square of the current applied. In some types of radio tubes a filament is heated to incandescence by an electric current.

Electric Fields.—The effect of one electrically charged body on another exists even when there is a considerable distance between them. The space around an electrically charged body is said to be under "strain" which allows it to act upon another charged body. This space, which extends in all directions around a charged body, is called an *electrostatic field.* At any considerable distance from the body, however, the field intensity or strength is small because it varies inversely as the square of the distance from the body.

An electrostatic field is an effect produced by electricity which is not moving. Electricity flowing in a wire sets up another kind of effect called a *magnetic strain* in the space surrounding the wire. The space in which this condition exists is called the *magnetic field.* A magnetic field is represented as consisting of imaginary *lines of force* which form closed circles around the wire. The direction of the magnetic field may be indicated by its effect on a compass needle held near the conductor.

Conductors and Insulators.—Matter may be regarded as belonging to two classes, one of which possesses many free electrons, and the other does not. A substance having a large number of free electrons is called a *conductor* and is said to offer a low resistance to the flow of an electric current through it. A substance which has relatively few free electrons is called an *insulator* and offers a high resistance to the flow of an electric current.

All substances, however, contain some free electrons and, theoretically, will allow the passage of an electric current, although the resistance of some may be so extremely high that the material is considered a good insulator. Further, the resistance of some materials is not constant. The resistance may vary, for example, inversely as the temperature of the material; that is, the material may serve as an insulator at a low temperature and as a conductor at a high temperature.

Leakage Current.—Examples of good conducting materials are the metals and that class of liquid conductors called the *electrolytes.* Examples of insulating materials are dry gases, glass, porcelain, hard rubber, and various waxes, resins, and oils. The very small current which can pass through or over the surface of an insulator is called a *leakage current.*

Difference of Potential.—If one piece of a substance is charged positively and a piece of another substance is charged negatively, there is said to be a *difference of potential* between them. When two such pieces are connected by a wire as in Fig. 1 and there is a flow of current through the wire, the electrons pass through the wire from the negatively charged piece to neutralize the positive charge on the other piece. The electric charges which accumulate at the ends of the wire have the effect of neutralizing the original conditions of charge.

Electromotive Force.—If the original difference of potential is maintained in a wire or other conductor by removing the neutralizing charges as they accumulate, the flow of the electric current will be steady and continuous. Such steady difference of potential or *electromotive force* may be provided by putting the charged bodies and their connecting wire into a closed circuit containing a device capable of developing an electromotive force.

Electromotive force may be developed by friction, by thermal means, by chemical action, or by induction. Electricity may be produced by frictional machines at high voltages but with very small amounts of current. This method of producing electromotive force is not practical because of the difficulties encountered in connection with insulation, dampness, and variation in performance.

Electromotive force may be produced by heating the junction (thermocouple) of two unlike metals. A table of the *thermo-electric power of metals* is given in table XII below. To illustrate the use of this table, the electromotive force developed at a junction of steel and constantan wires is 10.62 + 22.0 or about 32.6 microvolts. Electromotive forces when *positive and negative* are *added* to obtain the total effective value of voltage. Low voltages but fairly large currents are obtainable by this means.

TABLE XII.—THERMO-ELECTRIC POWER OF METALS
Smithsonian Tables

Substance	Microvolts	Substance	Microvolts
Aluminum	− 0.68	Platinum (hardened)	+ 2.42
Bismuth (pressed wire)	−97.0	Platinum (malleable)	− 0.818
Cadmium	+ 3.48	Selenium	+807.
Constantan	−22.0	Silver (pure hard)	+ 3.00
Copper (commercial)	+ 0.10	Steel	+ 10.62
Gold	+ 3.0	Tantalum	− 2.6
Iron (piano wire)	+17.5	Tellurium B	+500.
Lead	0.00	Tellurium A	+160.
Molybdenum	+ 5.9	Tungsten	− 2.0
Nickel	−22.8	Zinc	+ 2.79

Electromotive force may be produced by chemical action in a battery. This chemical action is due to the fact that a difference of potential exists between two different substances used in the battery, such as zinc and carbon when placed in certain chemical solutions. The efficiency of this chemical method is high, but the cost of thus producing electricity for most purposes is prohibitive because of the expense of the materials.

The ability of an *electric generator* to produce an electromotive force and thus maintain a difference of potential is due to the condition which results when the wires on the armature of the generator pass through the magnetic field of magnets, called *poles.*

The kinds of electromotive force may be classified as constant and alternating. A *constant electromotive force* does not change in direction of flow or in strength. An *alternating electromotive force* varies periodically in direction of flow and in strength.

Unit of Resistance.—As the free electrons move along a conductor it is supposed that they hit the atoms of the substance which lie in their path. The effect of such collisions is to reduce the velocity of the electrons. The

TABLE XIII.—SPECIFIC RESISTANCE OF METALS

Metal	Ohms per cir. mil-foot at 20°C.	Metal	Ohms per cir. mil-foot at 20°C.
Aluminum	16.98	Manganin	264.
Antimony	250.	Mercury	574.
Bismuth	720.	Molybdenum (drawn)	34.2
Brass	42.0	Monel metal	252.
Cadmium	45.6	Nichrome	600.
Climax	522.	Nickel	46.8
Constantan	294.	Palladium	66.0
Copper, annealed	10.35	Phosphor bronze	46.8
Copper, hard-drawn	10.60	Platinum	60.0
Excello	552.	Silver	9.53
German silver, 18 per cent	198.	Steel (soft)	108.0
German silver, 30 per cent (see Constantan)		Steel, manganese	420.
Gold	14.63	Tantalum	93.0
Iron, 99.98 per cent pure	60.	Therlo	282.
Iron (see Steel)		Tin	69.0
Lead	132.	Tungsten (drawn)	33.6
Magnesium	27.6	Zinc	34.8

extent of the opposition is proportional to the *electrical resistance* of the conductor. Resistance varies with the shape, substance, and temperature of the conductor. The unit of resistance is called an *ohm*. For very small resistances the millionth part of an ohm is used as a unit and is called a *microhm*. For high resistances a million ohms is used as a unit and called a *megohm*.

Unit of Electromotive Force.—The unit of electromotive force, or voltage, is called a *volt*. One volt is that voltage which will force a current of one ampere through a resistance of one ohm.

Unit of Conductance.—A circuit which offers but little resistance R to a current is said to have good conductance. If conductance is represented by G, then $G = 1/R$ or $R = 1/G$. The unit of conductance is an *ohm*.

Specific Resistance of Wire.—If r is the specific resistance of a substance, that is, the resistance of a *unit wire* (as defined below), then the resistance R of a conductor having a length of L feet and a cross-sectional area of A circular mils is

$$R = \frac{rL}{A},$$

a *mil* being 0.001 inch. The area of a wire one mil in diameter is one *circular mil*. The area of a circle in circular mils equals the square of the diameter in mils. A *unit wire* is a round wire one foot long and one mil in diameter (or having an end area of one circular mil).

To find the resistance in ohms of a length of any size of wire, multiply the specific resistance, that is, the resistance in ohms of one circular *mil-foot*, by the length in feet and divide by the square of the mil diameter (circular-mil area). Tables of specific resistances and wire sizes in mils are given in tables II and XIII on pages 13 and 47.

It is obvious that the resistance of a wire or other conductor varies directly with the length; that is, as the length increases, the resistance increases. Also, the resistance varies inversely with the cross-sectional area; that is, as the area increases, the resistance decreases.

Variation of Resistance with Temperature.—The variation of the resistance of a pure metal with changes in temperature is given by the equation

$$R_t = R_0(1 + a \times t)$$

in which t is the temperature of metal in degrees Centigrade, R_t is the resistance at t°C., R_0 is the resistance at 0°C, and a is a constant which has usually a value of about 0.004.

If it is assumed that $a = 0.004$, the equation may be stated thus: For each 2.5°C. rise in temperature above 0°C. the resistance increases about one per cent.

The resistance of some substances, however, does not follow this rule. Carbon, for example, decreases in resistance with an increase in temperature, and one alloy of nickel and copper shows no change in resistance with ordinary temperature increases.

Series and Parallel Circuits.—In radio work some units of apparatus are connected in series and others in parallel. If the various parts of a circuit are connected in such a way that the total current must flow through each part, the parts are said to be in *series*. If the analogy of the flow of electricity to the flow of the water is used, this corresponds to the pipe line shown in Fig. 2 in which pipes of various sizes and lengths are connected in series. If the various parts are connected in such a way that the total current is subdivided, the parts are said to be *parallel*. The corresponding condition in the pipe line is shown in Fig. 3. If each of the four paths offers the same resistance to current flow, then the total current at A will be divided into four equal parts, which unite again at B. The equivalent resistance R_s of a group of resistances r_1, r_2, r_3, r_4, and so on, connected in *series*, is equal to the sum of the separate resistances; that is, $R_s = r_1 + r_2 + r_3 + r_4 + \cdots$ The equivalent resistance R_p of a group of resistances r_1, r_2, r_3, r_4, and so on, connected in *parallel*, is equal to the reciprocal of the sum of the reciprocals of the separate resistances. That is,

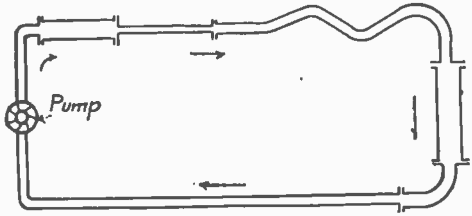


Fig.—2. Pipes connected in series.

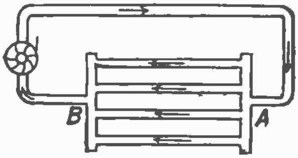


Fig. 3.—Pipes connected in parallel.

$$R_p = \frac{1}{\dfrac{1}{r_1} + \dfrac{1}{r_2} + \dfrac{1}{r_3} + \dfrac{1}{r_4}} \tag{3}$$

If the individual *parallel* resistances are equal, it is obvious that the total resistance is equal to the resistance of one path divided by the number of paths. Thus, if there are four paths of equal resistance r, the total resistance R_p is equal to $r/4$. An example will serve to explain the application of the formula when the individual *parallel* resistances are unequal. If r_1, r_2,

r_3, and r_4 are equally, respectively, 5, 10, 15, and 20 ohms, the total resistance becomes

$$R_p = \frac{1}{\frac{1}{5} + \frac{1}{10} + \frac{1}{15} + \frac{1}{20}} = \frac{1}{0.20 + 0.10 + 0.067 + 0.05} = \frac{1}{0.417}$$
$$= 2.4 \text{ ohms.}$$

It should be noted that in this parallel circuit the total resistance is less than that of any one of the branches.

Relation between Current, Voltage, and Resistance.—The "opposition" offered by the resistance R of a wire or other conductor to the flow of current through it reduces the effective velocity of the electrons and hence decreases the strength of current. In order to compensate for this opposition caused by the collision of electrons and, thus, to maintain a constant value of current flow, it is necessary to apply to the circuit an electromotive force or voltage E which is equal to the product of the current in *amperes* and the resistance in *ohms*, which may be expressed by IR when I is the current in amperes, R is the resistance in ohms, and E is in volts. This relation is known as *Ohm's law* and may be expressed in the three forms below:

$$E = IR, \text{ or voltage} = \text{current} \times \text{resistance, or volts} = \text{amperes} \times \text{ohms.}$$
$$I = \frac{E}{R}, \text{ or current} = \frac{\text{voltage}}{\text{resistance}}, \text{ or amperes} = \frac{\text{volts}}{\text{ohms}}.$$
$$R = \frac{E}{I}, \text{ or resistance} = \frac{\text{voltage}}{\text{current}}, \text{ or ohms} = \frac{\text{volts}}{\text{amperes}}.$$

Ohm's law holds true for a complete circuit or a part of a circuit. When the above equations are used for a part of a circuit, the values of voltage, current, and resistance must apply to that part only. It is shown later that, with modifications, Ohm's law may be applied also to radio circuits.

Power and Energy.—The work accomplished by the voltage E in moving an electron through a unit length D is equal to DE (because work equals the product of force times the distance through which it acts). A current of I amperes flowing in a wire or other conductor corresponds to a transfer of N electrons per second through a unit length D.

Power being defined as the rate at which work is done, the total work performed per second, or the *power*, is then $W = NDE$ or IE. The unit of power is a *watt*, which is the power expended by a current of one ampere flowing through a resistance of one ohm. One *kilowatt* is 1,000 watts.

1 watt = 0.7375 foot-pounds per second, or, 1 foot-pound = 1.356 watts per second.

1 mechanical horsepower = 33,000 foot-pounds per minute = 550 foot-pounds per second = 746 watts.

$$\text{Horsepower} = \frac{\text{watts}}{746}.$$

Since $E = IR$, then, by substitution, $W = I^2R$ and since $I = E/R$, by similar substitution, $W = E^2/R$.

Thus there are three forms of the equation for power W,

$W = EI$, or power = voltage × current, or watts = volts × amperes.

$$I = \frac{W}{E}, \text{ or current} = \frac{\text{power}}{\text{voltage}}, \text{ or amperes} = \frac{\text{watts}}{\text{volts}}.$$

$$E = \frac{E}{I}, \text{ or voltage} = \frac{\text{power}}{\text{current}}, \text{ or volts} = \frac{\text{watts}}{\text{amperes}}.$$

Each of the expressions $W = I^2R$ and $W = E^2/R$ can be stated in three forms in a similar manner.

Energy is expressed in the same units as work. The commercial unit of *electrical energy* is the *kilowatt-hour*. Electrical energy is measured by an instrument called the *integrating wattmeter* which automatically adds up the work done, even when there may be a continual variation of power.

The energy required to give velocity to the electrons is given up by them in the form of heat caused by their collisions with each other and with the atoms.

Direct Current.—The electric current which is supplied by all kinds of batteries is called a direct current; that is, it flows in only one direction through a circuit. In Fig. 4, for instance, if the pressure or voltage of the battery is steady, the current will be steady and will flow from the positive (+) terminal of the battery through the circuit to the negative (−) terminal of the battery. If the voltage is pulsating, that is, if it rises and falls in strength but acts in one direction only, then the current also rises and falls in strength and is called a *pulsating direct current*.

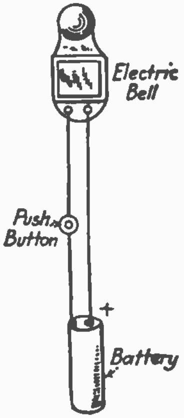


FIG. 4.—Electric circuit with battery.

Alternating Current.—When radio waves are changed into an electric current by means of a radio receiving apparatus, the current, instead of flowing in one direction not only changes its direction at a definite rate but also varies in strength. Such a current is called an *alternating current*. If there is an alternating voltage in a circuit, the variations in both strength and direction of the electric current correspond to the variations of the voltage. The flow of an alternating current is like the flow of water which would be produced in the pipe line in Fig. 5, when the water is agitated by the piston of the pump moving rapidly back and forth over a short distance. In that case the water simply surges first in one direction and then in the other. It no sooner attains speed in one direction than it is compelled to slow up and then to accelerate in speed in the opposite direction, and so on, over and over again. The water does not travel around the pipe circuit, as may be shown by the fact that an object placed in the water will simply oscillate back and forth.

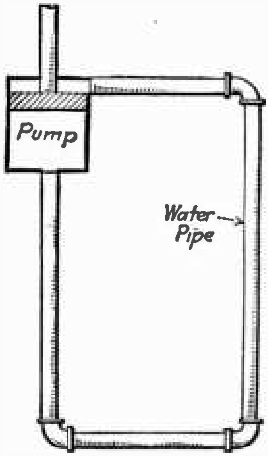


Fig. 5.—Agitation of water in a pipe circuit.

The alternating current which is used for most electric-light circuits changes its direction, or alternates, one hundred and twenty times per second. It is said to have a *frequency* (see page 9) of 60 complete alternations or *cycles* per second. The radio currents most used, however, may have frequencies ranging from 10,000 to 30,000,000 cycles per second, corresponding to wave lengths of 30,000 to 10 meters, respectively.

In order to distinguish the directions of flow, one direction is called the positive (+) and the other the negative (−). During the flow in one direction, the strength of the current varies from zero to a maximum and back to zero again. Figure 6 shows a simple way of indicating the variations in strength, direction, and time, when an alternating current is considered. The positive direction of flow is from *A* to *C*, the negative from *C* to *E*. During the flow from *A* to *C*, the strength of the current varies from zero to a maximum and again to zero, as shown by the curve *ABC*, which represents a half cycle.

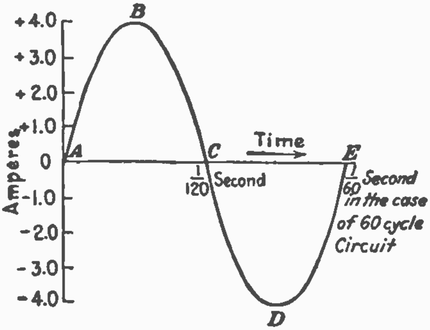


Fig. 6—Alternating-current cycle.

It is important to remember that the resistance offered by a circuit to the flow of an alternating current, that is, one which reverses periodically in direction and varies in strength, is not the same as the resistance to the flow of a direct current, meaning one which is steady in value and flows in only one direction.

Part 2

ELECTROSTATICS

Dielectric.—The dielectric property of a medium separating two conductors of electricity refers to the intensity of the *electrostatic field* which can be set up at a certain voltage without rupturing or breaking down the separating medium. If the intensity of the electrostatic field becomes too great the medium cannot withstand the stress which results, and a "breakdown" occurs, sometimes accompanied by a flow of electricity as an electric *arc*.

Dielectric strength is the ability of a substance to withstand an electrostatic breakdown and is expressed in volts per unit of thickness. Thus the dielectric strength of air is about 3,000 volts per millimeter, that of rubber about 16,000, and that of cambric cloth about 32,000 volts. An example of the breakdown of air under dielectric stress is seen in the *corona*, a bluish, brush-shaped discharge, which appears sometimes on high-voltage line circuits. An arc is also a discharge through air, differing from a corona in that it is brilliantly illuminated and is accompanied by noise.

If a difference of potential is applied across a dielectric, the electrons are forced to move in a direction from negative to positive in the dielectric but are still under the influence of their respective atoms. The explanation of this action was formerly based on an electrical displacement from the positive to the negative plate through the dielectric. Such a movement of electrons constitutes a flow of electric current. The flow of current is momentary because the electrons cannot move to adjacent atoms. Consequently when the pull on the electrons becomes equal to the force which produces the pull, the flow of current ceases. This momentary flow of current is known as a *displacement current*. Such a flow of current is produced only by a difference of potential and stops when the electric force is steady in value, although the stress in the dielectric exists as long as the difference of potential is maintained. If the electric force due to the difference of potential is reduced, the stress in the dielectric is reduced, and a flow of displacement current takes place in the opposite direction.

If the pull on the electrons is greater than the attraction of their atoms, the electrons break away and the *dielectric becomes a conductor*, and a rupture or breakdown occurs.

Condenser.—Electrical displacement in a dielectric may be produced by placing the dielectric between metal plates and connecting a battery or other source of electromotive force to the plates as in Fig. 7. Such an arrangement of metal plates and dielectric is called a condenser. The dielectric may be air or some other gas or any solid or liquid which is not a conductor.

When a battery is connected to a condenser, an *electrical displacement* takes place in a direction from the positive (+) to the negative (−) plate of the condenser. The amount of this electrical displacement depends on the value of the applied voltage and the kind of dielectric. A displacement current begins to flow in the dielectric and continues until the electric displacement assumes a steady value. *The movement of electrons in the dielectric* is in a direction from the negative (−) plate toward the positive (+) plate.

It must be understood that there is no actual movement of charges from one plate to another. The action of a condenser depends on the movement of *charges* across the dielectric such that the *positive electrons accumulate at one end and the negative electrons accumulate at the other.* A dielectric in this condition has electrical energy which is stored in an electrostatic form. From this point of view a condenser may be called a device which is capable of storing electrostatic energy.

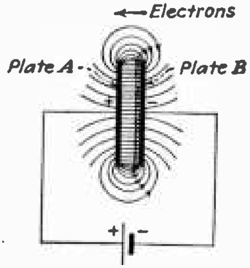


Fig. 7.—Simple condenser.

In the *external circuit* the movement of electrons is from the negative (−) to the positive (+) plate. Consequently, during the charging process the negative plate will acquire a greater negative charge and the positive plate a greater positive charge.

It is obvious that in a direct-current circuit of constant voltage, a condenser is charged very rapidly and the flow of displacement current is momentary. Because of this action it is customary to state that *direct current cannot flow through a condenser.* In an *alternating-current circuit, a displacement current will flow in the condenser,* because the applied voltage reverses periodically and the electric stress in the dielectric reverses in direction with every reversal of the voltage.

Capacity.—For a given condenser, the charge Q is proportional to the applied charging voltage E. This relation may be written $Q = C\,E$ where C is a constant called the *capacity* of the condenser. Thus the capacity of a condenser is an indication of the amount of electricity required to charge the condenser to a certain voltage. The unit of capacity is the *farad.* A farad is the capacity of a condenser in which a voltage difference of one volt gives the condenser a charge of one coulomb of electricity, a *coulomb* being the quantity of electricity supplied by a current of one ampere in one second. The *farad* is much too large a unit for practical purposes and it is customary to use instead the *microfarad* (one-millionth of a farad) and the micro-microfarad (one-millionth of a microfarad).

During the time a charge is accumulating in a condenser the voltage ($Q \div C$) due to this charge is increasing. This voltage tends to oppose the charging voltage E, and when the value of $Q \div C$ becomes equal to E, the charging process ends. It will be noticed that the equation $Q = C\,E$ does not contain a time factor; therefore, the same amount of charge is stored in a condenser whether it is built up slowly or quickly. But the rate of building up the charge depends on the value of the capacity C and the resistance R of the circuit. The larger the product of the factors C and R the greater is the time required to arrive at any given fraction of the applied charging voltage. This product ($C \times R$) is called the *time constant* of the circuit. The charging current I at any time t after the circuit is closed is

$$I = \frac{E}{R}(K)^{-\frac{t}{CR}}$$

where C is the capacity in farads, E is the applied charging voltage in volts, R is the total resistance of circuit in ohms, t is the time in seconds, and K is a constant having a numerical value of 2.7128.

When $t = CR$, $I = 0.368\,E \div R$; that is, the charge reaches 63.2 per cent of its final value and the charging current drops to 36.8 per cent of its initial value in a time CR. In other words the length of time required to charge a condenser depends on the product of the capacity of the condenser and the resistance of the circuit but does not depend on the value of the applied voltage.

Dielectric Constant.—The charge which a condenser will accumulate, for a given voltage and space between plates, depends on the nature of the dielectric. Thus the amount of charge which a given condenser will accumulate at a given voltage, and with glass as a dielectric, is about eight times the amount of charge it will accumulate when air is the dielectric. Air is used as the standard of comparison and said to have a dielectric constant of 1. If C_a is the capacity of a condenser having air as a dielectric and C_x is the capacity with another substance as the dielectric, then

$$\frac{C_x}{C_a} = K$$

where K is the dielectric constant of the material. In other words the dielectric constant is a factor by which the capacity of an "air" condenser must be multiplied to find the capacity of the same condenser when the new material is used. Values of dielectric constants are given in table XIV (page 56). If the voltage applied is from a source of alternating current, particularly

TABLE XIV.—DIELECTRIC CONSTANTS

Substance	Dielectric Constant[1]
Air	1.0
Glass	4 to 10
Mica	4 to 8
Hard rubber	2 to 4
Paraffin	2 to 3
Paper, dry	1.5 to 3.0
Paper (treated as used in cables)	2.5 to 4.0
Porcelain, unglazed	5 to 7
Sulphur	3.0 to 4.2
Marble	9 to 12
Shellac	3.0 to 3.7
Beeswax	3.2
Silk	4.6
Celluloid	7 to 10
Wood, dry	3.0 to 6.0
Molded insulating material, shellac base	4 to 7
Molded insulating material, phenolic base (bakelite)	5.0 to 7.5
Vulcanized fiber	5 to 8
Transformer oil	2.5 to 3.0
Water, distilled	81.0

[1] Sometimes called also "inductivity" or "specific inductive capacity."

that of very high frequency, the values of the dielectric constant may differ considerably from the values for direct current.

The capacity of a condenser depends on (1) area of the plates, (2) distance between plates, and (3) dielectric constant. Capacity may be increased by increasing the area of the plates or by bringing the plates closer together or by the use of a material with a larger value of dielectric constant.

The capacity of a condenser consisting of two parallel metal plates of the same size and shape, which are separated by a dielectric of uniform thickness and material, may be expressed as

$$C = 0.085\frac{KS}{t}$$

where C is the capacity in micromicrofarads, t is the thickness of dielectric between plates in centimeters, S is the surface area of one side of one plate in square centimeters, and K is the dielectric constant.

The allowable thickness of a dielectric for use in a condenser depends on the voltage which it must withstand, and the *dielectric strength* depends on the voltage which will rupture a piece of the material of unit thickness; thus, for a given voltage, a certain thickness for each material must be used. The material having the highest *dielectric constant* does not necessarily have the greatest *dielectric strength*.

Dielectric Leakage and Absorption.—Dielectric materials are not perfect insulators and have a small electric conductivity. A condenser will permit a very small current to flow through it continuously when a voltage is applied to its terminals, and it will discharge itself slowly if allowed to stand with its terminals disconnected. This is called the *leakage* of the condenser. Materials differ greatly in this respect, but in general the length of time during which a charge is retained depends on the degree of conductivity of the material.

Free and Residual Charges.—When the terminals of a charged condenser are connected by a conductor, a current flows and the condenser discharges. The charge which flows out instantaneously upon discharge is called the free charge. With some dielectrics, if the terminals are connected a second time, another and smaller discharge occurs, and this may be repeated several times. This so-called *residual charge* is due to the *absorbed charge* and indicates a slow recovery of the dielectric from the electric stress. In condensers made with oil or mica for the dielectric, the absorption is small. It is larger with glass and quite troublesome with materials similar to bakelite. The absorption is accompanied by the production in the dielectric of heat which represents a loss of energy.

Energy Stored in a Condenser.—The amount of energy required to charge a condenser depends on the capacity and the voltage between the plates to which the condenser is connected. The value of this energy W is

$$W = \tfrac{1}{2}CE^2$$

where C is the capacity of condenser in farads, E is the voltage to which the condenser is charged in volts, and W is the work in joules. (A joule is the work done in one second by a current of one ampere through a resistance of one ohm.)

Condensers in Parallel and in Series.—A group of three condensers connected in *parallel* is shown in Fig. 8. All of these condensers are subjected to the same impressed voltage and each accumulates a charge proportional to its capacity. Since capacity is proportional to the plate area, it is obvious that the method of connecting condensers in parallel has the effect of increasing the plate area of the conductors. A parallel connection of condensers gives a capacity which is larger than that of any one of the group. If C is the equivalent capacity of the group and c_1, c_2, c_3 are the capacities of the three condensers, respectively, then $C = c_1 + c_2 + c_3$.

A group of three condensers connected in *series* is shown in Fig. 9. Each condenser accumulates the same charge Q, and the total voltage is subdivided among the condensers in inverse ratio to their capacities. A series connection of condensers gives a capacity which is smaller than that of any of the group. If e_1, e_2, e_3 are the voltages across the condensers C_1, C_2, C_3, respectively, then the voltage E to which the condenser is charged is

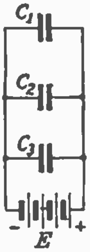


FIG. 8.—Three condensers in parallel.

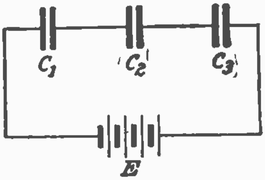


FIG. 9.—Three condensers in series.

$$E = e_1 + e_2 + e_3;$$

and since $E = Q \div C$ when the condenser is charged, then

$$\frac{Q}{C} = \frac{Q}{c_1} + \frac{Q}{c_2} + \frac{Q}{c_3}, \quad \text{and} \quad \frac{1}{C} = \frac{1}{c_1} + \frac{1}{c_2} + \frac{1}{c_3},$$

or

$$C = \frac{1}{\frac{1}{c_1} + \frac{1}{c_2} + \frac{1}{c_3}}.$$

Part 3

MAGNETIC CIRCUITS

Magnets.—A natural form in which iron is sometimes found, *magnetite*, a black oxide of iron, is called a *natural magnet*. If this substance is dipped into iron filings, the filings will stick to it. Also, if a piece of this ore is suspended by means of a silk cord, the piece of ore will assume a position such that its long axis is in a north and south direction.

An *artificial magnet* may be made by rubbing a small rod of iron or steel with a piece of magnetite. The iron rod then has the same properties as the magnetite and is said to be magnetized. This property is called *magnetic retentivity*. A bar of hard steel may retain such magnetic properties indefinitely and is called a *permanent magnet*. On the other hand, a bar of soft steel retains for a short time only the magnetism set up in it. Consequently soft iron or steel is used when it is essential that the magnetism must respond closely to changes of the magnetizing force. Other common forms of magnets are the horseshoe or U-shape type and the ring type with a small gap cut in it. Thin steel magnets are more powerful in proportion to their weight than thick ones, and, therefore, for a given weight of material, a *laminated magnet* (made of thin plates) is more powerful than a solid one. Another method of making a magnet is to enclose an iron or steel rod in a coil of insulated wire attached to a battery as shown in Fig. 10.

A *compass needle* consists of a piece of magnetized steel (permanent magnet) so mounted that it can swing on a pivot. Such a needle assumes a position which lies very nearly north and south. The end which points north is called the *north pole* of the needle and the other the *south pole*.

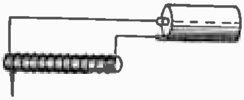


Fig. 10.—Coil and battery for making a magnet.

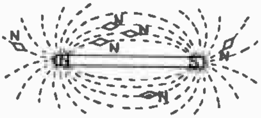


Fig. 11.—Lines of force around a magnet.

Magnetic Field.—The effects of magnetism indicate the existence of so-called *lines of magnetic force*, which, considered as a whole, are designated as the *magnetic flux*. The space in which these lines occur is known as the *magnetic field*. The magnetic lines of force seem to center in two regions near the ends of the magnet as shown in Fig. 11.

If two magnetic poles attract or repel the same pole, they are said to be alike, while if one repels and the other attracts the same pole, they are unlike. *Like poles repel* and unlike poles attract each other. By this action it is possible to determine the polarity of a magnet by means of a compass needle, because the south pole of the compass points to the north pole of the magnet and the north pole of the compass to the south pole of the magnet. It is assumed that the lines of force leave the magnet at the north pole, enter it at the south pole, and continue within the magnet to the north pole. Furthermore, the compass needle always tends to set itself in the direction of magnetic field in which it is placed; that is, the north pole of the needle points in the assumed direction of the magnetic lines of force. The magnetic force of attraction or repulsion between two poles varies inversely as the distance between them, provided the distance is considerable as compared with the size of the poles.

A fundamental law of magnetism is that one pole cannot occur alone; meaning, that for a north pole there must be an equal south pole. This may be verified by the fact that if a bar magnet is broken into two or more pieces, each piece will have its north and south pole.

Molecular Theory of Magnetism.—An explanation of magnetism is based on the assumption that each molecule of a magnet is a small magnet. In an unmagnetized piece of steel the small magnets are considered to be arranged in a haphazard manner as shown in *a* of Fig. 12. Under these conditions no magnetic effect is exhibited, because the poles neutralize each other. When however, a magnetizing force is applied, each small magnet assumes a position such that its north pole turns in the same direction as that of the magnetizing force. The bar now shows evidence of a north pole at one end and a south pole at the other, but inside the magnet each small north pole of a molecule is neutralized by an adjacent south pole. If the bar is broken, however, the poles on each end of the break no longer neutralize each other, and consequently each piece of the bar exhibits a north and a south pole.

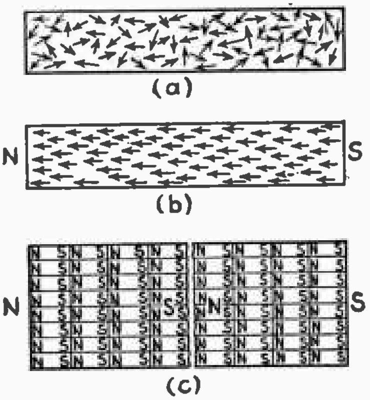
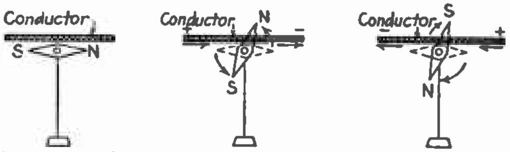


Fig. 12.—Arrangement of small magnets in steel bar.

Magnetic Shielding.—There seems to be no known insulator for magnetic flux. Consequently the lines of force cannot be confined to the magnetic circuit but spread out into the surrounding medium. This unconfined flux is called the *magnetic leakage*.

Sensitive apparatus can be protected or *magnetically shielded* from stray magnetic fields by enclosing it in an iron container. The iron container diverts practically all the stray flux from entering its interior.

Magnetic Field of a Wire Carrying Current.—If a compass needle is held near a wire carrying a current, the needle deflects, thus indicating the presence of a magnetic field, and assumes a position which is at right angles to the direction of current flow as shown in Fig. 13. The action of the needle shows that the magnetic flux exists in circles about the wire and that the direction of the magnetic field depends on the direction of the current. The relation between the direction of the current flow and the direction of the magnetic field is shown by the position of the compass needle, as in Fig. 14. If a current in a wire is flowing away from the observer, the direction of the lines of force is in a clockwise direction (the same as the travel of the hands of a clock). If a current in a wire is flowing toward the observer, the direction of the lines of force is in the opposite direction or counterclockwise. Another way of stating this relation is based on the *screw rule.* If a screw is rotated, its direction of travel corresponds to the direction of current flow, and its direction of rotation to the direction of the magnetic field.



No Current Passing Through Conductor

Current Passing Through Conductor Left to Right

Current Passing Through Cunductor Right to Left

Fig. 13.—Compass needle held near wire carrying electric current.

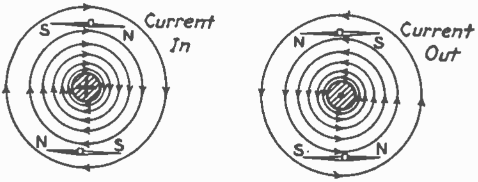
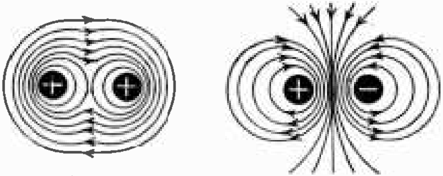


Fig. 14.—Relation between direction of current flow and magnetic field.

The magnetic field extends to an indefinite distance from a wire or other conductor, but at points some distance from the wire the effect becomes more feeble. If the current stops, the magnetic field, together with its effects, disappears. When the current is started through the wire we may think of its magnetic field as coming into existence and sweeping *outward*



Magnetic Attraction (Fields Interlink)

Magnetic Repulsion (Fields Repel)

Fig. 15.—Resultant magnetic field of currents in wires in opposite directions.

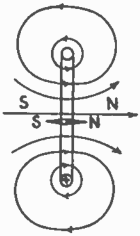


Fig. 16.—Direction of magnetic field around loop of wire.

from the axis of the wire as a center. An alternating current produces an *alternating magnetic field* which has the same frequency as the current and reverses every time the current does. It follows, then, that if the currents in two adjacent wires are in opposite directions the resultant magnetic fields are opposed, while if the currents are in the same direction the fields combine as shown in Fig. 15. The direction of the magnetic field around a loop of wire carrying a current is shown in Fig. 16.

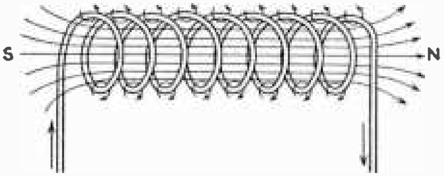


FIG. 17—Direction of magnetic field of a solenoid.

Solenoids.—A coil consisting of a number of turns of wire which is used for producing a magnetic field is called a *solenoid*. The direction of the magnetic field of a solenoid, as shown in Fig. 17, may be determined by the application of the screw rule (page 61). The winding may consist of several layers as in Fig. 18. The magnetizing power of a solenoid may be increased several hundred times by the use of a central core of soft iron.

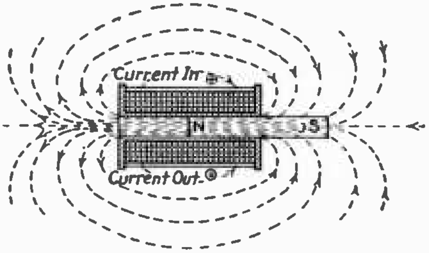


FIG. 18—Direction of magnetic field of multilayer coil.

Magnetic Circuit of Generator.—The magnetic circuit of a generator is shown in Fig. 19. The leakage flux is that portion of the magnetic field which passes from one field core *C* to the next, without entering the armature *A*. The flux leaving the field core divides when it reaches the yoke *Y* and again when it reaches the armature. It should be noted that the cross-sectional area of the yoke and of the cores must be large enough to carry the leakage flux as well as the useful flux. An increase in the leakage flux requires the use of an increased amount of iron in the cores *C* and of copper wire in the solenoids producing the magnetic field.

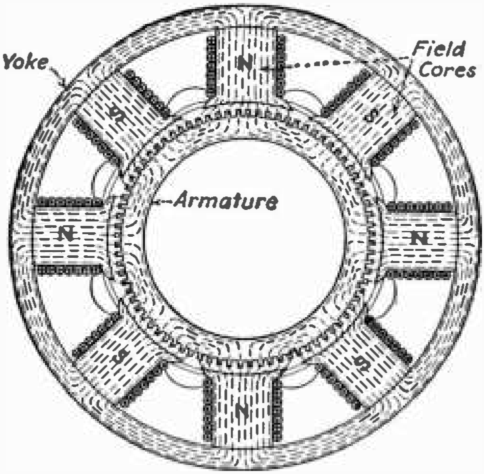


Fig. 19.—Magnetic circuit of electric generator.

Ampere-turns.—The value of the ampere-turns of a circuit is equal to the product of the turns of wire in the circuit and the amount in amperes of the current flowing through the turns. Thus, a current of 2 amperes flowing through 100 turns of wire gives 200 ampere-turns. It is, of course, essential to deduct from the total those ampere-turns, if any, which produce an opposing magnetic field.

Flux.—The flux in a magnetic circuit corresponds to current in an electric circuit. It is defined as the total number of lines of force in a magnetic circuit. Magnetic flux may be expressed in terms of a unit called a *maxwell* but more usually as *lines of force.*

The flux density of a magnetic field is the number of lines of force on a unit area at right angles to the direction of flux. The theoretical unit is called a *gauss* which is one line of force per square centimeter, but flux density is more commonly given in lines of force per square inch.

Magnetomotive Force.—The function of the magnetomotive force of a magnetic field is to drive the magnetic flux through a magnetic circuit. In this respect it is similar to the electromotive force of an electric circuit.

The magnetomotive force of a circuit is expressed in units called *gilberts*, which are calculated by multiplying the ampere-turns by 1.257.

Reluctance.—Reluctance of a magnetic circuit corresponds to the resistance of an electric circuit and is the opposition of a magnetic circuit to the flow of magnetic flux through it. The unit reluctance called an *oersted* is the reluctance of a centimeter-cube of air.

Permeance.—Permeance corresponds to the conductance of an electric circuit and is equal to the reciprocal of the reluctance. It is that property of a magnetic circuit which allows the passage of magnetic flux.

Permeability.—The permeability of a substance is the ratio of the flux existing in it to the flux which exists under the same conditions if the substance is replaced by air; that is, permeability is a measure of the ability of a substance to carry magnetic lines of force compared with the ability of air. The permeability of air is taken as 1. The permeability of ordinary iron and steel ranges from about 50 to 2,000 with a value of 5,000 or more for special steels.

Reluctance of a Magnetic Circuit.—The reluctance of a magnetic circuit is proportional to its length and inversely proportional to its cross-section multiplied by the permeability. This may be expressed as $R = L \div A\mu$, where R is the reluctance in oersteds, L is the length of the circuit in centimeters, A is the area of the cross-section of the circuit in square centimeters, and μ is the permeability.

A combination of *reluctances in parallel* is treated in the same manner as resistances in parallel. A combination of *permeances* (reciprocals of reluctances) in parallel is equal to the sum of the individual permeances, just as parallel conductances of an electric circuit are added to find the resultant conductance.

Magnetic Saturation.—The permeability of iron or steel varies with the kind of material and with the flux density. The value of permeability for a given flux density is equal to the value of flux density at that point divided by the corresponding value of magnetomotive force. The variation in permeability of a substance may be shown graphically by plotting values of magnetomotive force in gilberts per centimeter against the corresponding flux densities. This gives the so-called *magnetization curve* or normal *saturation curve* as shown in Fig. 20.

The accompanying curve of permeability may be drawn by plotting the ratio of flux density to magnetomotive force in gilberts per centimeter for a number of points of the curve in Fig. 20.

Law of Magnetic Circuit.—The quantities of flux, reluctance, and magnetomotive force of a magnetic circuit bear the same relation to each other as the current, resistance, and electromotive force of an electric circuit; that is, the flux is equal to magnetomotive force divided by the reluctance.

Hysteresis.—Experiments show that the magnetization lags behind the magnetizing force, meaning that the degrees of magnetization corresponding to values of an *increasing* magnetizing force are not the same as the degrees of magnetization corresponding to the same values of a *decreasing* magnetizing force. This effect is called hysteresis, and a typical cycle of magnetization called a *hysteresis loop* is shown in Fig. 21. It is generally considered that this lag of magnetization is due to molecular friction which results in the expenditure of energy in carrying the iron through a cycle of magnetization. The amount of energy spent thus is the *hysteresis loss.* Silicon steel has low hysteresis and eddy-current (page 11) losses and consequently is used very generally for the cores of high-efficiency solenoids. In the magnetic circuits of electric generators in which the iron loss is less important than in smaller apparatus, the less expensive open-hearth steel may be satisfactorily used.

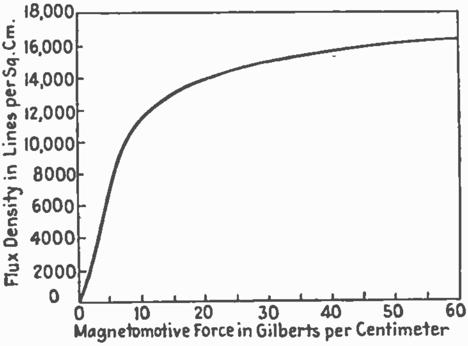


Fig. 20.—Magnetization or saturation curve.

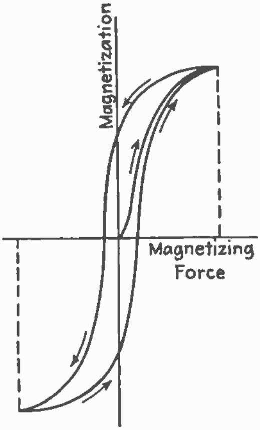


Fig. 21.—Cycle of magnetization or hysteresis loop.

Magnetic Linkage.—The lines of magnetic flux around a wire carrying a current are closed curves, and the electric circuit also is closed. The lines of magnetic flux are thought of as always *interlinked* with the turns of wire in the circuit. The number of flux lines passing through a coil will depend on the current, and any change in the current will change the number of *linkings.* The total number of linkings N is always equal to the number of turns of wire n times the magnetic flux ϕ; that is, $N = n\phi$. The number of linkings may be varied by changing the amount of flux (due to a change in current) or by changing the number of wire turns. Thus if a loop as in Fig. 22 is placed near a coil of wire carrying a current, some of the flux lines will pass through the loop. The number of these flux lines passing through the loop may be changed by varying the number of turns of wire in the coil or by changing the number of flux lines through the loop. The latter may be done by rotating the loop or by otherwise moving it with respect to the coil.

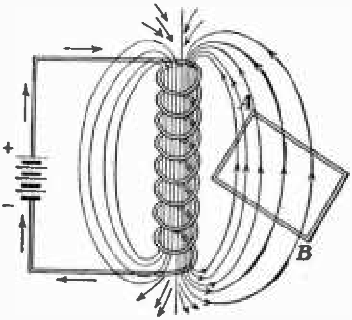


Fig. 22.—Flux lines of solenoid linked with circuit *AB*.

Induced Electromotive Force.—If there is any change in the number of linkings between the flux and the turns of wire, an electromotive force is induced in the circuit which will cause an induced current to flow when the circuit is closed. An example of this action is shown in the case of two solenoids placed as in Fig. 23. When a current starts in the solenoid *A*, a current will be *induced* in the solenoid *B* and will flow as long as the current in *A* is increasing. If the current in *A* becomes steady, no current will then be induced in *B*. If the current in *A* decreases, the current in *B* reverses. The magnetic field of the induced current always tends to oppose the change that causes the induced current.

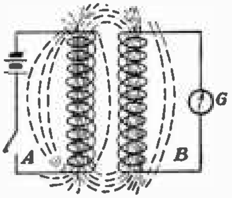


Fig. 23.—Induced electromotive force in solenoid.

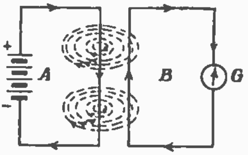


Fig. 24.—Induced electromotive force in parallel wires.

The case of parallel straight wires is illustrated in Fig. 24. If the current starts, changes, or stops in one of the wires, a current is induced in the other. Such an action occurs in cross-talk on telephone lines or where there is interference from alternating-current power lines. To reduce such cross-talk in telephone wires, the two wires of a pair are transposed at certain intervals so that over any considerable distance the voltage induced by adjacent wires acting on a transposed pair is zero.

The magnitude of the induced voltage depends on the *time rate* of change of the number of linkings. This is expressed as

$$\text{Induced voltage} = -\frac{N}{t} = -\frac{n\phi}{t}$$

where t is the time in seconds in which the change $n\phi$ takes place. To get the induced voltage in volts, this equation must be divided by 108. The *minus* sign indicates that the induced voltage acts in opposition to the effect which produces it.

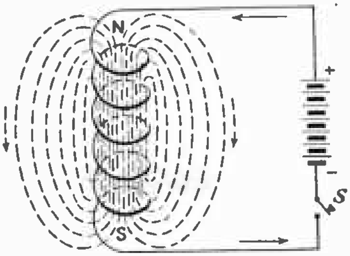


FIG. 25.—Magnetic flux in coil.

If a coil is connected to a battery as in Fig. 25 and the switch S is closed, current will flow in the coil. This current sets up a magnetic flux linking the coil. The value of this flux N is proportional to the current I and may be expressed as

$$N = LI$$

where L is called the *self-inductance* or simply the *inductance* of the circuit. The self-inductance of a circuit is the magnetic flux linked with it which is due to a unit of current flowing in it as given by the equation $L = N \div I$. The value of L depends on the number of turns of wire, on the shape and size of the turns of wire, and on the permeability (page 64) of the medium surrounding the circuit.

It is obvious that the greater the number of turns of wire and the greater the amount of iron in the core of a coil the greater is its self-inductance. Likewise, the greater the self-inductance of a circuit the greater is its property to oppose the voltage applied to it. Thus a circuit might have a self-inductance so large that no variable current could pass through it. A coil having this property is called a *choke coil.*

The unit of self-inductance is the *henry.* A coil is said to have a self-inductance of one henry if a rate of current change of one ampere per second produces an induced voltage of one volt. For practical work, smaller parts of a henry are used, such as the *millihenry* (one-thousandth of a henry) and the *microhenry* (one-millionth of a henry).

Electromotive Force of Self-induction.—As the flux increases in a circuit like Fig. 23, it induces an electromotive force (voltage) in the coil. The magnitude of this self-induced voltage depends on the number of turns of wire in the coil and the rate at which the flux increases. The direction of the induced voltage is such as to oppose the increase in the flux linkings of the coil, or, in other words, the induced voltage must oppose any increase of current. On the other hand, when the circuit is broken, the induced voltage is in the same direction as the original current and tries to keep the current flowing.

The electromotive force of self-induction e may be expressed, then, as

$$e = -L\frac{I}{t}$$

where e is the value of induced voltage in volts, L is *coefficient of self-induction* in henrys, and I/t is the rate of change of current with respect to time.

The *minus* sign, as already stated, indicates that the induced voltage opposes the change of current.

Energy of Magnetic Field.—It is a well-known fact that matter cannot set itself in motion and that energy for its movement must be supplied from outside itself. So in an electric circuit a current cannot set itself in motion and energy must be supplied from an available source of electromotive force. This is obvious because the current as it increases must flow against a *counter-electromotive force.* The establishment of a magnetic field about an electric circuit has been explained. When this field collapses or disappears, the energy stored in the field is returned to the circuit. The maintenance of a *constant* field, however, does not require an expenditure of energy. It can be shown that the energy W of a magnetic field is

$$W = \tfrac{1}{2}LI^2$$

where W is the energy in the magnetic field in watt-seconds, L is the inductance of the circuit in henrys, and I is the current in amperes.

If two coils are in such a relation to each other that a voltage is induced in one because of a change of current in the other, the coils are said to possess *mutual inductance.* It follows, then, that the voltage e_A induced in coil A due to rate of change of current I_B/t in coil B is

$$e_A = -M\frac{I_B}{t} \text{ volts.}$$

Likewise, the voltage e_B induced in coil B due to a rate of change of current I_A/t in coil A is

$$e_B = -M\frac{I_A}{t}$$

where M is the *mutual inductance* in henrys and t is the time in seconds.

The mutual inductance of two circuits depends on the size and construction of the circuits, their distance apart, their relative position, and the nature of the material between them, because these factors affect the magnetic flux which links both circuits. The mutual inductance decreases rapidly as the distance between the two circuits is increased.

If two coils are placed so that their axes are in the same line, their mutual inductance is largest for that spacing. If the axes of the coils are at right angles, their mutual inductance has its lowest value, and if the axes of the coils are parallel, their mutual inductance is greater than for the right-angle position. A metallic sheet placed between two coils has a shielding effect and reduces the mutual inductance by shielding.

Induction Coil.—The action of an induction coil, illustrated in Fig. 26, depends on mutual inductance. As shown here, the *primary* or low-voltage winding, of a few turns of large wire, is wound on an iron core C and connected to a battery. When a current flowing in the primary winding magnetizes the core, the armature A is pulled toward the core and breaks the primary circuit. This rupture of the primary circuit reduces the attractive force of the core and releases the armature which is then pulled back by the attached spring, thus again completing the primary circuit; and the action of the device will be repeated. A *condenser* is placed in parallel with the points of contact of the armature in the primary circuit to reduce *sparking* when the circuit is broken. The frequency of movement of the armature depends on its weight as well as the stiffness and length of its spring.

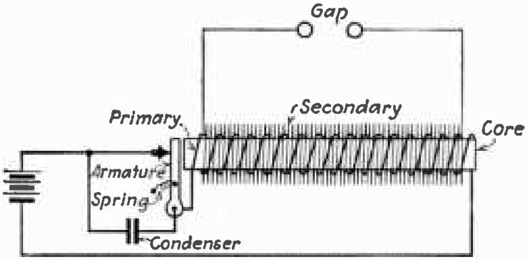


FIG. 26.—Primary and secondary windings of induction coil.

The interruption of the primary current is accompanied by a change of flux in the core. This varying flux induces a high alternating voltage in the *secondary* or high-voltage winding which has many turns of fine wire. The secondary winding is heavily insulated from the primary. An *induction coil* may be used to supply the high voltage required in charging the condensers of spark transmitters (page 40). By suitable design the secondary winding may be made to discharge across the air gap shown in the figure. The power of an induction coil, however, is limited by the capacity of the device for interrupting the circuit.

Coefficient of Coupling.—Two circuits are said to be *coupled* when the mutual inductance between them is greater than zero. The theoretical *maximum value* of mutual inductance of two coils or circuits is $M_m = \sqrt{L_1L_2}$ where L_1 is the total self-inductance in henrys of one circuit, L_2 the total self-inductance in henrys of the other circuit, and M_m the maximum mutual inductance in henrys between the two circuits. This, however, represents a condition of no leakage. The degree of *coefficient of coupling* k is the ratio of the actual M to the theoretical maximum value of mutual inductance; that is,

$$k = \frac{M}{\sqrt{L_1L_2}}.$$

Inductances in Series and in Parallel.—Inductances in series may be added like resistances. If inductance coils are so far apart that *mutual* inductance is negligible, inductances in parallel combine like resistances in parallel. If mutual inductance is considered, the total value of *inductances in series* L_s is

$$L_s = L_1 + L_2 + L_3 \cdots +2(M_{1-2} + M_{1-3} + M_{2-3} + \cdots).$$

Some or all of the mutual inductances may be negative. For two *inductances in parallel* the total inductance L_p is in henrys,

$$L_p = \frac{L_1L_2 - M^2}{L_1 + L_2 - 2M}.$$

The term $2M$ changes sign if M is negative.

Part 4

ALTERNATING-CURRENT CIRCUITS

Reactance.—A constant direct current in a circuit meets no opposition other than the resistance. In the case of a variable current, however, the conditions are different. In a circuit with *inductance*, the flow of a variable current is opposed by the voltage induced because of the variation of the current. In a circuit containing *capacity*, the condenser charges and discharges as the current changes and consequently it influences the flow of current. In a circuit containing both inductance and capacity, the effect of one may be offset by the effect of the other. Usually, however, one of these quantities has the stronger effect, so that, in addition to the resistance, the current meets another opposition called the *reactance.* Reactance due to inductance is named *inductive reactance,* and that due to capacity is *capacity reactance.*

The explanation of the variation of reactance with the frequency of the changes of current is simple. The more rapidly the current changes the greater is the induced voltage in a circuit and hence the greater the inductive reactance. In the case of a condenser, however, as the current changes are increased, the reactance becomes less. This happens because the greater the number of charges and discharges of the condenser taking place every second the greater is the quantity of electricity (current) which flows. In most cases the reactance of a circuit for radio service is greater than its resistance.

In order to determine the value of the current in a circuit it is necessary to combine the reactance with the resistance in order to get the total opposition or *impedance* to the flow of the current.

Alternating Current.—An alternating current is one in which electricity flows around the circuit, first in one direction and then in the opposite direction. It starts from a value of zero, increases to a maximum, drops to zero again, reverses its direction of flow, increases to a maximum, and finally drops to zero. The highest value of current reached is the *amplitude* of the current. During this interval of time the current is said to have passed one complete "cycle" of changes. The number of such cycles per second is called the *frequency.*

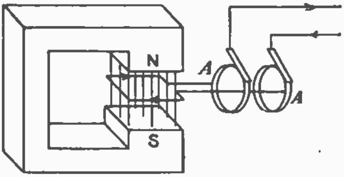


FIG. 27.—Magnetic field of simple dynamo.

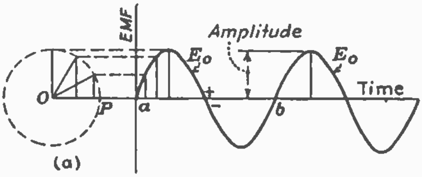


FIG. 28.—Circle diagram and wave curve representing alternating voltages.

An alternating voltage of this kind may be produced in a coil revolving in a uniform magnetic field, such as in the simple dynamo of Fig. 27. The single turn of wire is shown in such a position that the magnetic flux passing through it is a maximum. When the wire is rotated in either direction, the flux passing through it is changed, and hence a voltage is induced. As the wire is rotated, the change of flux through it is greater in some positions than in others and the voltage at the *slip rings* S varies in a definite manner. In a circle diagram, such as at *a* of Fig. 28, the vertical distance from the horizontal axis to the end of a revolving line represents the induced voltage. Thus the vertical lines as shown represent the voltages induced when the coil has passed through angles of 30, 60, and 90 degrees, respectively. If a chart is made taking the distance along a horizontal line to represent degrees of revolution and the vertical distance from this line to represent induced voltages, a *wave curve* as in *b* of Fig. 28 is obtained.

A pure *sine wave* of voltage may be expressed as $e = E_0 \sin wt$ (page 12). where e is the instantaneous value of voltage in volts at a time t, E_0 the maximum value of voltage in volts, w is $2\pi f$ in which f is frequency in cycles per second, t the time in seconds, and π is 3.1416.

This equation when plotted on a curve sheet gives a sine-wave diagram as shown by *b* in Fig. 28. The *amplitude* of the wave is marked in the figure.

Harmonics.—Ordinary alternating-current generators do not have magnetic fields which are exactly uniform, so that the current and voltage produced do not go through their changes in the same way as the ideal *sine wave* illustrated in the figure. Such irregular or distorted currents and voltages have, in addition to the fundamental frequency, other frequencies called *harmonics* which are multiples of the fundamental. The fundamental frequency is sometimes called the *first harmonic.* The second harmonic has a frequency twice that of the fundamental; the third, a frequency three times the fundamental; and so on.

The usual alternating-current lighting circuit carries a current having a frequency of 60 cycles per second. The currents used in radio work may have frequencies between the limits of about 10,000 to 15,000,000 cycles per second. Alternating currents which have a frequency of less than 10,000 cycles per second are *audio-frequency currents*, while those with frequencies greater than 10,000 cycles are *radio-frequency currents.*

Effective Values of Alternating Quantities.—If a direct-current instrument for measuring current flow is put into an alternating-current circuit, its indicator or needle pointer cannot follow the rapid changes of current and so takes a position which corresponds to the average of all the current values during one cycle. This average value, however, is zero, because the changes of current in one direction are the same as those in the other direction. The same behavior is noticed if a direct-current volmeter is put into an alternating-current circuit.

The indicator of an *alternating-current instrument* always deflects in the same direction regardless of the direction of the current or voltage. This deflection is proportional to the square of the current and, on an alternating-current circuit, would be determined by the average of the squares of all the current values during a cycle. For an alternating-current sine wave it can be shown that the ammeter deflection is proportional to a value which is one-half of the square of the maximum value.

But the effectiveness of an alternating current is not based on its average value but on its *heating effect* and is expressed in terms of an equivalent direct current which would produce heat at the same rate.

The heating effect of a current is proportional to the square of its value (amperes). For a direct current I then, heating effect is proportional to I^2. For an alternating current the heating effect is proportional to the average of the square of the current values in one cycle, or, proportional to one-half the square of the maximum current. This may be expressed as $I_0^2/2$ where I_0 is the maximum value (amplitude) of current. From these relations it may be shown that $I = \sqrt{I_0^2/2}$ or $I = 0.707\ I_0$; that is, if an ammeter is in an alternating-current circuit having a current whose maximum value is I_0 (assume 100 amperes for example) the instrument (ammeter) will have a reading of the *effective current* I of $0.707\ I_0$ (or 70.7 amperes). Likewise, an alternating-current voltmeter will always read the effective value of the voltage, which is equal to the maximum value multiplied by 0.707. Conversely, the effective values multiplied by 1.414 give the corresponding maximum values.

Circuit Having Resistance Only.—If an alternating voltage is applied to a circuit having resistance only, the current *at any instant* is found by dividing the voltage at that instant by the resistance of the circuit. In this type of circuit the current is zero when voltage is zero, the current is highest when voltage is highest, and, in fact, the changes in current keep step with those of the voltage. The current and voltage are said to be "in phase." For this case, then, in an alternating-current circuit having resistance only (*non-inductive*),

$I = E/R$ where I and E are effective values of current (amperes) and voltage (volts).

The power in this circuit, at any instant, is equal to the product of the values of current and voltage at that instant. The *average* power for a cycle, however, is equal to the product of the effective current and the effective voltage; that is,

$$\text{Average power } P = I \times E.$$

Phase of Current.—Difference in phase of a current is nothing more than difference in position of voltage and current waves in a cycle. It is generally referred to as difference in time, expressed as a fraction of the length of a cycle, thus: one-quarter of a cycle, one-half of a cycle, and so on. Phase difference may be expressed also as an angle. Thus a difference in phase of one cycle is considered as the equivalent of an angle of one revolution, or 360 degrees. One-quarter of a cycle then corresponds to 90 degrees, and one-half of a cycle to 180 degrees.

The consideration of phase difference is useful in circuits in which the *current and voltage do not pass through their maximum values at the same time.* Thus, in Fig. 29, the current lags behind the voltage to an extent that the *phase difference* is one-eighth of a cycle, or 45 degrees.

In a circuit containing only non-inductive resistance the current and voltage are *in phase* as indicated in Fig. 30. On the other hand, in any circuit having a reactance there must be a difference in phase between the current and the voltage.

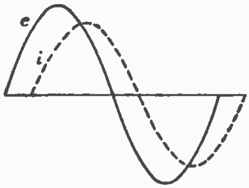


Fig. 29.—Diagram showing phase difference between voltage and current.

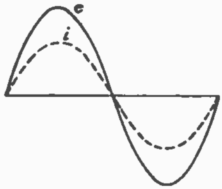


Fig. 30.—Phase relations with non-inductive resistance (voltage and current in phase).

Circuit Having Inductance Only.—An approximation to a circuit having inductance only is one consisting of a large inductance coil of heavy wire with a very low resistance. When an alternating voltage is applied to this circuit, the variations of the current induce a voltage in the circuit which increases as the inductance and also the rate of current variation are increased.

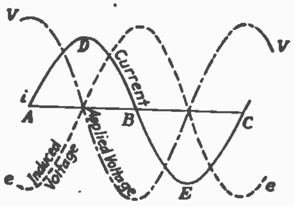


Fig. 31.—Diagram of applied and induced voltages (angle of lag 90 degrees).

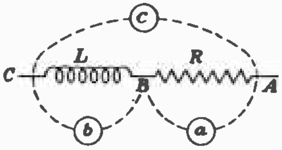


Fig. 32.—Non-inductive and inductive resistances in series.

In Fig. 31 the current varies in value most rapidly at points *A*, *B*, and *C* where it passes through zero. At these points the induced voltage has its maximum value. At points *D* and *E*, where, momentarily, the current does not change at all, the value of the induced voltage is zero. It can be shown that the *applied voltage* and the *induced voltage* are, at every instant, equal and opposite as shown in the figure. The effect of the *induced* voltage is to oppose changes in the current. Consequently, in this case, the current is found to lag behind the *applied* voltage by 90 degrees.

The induced voltage has a value of $2\pi fLI$ in which π is 3.1416, f is the frequency in cycles per second, L is inductance in henrys, and I is the effective value of the current in amperes. From this relation the effective value of the current I is

$$I = \frac{E}{2\pi fL}.$$

Inductive Reactance.—The term $2\pi fL$ is known as inductive reactance, sometimes expressed as X_L, and is measured in ohms. Inductive reactance increases as the frequency or inductance or both are increased. Thus, at 50,000 cycles per second the reactance of a coil having an inductance of 0.3 henry is

$$X_L = 2 \times 3.1416 \times 50{,}000 \times 0.3 = 94{,}245 \text{ ohms.}$$

This inductive reactance reduces the current just as a resistance of the same value would, but no energy is lost in heat. In a purely inductive circuit, energy is stored in the magnetic field in one-half of a cycle and returned to the circuit during the other half of the cycle.

Circuit Having Resistance and Inductance in Series.—If i is the *instantaneous current*, the voltage required to force this current through a non-inductive resistance R is Ri, and the voltage required to overcome the induced voltage of the inductance is X_Li. Hence, the *instantaneous* value of the applied voltage e is $Ri + X_Li$. But these values of non-inductive and inductive voltage cannot be used to calculate the *effective* applied voltage, because the voltages Ri and X_Li are not in phase. When the voltage Ri is zero, the voltage X_Li is at a maximum. The sum of the two voltages may have a maximum value which is less than the sum of their individual maximum values.

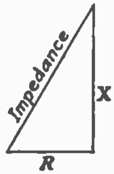


Fig. 33.—Size of right triangle representing relation between impedance, reactance, and resistance.

This may be shown by an experiment in which an alternating current is passed through a circuit containing non-inductive and inductive resistances connected in series as in Fig. 32. Three voltmeters marked a, b, and c are used to measure the voltages between the points A and B, B and C, and C and A, respectively. The *effective* voltages indicated by the voltmeters are such that the reading of instrument c is not equal to the reading of b plus that of a, as would be expected for direct current. The voltmeter a indicates now a reading of RI, and b a reading of X_LI where I is the *effective* value of current, such as would be obtained with an alternating-current ammeter. The voltmeter c indicates the *effective* value E of the applied voltage which is represented by the hypotenuse of a right triangle whose sides are RI and X_LI. The relation between the sides and hypotenuse of a right triangle is such that

$$E^2 = (RI)^2 + (X_LI)^2 = I^2(R^2 + X_L^2).$$

From this the effective value of the current produced by the effective applied voltage E is

$$I = \frac{E}{\sqrt{R^2 + X_L^2}}.$$

Addition of Alternating Quantities.—The addition of alternating currents is best explained by means of a diagram. In Fig. 34 the curves I_1 and I_2 represent the instantaneous values over one cycle of two alternating currents which are in phase. The sum of currents I_1 and I_2 at any point in the cycle is obtained by finding the height of each curve at the given point and adding the two heights. The values thus obtained can be used to obtain the current curve I_3.

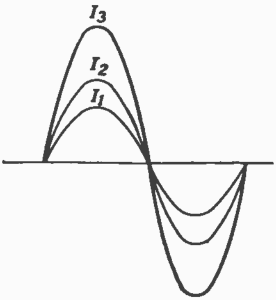


FIG. 34.—Instantaneous values of two alternating currents in phase.

For two currents which are not in phase, as I_1 and I_2 in Fig. 35, the procedure is exactly the same, although consideration must be given to the fact that values above the reference line are considered as positive, and those below the line as negative. In this case the sum of the currents I_1 and I_2 gives the current curve I_3. It should be noted that the resultant current I_3 is not in phase with either I_1 or I_2.

The term $\sqrt{R^2 + X^2}$, known as the *impedance* of a circuit, takes the place in alternating-current calculations of the resistance in direct-current work. The relation between impedance, resistance, and reactance is the same as that between hypotenuse, base, and height of the right triangle of Fig. 33.

Power Factor.—The power lost in heat in any circuit is I^2R. The apparent power is EI. To get the actual power, the apparent power must be multiplied by a number called the *power factor;* that is,

$$\text{Actual power} = EI \times \text{power factor, where}$$

$$\text{Power factor} = \frac{\text{resistance}}{\text{impedance}} = \frac{R}{X}.$$

Circuit Having Capacity Only.—When an alternating voltage e is applied to a circuit containing capacity, the voltage starts from a value of zero, as at *a* in Fig. 36, and as long as the voltage increases in an assumed positive direction, the current flows *into* the condenser. The direction of flow of this current is positive and will continue in that direction as long as the voltage continues to increase. When the point *b* is reached, the voltage *e* stops increasing and the current becomes zero again. Between the points *b* and *c* the voltage is decreasing. Consequently the current now flows *out of* the condenser and will be considered as having a negative direction of flow. Beyond the point *c* the voltage reverses and charges the condenser in the opposite direction, hence the direction of flow of the current still is negative. When the voltage *e* reaches its negative maximum, the current reverses and becomes positive. It should be apparent, therefore, for the conditions of voltage and current relations illustrated by this figure, that the current which charges the condenser is, in phase, 90 degrees ahead of the applied voltage. In general, the charging current is increased when the capacity is increased, when the frequency is increased, and when the applied voltage is increased.

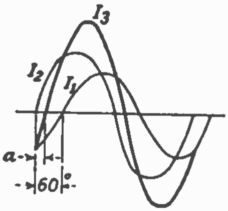


Fig. 35.—Instantaneous values of two alternating currents not in phase.

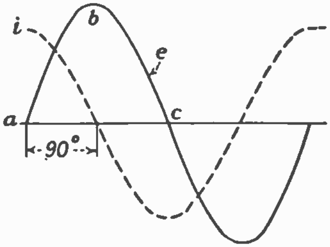


Fig. 36.—Voltage and current relations in charging a condenser (90 degrees difference in phase).

These relations may be expressed by symbols, thus,

$$I = 2\pi f C E$$

in which I is the effective value of the charging current in amperes, f the frequency in cycles per second, C the capacity in farads, E the effective value of the applied voltage in volts, and π is 3.1416.

Capacity Reactance.—Similar to the inductive reactance X_L is the capacity reactance X_c of a condenser, which is expressed in ohms by the equation

$$X_c = \frac{E}{I} = \frac{1}{2\pi f C}.$$

This equation shows that the capacity reactance increases if the capacity is reduced or if the frequency is lowered. For instance, at 60 cycles per second the reactance of a condenser having a capacity of 0.2 microfarad is

$$X_c = \frac{10^6}{2 \times 3.1416 \times 60 \times 0.2} = 13{,}350 \text{ ohms.}$$

The figure 10^6 is necessary to change microfarads into farads. At 100,000 cycles per second, however, the reactance drops to a value of 8 ohms. It is clear, therefore, that a condenser offers less opposition to a high-frequency current than to one of low frequency; in other words, the greater the frequency of the applied voltage the greater the current flow.

Theoretically no power is dissipated in a condenser because the electric energy stored during the charging process is given back to the circuit when the condenser discharges. In well-designed condensers in which the plates are separated by an air space the loss is very small, but in condensers in which the plates are separated by solid dielectrics this loss is appreciable. A condenser of the latter kind behaves as if it had a resistance in series with it, the value of which depends upon the kind of dielectric, the capacity, and the frequency. This resistance effect decreases as the capacity increases and as the frequency increases.

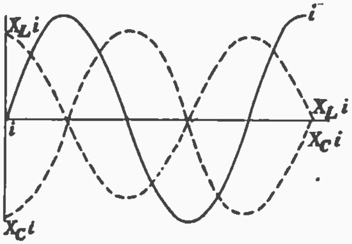


Fig. 37.—Voltage relations with resistance, inductance, and capacity in series.

Circuit Having Resistance, Inductance, and Capacity in Series.—When an alternating voltage is applied to a circuit in which a resistance R, an inductance L, and a capacity C are connected in series, a current will flow producing a voltage IR across the resistance, IX_L across the inductance, and IX_c across the capacity. The terms X_L and X_c are the *inductive reactance* and the *capacity reactance*, respectively. If these several voltages are referred to the current with regard to phase, it is seen that the voltage IR is in phase with the current, the voltage IX_L leads the current by 90 degrees, and the voltage IX_c lags behind the current by 90 degrees. These relations are represented in Fig. 37.

For complicated alternating-current circuits the use of the *sine wave* diagram is quite cumbersome and represents instantaneous values only. A clearer relation between the quantities concerned is obtained by a *vector diagram.* In such a diagram an alternating quantity may be represented by a line called a "vector" which indicates both direction and effective value. Thus, in Fig. 38, if the vector I represents the direction and effective value of the current, then the voltage IR, being in phase, must lie along the "current" vector. The voltage IX_L which leads the current I by 90 degrees is drawn 90 degrees ahead of I in a counterclockwise rotation, and, similarly, IX_c is drawn 90 degrees behind I. It is clear from this figure, as in the one above, that the voltages IX_L and IX_c are in direct opposition to each other. The net effect is found by subtracting the smaller from the larger, obtaining then the quantity $I(X_L - X_c)$, as shown in drawing *b* of Fig. 38. The effective value of the applied voltage E, then, is the hypotenuse of a triangle having IR for one side and $I(X_L - X_c)$ for the other side. These quantities are so related that

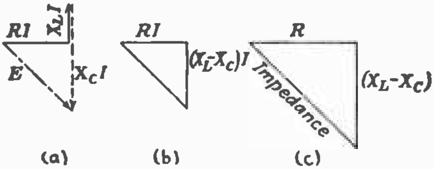


Fig. 38.—Vector diagram.

$$E = \sqrt{(IR)^2 + (IX_L - IX_c)^2}$$

from which

$$I = \frac{E}{\sqrt{R^2 + (X_L - X_c)^2}}.$$

The impedance Z in ohms is equal to $\sqrt{R^2 + (X_L - X_c)^2}$. A circuit of this kind acts as though it has a single reactance equal to the difference between the inductive reactance and the capacity reactance. If the inductive reactance is the greater, the circuit acts like an inductive circuit, but if the capacity reactance is the greater, the circuit acts like a condenser circuit. The quantities resistance, inductive reactance, capacity reactance, and impedance are related as in the right triangle of drawing *c* in Fig. 38.

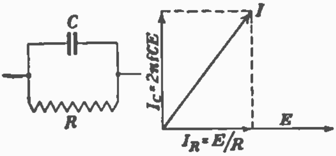


Fig. 39.—Voltage and current relations in circuit with capacity and resistance in parallel.

Circuit Having Resistance and Capacity in Parallel.—In a circuit having parallel paths, the voltage across each of the paths is the same, but the current in each path may be different. This effect is opposite to that of a series circuit, in which the same current flows through each part of the circuit but the voltages across the individual parts may be different.

If an alternating voltage is applied to a circuit consisting of a capacity C and a resistance R in parallel, the current and voltage relations are shown as in Fig. 39. In this case the applied voltage E is used as the reference line. The condenser current I_c is drawn 90 degrees ahead of E, and the resistance current I_R is drawn in phase with E. The external current I is the resultant of I_c and I_R. The current I is expressed by

$$I = E\sqrt{\frac{1}{R^2} + (2\pi fC)^2}.$$

The term $\sqrt{\frac{1}{R^2} + (2\pi fC)^2}$ is called the *admittance* of the circuit and its reciprocal is the *impedance.*

A parallel combination of this kind is the equivalent of a *leaky condenser* or of an *antenna* (page 82) having defective insulation.

Circuit Having Inductance and Capacity in Parallel.—If an alternating voltage is applied to a circuit consisting of inductance and capacity in parallel, the current and voltage relations are as shown in Fig. 40. The condenser current I_c leads the applied voltage E by 90 degrees and the coil current I_L lags behind E by 90 degrees. If I_c is greater than I_L, the resultant external current is 90 degrees ahead of E, while if I_L is greater than I_c, the resultant current lags 90 degrees behind E. If $I_c = I_L$, *no* current will flow in the external circuit. This is the condition called "parallel resonance," and the *resonant frequency* is $f_r = 1/2\pi\sqrt{LC}$

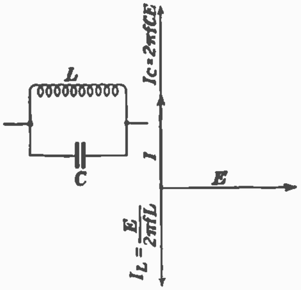


Fig. 40.—Voltage and current relations in circuit with inductance and capacity in parallel.

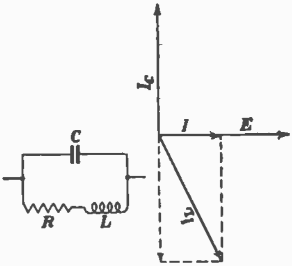


Fig. 41.—Voltage and current relations in circuit having capacity in parallel with inductance and resistance in series.

Circuit Having Capacity in Parallel with Inductance and Resistance in Series.—In practice an inductance coil has always resistance. The introduction of resistance into the circuit of Fig. 40 (inductance and capacity) changes the current and voltage relations to those of Fig. 41.

At resonance $\frac{1}{R^2 + (2\pi fL)^2} = \frac{C}{L}$. The resultant current I then is in phase with the voltage and is equal to $I = \frac{ER}{R^2 + (2\pi fL)^2}$ or, by substitution, $I = E\frac{RC}{L}$, meaning that the circuit acts as if it had a resistance of $L \div RC$ where L is the inductance in henrys, R is the resistance in ohms, and C is the capacity in farads.

Part 5

RADIO CIRCUITS

Radio currents are merely alternating currents of low power but of *high frequencies* ranging from 1,000,000 to about 300,000,000 cycles per second. Ordinary alternating-current power, on the other hand, is generated and transmitted over wires at frequencies from 25 to 60 cycles per second. It is this great difference in frequency which accounts for the difference in the behavior of a radio circuit of very high frequency when compared with an alternating-current circuit of low frequency.

In a radio circuit the inductive reactance of even a small induction coil consisting of a few turns of wire must be given due consideration. A condenser of small capacity which would block out almost entirely the flow of a low-frequency current will pass readily a current of the high frequencies of radio currents. At the so-called "radio frequencies" (20,000 to 3,000,000 cycles per second) the *mutual effect* of one circuit on another is increased, the *skin effect* (page 88) is much greater, the *eddy currents* (page 11) are larger, and the *dielectric losses* (page 58) are increased.

TABLE XV.—EFFECT OF FREQUENCY VARIATION ON REACTANCES

Frequency, cycles per second	Inductive reactance of coil, ohms	Capacity reactance of condenser, ohms	Total reactance, ohms
60	0.188	−530,000	−530,000
1,000	3.142	− 31,840	− 31,837
100,000	314.2	− 318.4	− 4.2
100,700	316.23	− 316.23	0
1,000,000	3,142	− 31.84	3,110

The effect upon the inductive reactance of a coil and the capacity reactance of a condenser when the coil and the condenser are in series as the frequency is increased from 60 to 1,000,000 cycles is shown in table XV from *Bureau of Standards Bulletin* 40. In this case the coil has an inductance of 500 microhenrys and the condenser a capacity of 0.005 microfarad.

It is obvious that the *inductive reactance* of the coil increases from a small to a considerable value as the frequency is increased. The *capacity reactance* of the condenser, on the other hand, changes from a high value at low frequencies to such a small value at high frequencies that it may be neglected in most calculations.

Series Resonance.—In a circuit in which a resistance, an inductance, and a capacity are in series, the *total reactance* will be zero at a frequency at which the inductive reactance is equal to the capacity reactance. This frequency is called the *resonance frequency* of the circuit, and the circuit is said to be in "resonance," meaning that it is *tuned* to the operating frequency of the circuit. Since at resonance $X_L = X_c$ or $2\pi f_r L = 1/2\pi f_r C$, the resonant frequency is $f_r = 1/2\pi\sqrt{LC}$ where L is in henrys and C in farads, or $f_r = 159{,}200/\sqrt{LC}$ where L is in microhenrys and C in microfarads. The *resonant wave length* is then $1{,}884\sqrt{LC}$ where L is in microhenrys and C in microfarads.

At this *condition of resonance* the current is greatest and the impedance is least; and the equation for current I becomes $E \div R$. The voltages across either the inductance or the capacity, however, may be much greater than E, as they exist in their respective circuits even though the resultant effect on the circuit as a whole is that the one neutralizes the other. Thus, if in a circuit of a radio receiving set the voltage of an auxiliary circuit including a condenser is impressed on the input side (grid circuit page 36) of a vacuum tube, then at the point of resonance the condenser voltage may have a value many times that of the incoming voltage.

Likewise in a transmitting circuit the voltage between the *antenna* and the *ground connection* may have a high value at resonance so that the antenna of a radio transmitting station must have an insulation which is adequate for a relatively high voltage.

Tuning.—A circuit is *tuned* to resonance when the *reactance* is reduced to zero, so that the *impedance* of the circuit consists only of the resistance. At frequencies other than the *resonant or tuned frequency*, the inductive and capacity reactances are unequal and their difference enters the expression for impedance (page 37). At frequencies less than the resonant frequency, the capacity reactance is larger than the inductive reactance, hence at low frequencies the current is reduced by the capacity while at high frequencies it is reduced by the inductance.

In the expression $f_r = 1/2\pi\sqrt{LC}$ it is seen that the resonant frequency depends on the product $L \times C$. On page 17 is given a table showing the relations between f_r and $L \times C$.

Resonance Curve.—The response of a tuned circuit to a given frequency is indicated by a resonance curve which shows the *reduction of the current on both sides of the point of resonance.* Such a curve is obtained by plotting the current (or current squared) against a range of frequencies around the resonant value. The curve in Fig. 42 is drawn for a circuit in which $R = 4.4$ ohms, $L = 377$ microhenrys, $f = 169{,}100$ cycles per second, and the applied voltage $E = 19.2$ volts. The values for I^2 as C is varied from 2,200 to 2,500 microfarads are obtained from the expression

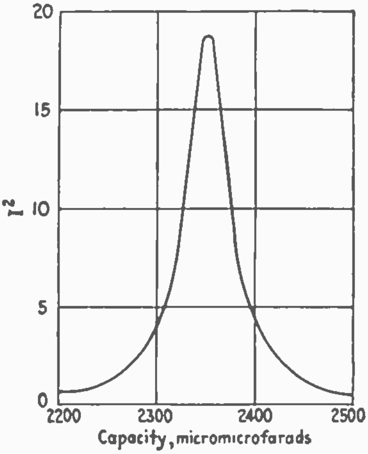


FIG. 42.—Resonance curve.

$$I^2 = \frac{E^2}{R^2 + (X_L - X_c)^2}$$

where X_L and X_c are, respectively, the inductive and the capacity reactances.

At resonance the value of the current is $I = E \div R = 4.36$ amperes. The voltage across the inductance at resonance is $X_L I = 2 \times 3.1416 \times 169{,}100 \times 377 \times 10^{-6} \times 4.36 = 1{,}750$ volts. In terms of capacity reactance X_c and resonant current I, the voltage across the condenser at resonance is $X_c I$ or 1,750 volts. It is obvious, of course, that these voltages are much greater than the applied voltage of 19.2 volts. If the resistance of the circuit is increased, the current at resonance is decreased in a somewhat greater proportion.

The "sharpness" of resonance, or *selectivity*, is a quantity which indicates the fractional change in current for a given fractional change in either C or L at resonance. It may be shown that the *sharpness of resonance* thus defined is equal to the ratio of the inductive reactance X_L to the resistance R, that is, $2\pi fL/R$. It should be noted that as the value of resistance is made less, the resonance curve becomes sharper and that as R is increased, the curve becomes flatter.

Parallel Resonance.—In the paragraph on series resonance (page 82) an explanation was given of the behavior of a circuit in allowing the flow of maximum current for a given applied voltage. The same principle is applied in preventing the flow of a current having a certain frequency but in allowing the flow of currents having other frequencies. The device used for this purpose is called a *filter* and consists of an inductance in parallel with a capacity. By suitable adjustment of the values of inductance and capacity, the circuit of a filter can be made to oppose a current of a given frequency. This procedure involves the principle of *parallel resonance.*

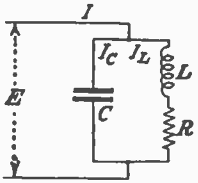


Fig. 43.—Circuit consisting of condenser in parallel with inductance and resistance to illustrate parallel resonance.

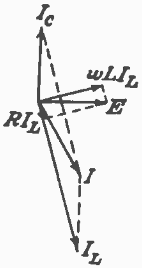


Fig. 44.—Vector diagram of current and voltage for capacity in parallel with resistance and inductance.

If an alternating voltage E is applied to a circuit consisting of a condenser in parallel with an inductance and a resistance, as in Fig. 43, the total current I flowing in the external circuit will divide into a current I_L flowing through the coil and a current I_c flowing through the condenser. If ammeters are put into the various circuits and the capacity varied, it will be seen that the value of I_c approaches that of I_L and that the value of the total current I decreases. At some definite value of capacity the total current will reach its lowest value. At this point the currents I_c and I_L are nearly equal but may have values many times that of the total current.

A mathematical treatment of the action of this circuit shows that the total current I is the vector sum (page 10) of the currents I_L and I_c in the two branches. If the condenser loss is neglected,

$$I_c = -2\pi fCE \quad \text{and} \quad I_L = \frac{E}{\sqrt{R^2 + (2\pi fL)^2}}.$$

The sum of the two currents with consideration for their phase relationship is

$$I = E\sqrt{\left(2\pi fC - \frac{2\pi fL}{R^2 + (2\pi fL)^2}\right)^2 + \left(\frac{R}{R^2 + (2\pi fL)^2}\right)^2}.$$

The vector diagram is shown in Fig. 44. When $C = \frac{L}{R^2 + (2\pi fL)^2}$, the total current I is in phase with the voltage E and is equal to $I_R = \frac{ER}{R^2 + (2\pi fL)^2}$. This is the condition for parallel resonance and gives a value of the external current which is a minimum in the case where the capacity C is varied. If parallel resonance is obtained by varying the inductance instead of the capacity, the conditions for minimum current in the external circuit are slightly different.

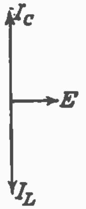


FIG. 45.—Vector diagram of current and voltage for condition of parallel resonance.

At *radio frequencies* (page 39), however, the resistance of an inductance coil is very small, compared with the coil reactance. In this case the relation between C and L as given above for parallel resonance becomes $2\pi f_r C = 1/2\pi f_r L$ where f_r is the resonant frequency and $f_r = 1/2\pi\sqrt{LC}$. In other words, the value of f_r for parallel resonance is the same as the resonant frequency in series resonance (page 82). This indicates that at parallel resonance, the series combination of condenser and coil is apparently in a condition of *series resonance*. It will be remembered that in series resonance, the condenser and coil voltages are equal and opposite. Consequently, since the condenser and coil currents are nearly equal and opposite, their difference accounts for an external current of very low value. The total resonant current is then $I_r = ER/(2\pi f_r L)^2$. A vector diagram for this case is shown in Fig. 45. The total current, being the vector sum of I_c and I_L, may be very small. The equivalent effect of the coil and condenser together upon the external current is that of a large impedance having a value of $(2\pi f_r L)^2/R$.

On either side of the point of resonance the value of the total current increases if the inductance or the capacity or the frequency is changed. This variation in current value with change in frequency is shown in Fig. 46, for a circuit in which L is 377 microhenrys and C is 0.002,35 microfarad.

At low frequencies the increase in current is due to the effect of the capacity, and at high frequencies it is due to the effect of the inductance.

A *series* combination, therefore, of inductance and capacity has a reactance which is equal to zero when $2\pi fL = 1/2\pi fC$, while a *parallel* circuit under the same conditions has a reactance which is so great that theoretically it is equal to infinity. Hence a series combination is used when a current of a certain frequency is to be a maximum, and a parallel combination is used when a current of that frequency is to be excluded from a circuit.

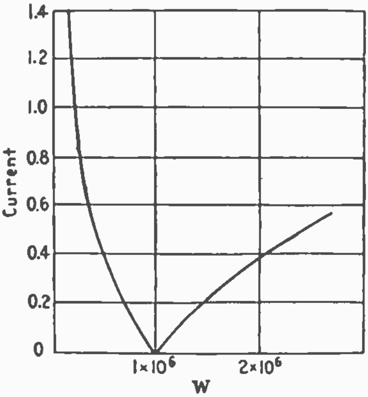


FIG. 46.—Resonance curve of parallel circuits.

Capacity of Inductance Coils.—All kinds of inductance coils have capacity in addition to inductance. This is due to the capacity which exists between the turns of wire as well as to the *stray capacity* such as that between the terminal posts and that between the coil and ground. This capacity is called the *distributed capacity* of a coil, and, although its value is small, it is of the same order as other capacities used in radio circuits. A coil, then, must be treated as if it were an inductance in parallel with a capacity. Hence even a coil by itself has a definite frequency of resonance which depends on its inductance and capacity. Neither the distributed capacity nor the inductance varies with frequency, but the equivalent inductance of the coil (considered as inductance in parallel with capacity) varies according to the relation

$$\text{Equivalent inductance} = \frac{L}{1 - (2\pi f)^2 LC}.$$

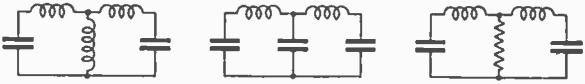
In this equation L is inductance in henrys and C is distributed capacity of the coil in farads.

The reactance of a coil varies with the frequency of the current it carries, increasing up to the frequency of resonance. Coils used for radio-frequency work (page 39) should be designed for low distributed capacity.

Part 6

COUPLED CIRCUITS

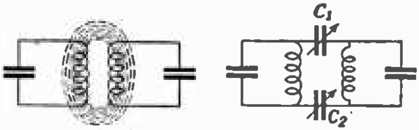
Coupling.—When two circuits have *some part in common* or are linked by a magnetic or electrostatic field, they are said to be coupled. There are two general classes of coupling, the direct and the indirect.



(a)-Inductance (b)-Capacity (c)-Resistance

FIG. 47.—Three types of direct coupling.

Three types of *direct coupling* are illustrated in Fig. 47. This indicates that two circuits may be coupled directly by the use of (1) inductance, (2) capacity, or (3) resistance. *Indirect coupling* is illustrated in Fig. 48 by two types, the *inductive* and the *capacitive*. The *primary* is considered to be that circuit to which the voltage is applied, and the other circuit is called the *secondary* circuit.



(a)-Inductive (b)-Capacitive

FIG. 48.—Two types of indirect coupling.

Close or *tight* coupling is said to exist when a change of current in one circuit produces a considerable effect upon the other. When coupling is *loose*, one circuit produces only a slight effect upon the other.

In *direct inductive coupling*, the coupling is made closer by increasing the amount of common inductance without changing the total inductance of the circuit. In *direct capacity coupling*, the coupling is made closer by reducing the capacity of the common condenser. In *indirect inductive coupling*, the coupling is made closer by moving the coils nearer or by increasing the inductance or either coil. In *indirect capacity coupling*, the coupling is made closer by increasing the capacity of the coupling condensers C_1 and C_2 as in Fig. 48. Direct coupling is not used much in radio work because *sharp tuning* or *loose coupling* is difficult to get together with an efficient transfer of power from one circuit to another. Indirect capacity coupled circuits are used mostly in radio-receiving and amplifying circuits.

Resonance Curves.—Two circuits will resonate to but *one* frequency if the coupling between them is *loose*, but if the coupling is *tight*, *two* resonant frequencies are observed. One of these is lower than the frequency of each circuit by itself and the other is higher. As the coupling is made tighter, the two *resonant frequencies* are spread farther apart in value. The resonance curve of a circuit with loose coupling is indicated by the dotted curve in Fig. 49, and that for a circuit with tight coupling, by the full-line curve. These two resonant frequencies are caused by the mutual inductance (page 68) of the two circuits. The mutual inductance and also the individual inductances of the two circuits vary momentarily and affect the *coefficient of coupling* which is equal to $M \div \sqrt{L_1L_2}$.

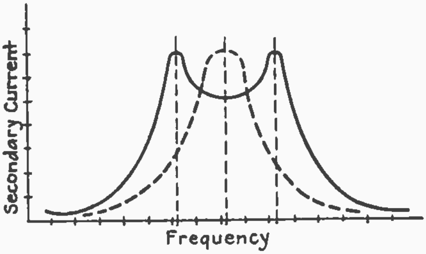


Fig. 49.—Resonance curve of circuit with loose and tight coupling.

If a primary circuit and a secondary circuit are adjusted separately to have the same frequency f, it can be shown that the relation between this frequency, the coefficient of coupling, and the two *resonant frequencies* f_1 and f_2 is

$$f_1 = \frac{f}{\sqrt{1+k}} \qquad \text{and} \qquad f_2 = \frac{f}{\sqrt{1-k}}.$$

As the coupling is made looser, k decreases because the mutual inductance M becomes smaller (compared with L_1 or L_2) and the two frequencies f_1 and f_2 approach each other in value and finally become equal.

Part 7

HIGH-FREQUENCY RESISTANCES

Skin Effect.—When a voltage is applied to a wire, the effect of the self-induced voltage in the wire, as the current builds up, acts to increase the current flow near the surface of the wire and to oppose the flow near the center. With a *direct-current* voltage, the distribution of current over the cross-section of the wire finally becomes uniform; but with a *high-frequency alternating* voltage the current strength is greatest near the surface of the wire because the current does not have time to reach a steady value on account of the rapid changes of voltage. This behavior, called *skin-effect*, is equivalent to a reduction of the cross-sectional area of the wire and accounts for the observed increase in resistance at high frequencies.

Effective Resistance.—The resistance of a wire to a high-frequency current is, therefore, several times greater than its resistance to direct current. The effective resistance at a given frequency is found by dividing the power loss by the square of the effective current.

Effective resistance of a circuit may be increased appreciably by induction between it and adjacent circuits or other conducting bodies. A condenser in a radio circuit increases the effective resistance because of the heating of the dielectric insulating material and also because of the energy loss due to the "brush" discharge accompanying its operation at high voltages. Another factor which adds to effective resistance is the spark resistance of a so-called "spark gap."

Form of Conductors.—Thin tubing is more suitable than a solid wire as a conductor for high-frequency currents, because the core of a solid wire is ineffective on account of skin effect. For a given cross-section, thin tubing has a high-frequency resistance less than that of any other form of conductor. Stranded wire, to be effective, must be made of enameled or otherwise insulated strands so placed that each strand comes to the surface as much as any other strand. A stranded cable in which the strands are braided is better than one in which they are merely twisted. When a conductor in the form of a strip is used, precautions should be taken to make the perimeter large in proportion to the area.

Part 8

DAMPED OSCILLATIONS

Oscillating Circuits.—If a constant alternating voltage is applied to a radio circuit, a constant alternating current is produced with an amplitude which does not vary; that is, the circuit is made to *oscillate* at the frequency of the applied voltage, and the oscillations produced are *forced oscillations*. Energy losses in the circuit are supplied from the external source of power. Oscillations of current, however, may be produced in a circuit without the application of an external voltage, as in the discharge of a condenser.

Condenser Discharge.—When a charged condenser is connected to a circuit containing inductance and resistance, as in Fig. 50, oscillations of the current will be produced but they will continually diminish in strength, as indicated in Fig. 51, because the electrical energy is spent in overcoming the resistance of the circuit.

As the condenser discharges, a current flows out of it, and the difference of voltage between the plates becomes less. The condenser is thus giving up its energy, which is transferred to the magnetic field of the coil. When the condenser has discharged and its plates are at the same voltage, the current still flows, and consequently the condenser begins to be charged in the opposite direction. If there is no resistance in the circuit, the voltage of the condenser will attain its original value and the current will drop to zero. Energy, however, is being lost in heat and radiation. The effect of the condenser voltage is now to oppose the current flow, and energy is being transferred from the coil to the condenser. At this point the condenser has been recharged, but in a direction opposite to that at first. Then the condenser begins to discharge again and the flow of current continues until the condenser is charged once more as originally. The total amount of energy in the condenser continually decreases until it is all spent and the oscillations cease.

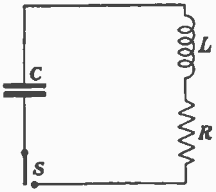


FIG. 50.—Condenser connected to circuit with inductance and resistance.

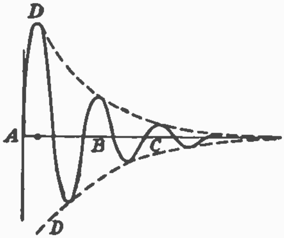


FIG. 51.—Continually diminishing oscillations in condenser which is discharging.

It is evident that the value of the current is greatest when the voltage of the condenser is zero. As the condenser voltage approaches its greatest value the current decreases to zero and then flows in the opposite direction. Current alternations of this kind in a circuit are called *electric oscillations* and, because no external source of voltage is used, they are known as *free oscillations*. Oscillations which continually decrease in strength are called *damped oscillations*. If the energy losses of the circuit are supplied from an external source, *undamped oscillations* are produced which do not decrease in strength but persist indefinitely. Hence the resistance of the circuit must be known to determine the rate at which the oscillations decrease. The series of oscillations produced when a condenser discharges is called a *wave train.*

Frequency.—It can be shown that if R, L, and C are the resistance in ohms, inductance in henrys, and capacity in farads, respectively, of a circuit, the frequency f of "free" oscillations in the circuit and likewise the natural frequency of the circuit is

$$f = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \left(\frac{R}{2L}\right)^2}.$$

In an *aperiodic circuit,* that is, one which has no true natural period at which currents will tend to oscillate in it, the quantity $(R/2L)^2$ is greater than $1/LC$. Consequently free oscillations are not produced and the current drops to zero value but does not reverse in the direction of flow. In most radio circuits, however, the quantity $R/2L$ is small enough to be neglected, and hence the expression for frequency becomes, approximately,

$$f = \frac{1}{2\pi\sqrt{LC}}.$$

Decrement.—The rate at which oscillations are *damped* or decreased depends upon the resistance and inductance of the circuit. The rate of damping increases as the resistance is increased and as the inductance is reduced. The numerical measure of the rate of decrease is taken as the *natural logarithm* (page 12) of two maximum values which are one cycle apart. This value is the *decrement* for a complete oscillation. Except for large values, the decrement is approximately equal to the decimal difference between successive maximum values; thus, if the decrement is 0.1, each maximum value is approximately 0.1 greater than the next.

When the resistance of the circuit is not very great the decrement may be expressed in three forms, as follows:

$$\text{Decrement} = \pi\left(\frac{R}{2\pi fL}\right) = \pi R(2\pi fC) = \pi R\sqrt{\frac{C}{L}}.$$

The radio laws of the United States limit the decrement to values not greater than 0.2 because of the interference caused by stations which are damped highly. For a decrement of 0.2, the number of oscillations which are completed before the amplitude falls to one per cent of the first value is about 23. This number is obtained by dividing 4.6 (natural logarithm of 100) by the decrement 0.2.

If the decrement is small, sharper tuning is possible than if the decrement is large. There is also less interference with a station that is working at a different frequency if the decrement is small.

Oscillations in Coupled Circuits.—If a primary circuit (page 87) excited by a charged condenser is closed directly or by means of a spark gap and acts upon a closed secondary circuit (page 87), the resulting reactions are quite complicated. In general, the oscillations in each circuit consist of two damped oscillations at different frequencies. Energy is transmitted alternately from one circuit to the other, and back again.

In order to get efficient radiation of energy, the electrical energy of the system should be prevented from returning to the primary circuit after it has once entered the secondary. If this is done, the secondary circuit oscillates at the natural frequency. This kind of excitation is called *impulse excitation* and may be obtained by the use of an arrangement known as the *quenched gap*, as explained below.

Quenched Gap.—In a quenched gap the spark gap in a primary circuit consists of a number of short gaps in series. This arrangement prevents the recurrence of a spark discharge after the first primary oscillation. At this point the secondary contains all the energy and oscillates at its natural frequency.

SECTION III

RADIO ACCESSORIES AND INSTRUMENTS

Part 1

INDUCTANCE COILS, CONDENSERS, AND FILTERS

Inductance Coils.—In radio work an inductance coil may be used with a condenser for tuning a circuit, and an inductance coil may serve also to transfer energy to another coil by induction. The inductive effect of a coil depends on the size of the coil, the wire, and the kind of winding. The turns of wire must be insulated from each other by a covering, or by spacing in a single-layer coil, and must be wound in the same direction. In general, inductance coils may be classified according to their use in radio reception, or in transmission.

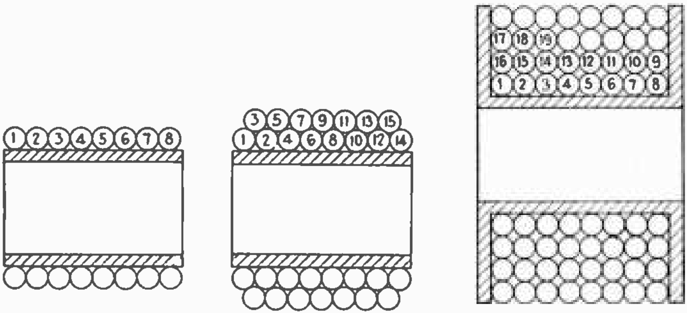
Inductance Coils Used in Radio Reception.—The coils used in radio receiving sets are wound with magnet wire, silk or cotton-covered or enameled. The wires should be spaced closely on a tube of insulating material such as pasteboard, wood, fiber, bakelite, or a similar material. Insulated "litzendraht" (litz wire) is sometimes used for magnet wire.

The use of a stranded enameled wire like *litzendraht* instead of a solid wire has the advantage that it offers a lower resistance at radio frequencies than solid wire. Over the range of frequencies from 600 to 1,500 kilocycles per second the resistance of a solid wire is about 40 per cent greater than that of a twisted cable wire. At frequencies less than a few kilocycles per second and also at frequencies greater than about 1,500 kilocycles, however, the resistance of solid wire is less than that of a twisted-cable type of wire.

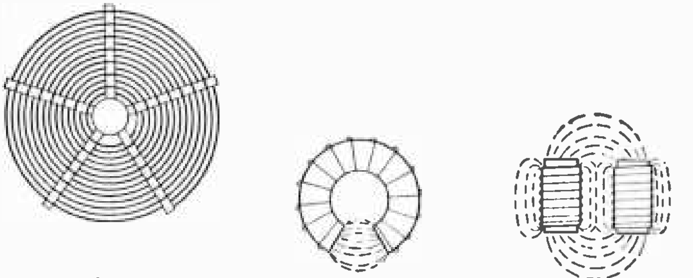
Inductance coils may be wound with single-layer, multilayer, bank, spider-web, honeycomb or duolateral, toroid (doughnut shape), or binocular types of windings. A number of these types are illustrated in Fig. 1.

Various forms of winding have been devised to reduce the distributed capacity (page 86) and hence to increase the range over which a coil may be used with a given condenser. Another important objective is to increase the efficiency of the inductance by reducing the dielectric losses (page 57) as much as possible and, also, in some cases, to confine the magnetic field of the coil.

The single-layer coil is the standard type of inductance in radio sets for the reception of broadcasting. It may be "space" wound (as in Fig. 3, page 97) on tubing or self-supported (without tubing). The dielectric loss in a coil wound on a frame made of narrow insulating strips is less than that of a coil wound on a tube.



(a)-Single Layer (b)-Bank (c)-Multiple



(d)-Spiderweb (e)-Toroidal Coil (f)-Binocular Coil

FIG. 1.—Types of inductance coils.

In commercially operated radio equipment for telegraphic service (dot-and-dash), the multilayer or the bank-wound coil is generally used, because it affords a large inductance in a small space. A bank-wound coil has much less distributed capacity than a multilayer coil.

Transmitting Inductance.—The transmitting inductance coil used for radio transmission is usually wound according to the type of the transmitter. Spark transmitters (page 40) may use coils of large copper wire, brass tubing, or strips on an insulated frame. In most modern transmitters of this kind the coils are wound with "strip" wire, the turns being in a flat spiral form, and are wound edgewise. Arc and vacuum-tube transmitters (page 467) use coils of similar shape but are generally made with heavy twisted cable. At frequencies below a few kilocycles per second and also at frequencies above about 1,500 kilocycles the resistance of solid wire is less than that of twisted cable.

Iron-core Inductances.—This type of coil has a large number of turns of wire on an iron core which may be of either the closed or the open type. It acts as an impedance to the flow of a varying or alternating current and is used in audio-frequency circuits. Iron-core coils of this kind may have inductances ranging up to several hundred henrys. Iron cores are not used in coils required for coupling *radio-frequency* circuits because they increase the inductive reactance and thus prevent the current from reaching its maximum value in any alternation before the voltage reverses. Iron, however, is used in *audio-frequency* transformers and usually also in intermediate transformers.

The alternating-current inductance of an iron-core coil decreases rapidly as the core becomes increasingly magnetized. This action is of importance in the *choke coils.* It may happen that a rectified current (page 39) magnetizes the core to such an extent that the suppressing effect of the choke coil is considerably diminished.

Choke Coil.—The choke coil is a coil with a large inductance which is inserted in a circuit to offer a high inductive reactance to a varying current and thus prevent any sudden surge of current, as well as also to limit the current to a certain range. One of its uses is in direct-current supply circuits to protect apparatus from excessive currents. Choke coils (with or without iron cores depending on their use) are called *reactance coils* and may serve the same purpose or may be employed to exclude currents of unwanted frequencies.

Reactance Coil.—A reactance coil is made with a number of turns of wire on an iron core. The value of reactance may be varied by means of taps on the winding or by moving the iron core into or out of the coil. At commercial frequencies (25 to 60 cycles per second) such coils are used in alternating-current circuits to put the circuit into a condition of *resonance* (page 82) and also to insert an inductive reactance which will decrease the value of the current.

Radio-frequency Choke Coil.—At radio frequencies such coils with air cores have a very high reactance. They may be used to prevent the flow of a radio-frequency current in a circuit. A reactance coil used for this purpose is called a *radio-frequency* choke coil.

A choke coil which is to be used to prevent the flow of a radio-frequency current may have an inductance of about 1,000 microhenrys with two or three hundred turns of wire on a half-inch tube.

A choke coil used in a *filter circuit* (page 36) must not have an excessive resistance to direct current and the inductance must be large enough to smooth out current ripples. An iron core with an air gap is used to provide a strong, confined magnetic field. A coil of this kind in a radio receiver may have an average value of inductance of 75 henrys. A large coil of this type is called a *filter reactance.*

A reactance regulator is an iron-core reactance coil having a tapped winding and is used in series with the primary winding of a transformer to give resonance at a certain frequency.

Variometer.—A variometer is an arrangement which provides a fine adjustment of inductance. It consists of insulated wire wound on insulated frames so arranged that the inner one may be turned within the other. The two coils are connected in series and each has the same number of turns. When the movable coil is in such a position that its magnetic field is in the same direction as that of the stationary coil, the inductance is greatest. When the movable coil is turned so that its field is directly opposed to that of the other coil, the inductance is least.

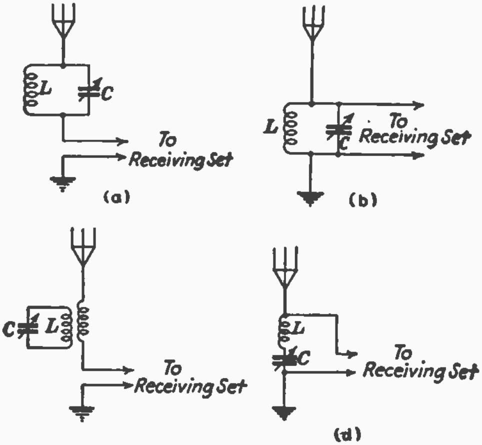


FIG. 2.—Types of wave traps.

In transmitters operated with vacuum tubes the variometer is generally used to provide close tuning. Its design is the same as that of a variometer for a radio receiver but it is much larger and stronger.

Wave Traps.—A wave trap is a combination of an inductance and a condenser so arranged that it utilizes the principle of resonance in the elimination of undesired signals. The values of inductance and capacity used are generally the same as those found in the tuned radio-frequency circuits of the receiving set, because the wave trap must be capable of tuning to the same range of frequencies as the receiver. Three varieties of wave traps, under various names, have been much used.

In the first of these a coil and a variable condenser in parallel are connected in the antenna circuit as shown in *a* of Fig. 2. The wave-trap circuit is adjusted for resonance with the undesired signal and, in that condition, offers a high impedance to the frequency to which it is adjusted but a smaller impedance to other frequencies. The *trap circuit*, used as in *b* in Fig. 2, offers a low impedance to the frequency to which it is tuned but a high impedance to other frequencies.

The arrangement shown in *c* of Fig. 2, when tuned to the interfering frequency, induces in the antenna circuit a voltage which acts in opposition to that of the undesired signal.

In another scheme the coil and condenser, connected in series, are placed in the *antenna circuit* as shown in *d* (Fig. 2). When the trap circuit is tuned to the interfering frequency it offers a low impedance to that frequency which is thus by-passed to ground.

Calculation of Inductance of Coils.—Formulas are given in this section for the calculation of the inductance of coils in the form of a helix of round wire or of strip wire wound edgewise, of a flat spiral coil, of a multilayer coil, and of a single-layer coil. The formulas cannot be used for iron-core inductances.

Inductance of Helix of Round Wire.—The inductance of the helical single-layer coil or solenoid of Fig. 3 is given in microhenrys by

$$L = \frac{0.0395 a^2 n^2 K}{b}$$

where a and b are shown in Fig. 3, a being the mean radius of the solenoid and b the total length of the solenoid; n is the number of turns of wire in the single layer; d is the diameter of the bare wire; and K is a *shape factor* depending on the relative dimensions, all lengths being exprsesed in *centimeters.* A brief table of values of K is given on page 98. In the figure, D is the pitch of the winding or the distance between the centers of adjacent wires in centimeters, and c is the radial thickness of the winding in the same units.

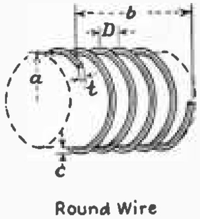


FIG. 3.—Helical single-layer solenoid.

Example.—Find the inductance of a solenoid which has 15 turns of bare wire 0.4 centimeter in diameter, the pitch of the winding being 1.1 centimeters and the diameter of the core 24 centimeters.

In the formula $d = 0.4$, $D = 1.1$, $n = 15$, $b = nD = 16.5$, $a = 12 + 0.2 = 12.2$ centimeters. Then since the ratio of diameter to length is $2a/b = 24.4/16.5 = 1.48$, K as read from the table on page 98 is 0.598. By using these values in the formula, the inductance L in microhenrys is given by

$$L = \frac{0.0395 \times 12.2^2 \times 15^2}{16.5} \times 0.598 = 48.0 \text{ microhenrys.}$$

If it is desired to compute the inductance more closely than a few per cent, more accurate formulas should be used as given in *Bureau of Standards Circular* 74 and in *Bureau of Standards Scientific Paper* 169.

TABLE XVI.—SHAPE FACTOR K OF HELICAL INDUCTANCE COILS

Ratio of diameter $2a$ to length b	K	Ratio of diameter $2a$ to length b	K	Ratio of diameter $2a$ to length b	K
0.00	1.000	0.70	0.761	3.50	0.394
0.05	0.979	0.80	0.735	4.00	0.365
0.10	0.959	0.90	0.711	5.0	0.320
0.15	0.939	1.00	0.688	6.0	0.285
0.20	0.920	1.25	0.638	7.0	0.258
0.25	0.902	1.50	0.595	8.0	0.237
0.30	0.884	1.75	0.558	9.0	0.219
0.40	0.850	2.00	0.526	10.0	0.203
0.50	0.818	2.50	0.472	25.0	0.105
0.60	0.789	3.00	0.429	100.0	0.035

Inductance of Helix of Edgewise-wound Strip.—Referring to Fig. 4, in this case the formula for the inductance of a helix of edgewise-wound strip is

$$L = \frac{0.0395a^2n^2K}{b} - \frac{0.0126n^2\,ac}{b} \text{ microhenrys.}$$

where K is the shape factor as given in the above table.

Example.—As an illustration of use of the formula, a helix of 30 turns is wound with metal strip, which is 0.635 centimeter in width, to form a solenoid of which the mean diameter is 25.4 centimeters. Here $D = 0.635$, $a = 12.7$, $c = 0.635$, $b = nD = 30 \times 0.635 = 19.05$. For $2a/b = 1.333$, $K = 0.623$.

Then from the above formula the inductance is

$$L = \frac{0.0395 \times 12.7^2 \times 900 \times 0.623}{19.05} - \frac{0.0126 \times 900 \times 12.7 \times 0.635}{19.05}$$

$$L = 187.4 - 4.9 = 182.5 \text{ microhenrys.}$$

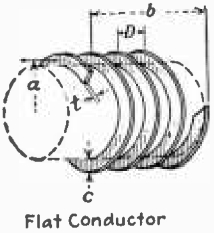


Fig. 4.—Helix of edgewise-wound strip.

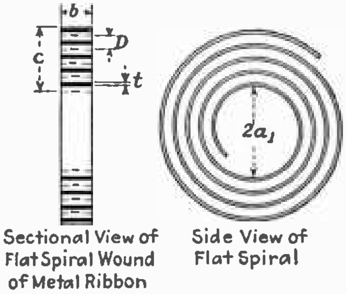


Fig. 5.—Flat spiral.

Inductance of Flat Spiral.—The inductance of a flat spiral as shown in Fig. 5 is given by

$$L = 0.01257an^2\left[2.303\left(1 + \frac{b^2}{32a^2} + \frac{c^2}{96a^2}\right)\log_{10}\frac{8a}{d} - y_1 + \frac{c^2}{16a}\,y^2\right]$$

where $a = a_1 + \frac{1}{2}(n - 1)D$; $d = \sqrt{b_2 + c_2}$; and y_1 and y_2 are shape factors given in table XVII.

Table XVII.—Shape Factors for Flat Spiral Inductances

b/c	y_1	y_2	b/c	y_1	y_2
0	0.500	0.597	0.50	0.796	0.677
0.025	0.525	0.598	0.55	0.808	0.690
0.05	0.549	0.599	0.60	0.818	0.702
0.10	0.592	0.602	0.65	0.826	0.715
0.15	0.631	0.608	0.70	0.833	0.729
0.20	0.665	0.615	0.75	0.838	0.742
0.25	0.695	0.624	0.80	0.842	0.756
0.30	0.722	0.633	0.85	0.845	0.771
0.35	0.745	0.643	0.90	0.847	0.786
0.40	0.764	0.654	0.95	0.848	0.801
0.45	0.782	0.665	1.00	0.848	0.816

Example.—A flat spiral of 38 turns is wound with copper ribbon of which the cross-sectional dimensions are 0.953 centimeter (3/8 inch) by 0.795 centimeter (1/32 inch), the inner diameter being 10.3 centimeters, and the measured pitch 0.4 centimeter. Here $n = 38$, $b = 0.953$, $D = 0.4$, $c = nD = 38 \times 0.4 = 15.2$, $2a_1 = 10.3$; therefore $a = 5.15 + \frac{37}{2} \times 0.4 = 12.55$;

$$d = \sqrt{0.953^2 + 15.2^2} = 15.23 \text{ centimeters},$$

$$\frac{8a}{d} = 6.592; \quad \frac{b^2}{32a^2} = 0.0002; \quad \frac{c^2}{96a^2} = 0.0152, \quad \frac{c^2}{16a^2} = 0.091;$$

$\frac{b}{c} = 0.0627$. From the table,

$y_1 = 0.5604$ and $y_2 = 0.599$. Then from the preceding formula,

$$L = 0.01257 \times 12.55 \times 38^2 \times [2.303 \times 1.015 \times \log_{10} 6.592 - 0.560 + 0.091 \times 0.599]$$

$L = 323.3$ microhenrys (correct to one-third of 1 per cent).

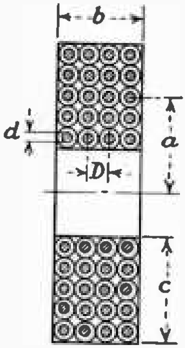


FIG. 6.—Multilayer coil for wave meter.

Inductance of Multilayer Coil.—The coil is made of insulated wire closely wound as in Fig. 6. Such coils are used in wave meters. The inductance is given by

$$L = \frac{0.0395a^2n^2K}{b} - \frac{0.0126n^2ac}{b}(0.693 + E)$$

where E is given by the following table:

b/c	E	b/c	E	b/c	E
1	0.000	8	0.266	20	0.310
2	0.120	9	0.273	22	0.313
3	0.175	10	0.279	24	0.316
4	0.208	12	0.289	26	0.318
5	0.229	14	0.296	28	0.320
6	0.245	16	0.302	30	0.322
7	0.256	18	0.306		

Example.—A coil has 15 layers of insulated wire, with 15 turns to a layer, the mean radius being 5 centimeters. The coil is 1.5 centimeters deep and 1.5 centimeters in axial length.

Here $a = 5$, $n = 255$, $b = c = 1.5$. From table XVI, K is 0.267, and E is zero. Then the formula gives

$$L = \frac{0.03948 \times 25 \times 225^2}{1.5} \times 0.267 - \frac{0.01257 \times 225^2 \times 5 \times 1.5}{1.5} \times 0.693$$

$$L = 8{,}887 - 2{,}205 = 6{,}682 \text{ microhenrys.}$$

Inductance of Single-layer Coil.—The inductance of the single-layer coil shown in Fig. 7 is computed by the formula for the helix.

Example.—A coil has 400 turns of wire in a single layer, the pitch of the winding is 0.1 centimeter, the radius of the coil measured to the center of the wire is 10 centimeters. Here $a = 10$, $n = 400$, $D = 0.1$, $b = nD = 40$. Since $2a/b = {}^{20}\!/_{40} = 0.5$, K is 0.818 (table XVI), then

$$L = \frac{0.03948 \times 100 \times 400^2}{40} \times 0.818 = 12{,}920 \text{ microhenrys.}$$

For any other inductance calculations see *Bureau of Standards Circular* 74, Sections 66 to 73, and *Bureau of Standards Scientific Paper* 169.

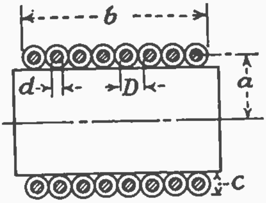


FIG. 7.—Single-layer coil.

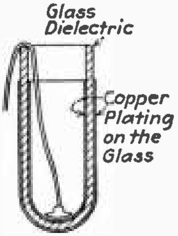


FIG. 8.—Leyden-jar condenser.

Condensers.—Condensers are made with either a fixed or a variable capacity, depending upon the purpose for which they are used. In general, condensers are classified in two groups—those for low voltages (less than 500 volts) and those for high voltages (over 500 volts).

Fixed Condensers.—In radio work a fixed condenser is generally used as a by-pass to allow the flow of alternating current but to prevent or "block" the flow of direct current. One type of fixed condenser for low-voltage service consists of sheets of aluminum foil separated by sheets of waxed paper. These sheets may be pressed together and confined between blocks of insulating material, or they may be rolled and put into a metal container. Generally, the assembly is pressed into form, held in place by a clamp, and sealed with paraffin or wax. Such condensers may be obtained with a number of voltage ratings ranging from about 150 to 1,000 volts.

For high-voltage service a wider spacing between the plates is necessary than for low-voltage, and air or oil is used as the dielectric. If the capacity is to be variable, the condenser consists of two sets of plates, one stationary, and one movable. A fixed condenser with a dielectric of air or oil is bulky when built in large capacities but has the advantage that the dielectric is self-healing if a rupture occurs. Several types of such high-potential condensers are the *mica condenser*, the *Leyden-jar type*, and two others, the *compressed-air type* and the *glass-plate tin-foil type*, which are not used in modern installations.

The *Leyden-jar type*, as shown in Fig. 8, consists of a large glass jar coated on the inside and outside, including the bottom, with a coating usually of copper deposited by an electrolytic process. In a jar of standard size with a capacity of 0.002 microfarad the copper coating extends to within 4 inches of the top. A puncture in this type of coating is indicated by the fiery appearance around the hole. The glass dielectric will break down at a voltage of about 35,000 volts.

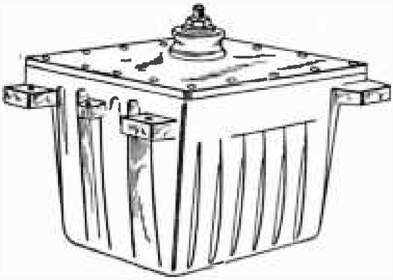


FIG. 9.—Mica condenser.

The *mica condenser*, such as the Dubilier transmitting type, consists of several sections in an aluminum case. Each section is made up of about a thousand sheets of mica and tin foil, one section of tin foil being separated from the next by a sheet of mica which is cut somewhat wider than the foil sheets to avoid brush discharges between them. An insulating adhesive material is forced through the condenser to eliminate air, moisture, and vacuum pockets. Finally wax is poured over the section assembly in the case, and a pressure plate is screwed on to maintain a constant spacing of the various parts. One terminal of the condenser comes out through the cover of the case, and the case itself often serves as the other. The advantages of a mica condenser such as the one shown in Fig. 9 are that it has a large capacity in a small space, its construction is rugged, its capacity is constant, and its losses are small. The maximum working voltage of the type illustrated is 25,000 volts.

In a *compressed-air condenser* the plates are set up in a closed container in an air pressure of several hundred pounds per square inch. The dielectric strength of compressed air is much greater than that of free air and consequently this type of condenser is suitable for high-voltage work. Although such a condenser is self-healing if a breakdown occurs, it has the disadvantage that apparatus is necessary to maintain the air pressure.

The *glass-plate tin-foil condenser* has sheets of tin foil which are separated by plates of glass. In this type the condenser is in a container filled with oil. The oil is actually the dielectric. The sheets of tin foil must be much smaller than the sheets of glass to prevent brush discharge at the edges of the glass.

In general, a fixed condenser using a solid dielectric is not self-healing. A special type of condenser often used as a protective device is constructed with mica and tin foil in such a way that if a puncture takes place, the foil around the hole melts away until the gap formed becomes long enough to break the arc.

Condensers for radio transmitters using short-wave circuits must be so designed that atmospheric conditions will not cause any change in their capacity, and the plates must be well separated in order to obtain a high breakdown potential. Transmitting condensers are rated according to their capacity and breakdown potential. The plates are usually of brass or aluminum with rounded edges to reduce the tendency to brush discharge. The design of the frame and of the plate assembly is intended to decrease the creepage loss as much as possible.

Filter Condensers.—A filter condenser must have a breakdown voltage considerably greater than the full working voltage of the rectifier in order to withstand a surge of high voltage. A fixed condenser for such use is made with tin foil and a dielectric of either paper or mica. Condensers with paper dielectrics are now made for a maximum voltage of about 2,500 volts.

Variable Condensers.—A variable condenser, used for radio tuning purposes, generally consists of two groups of aluminum plates so arranged that one group may be moved with respect to the other. In most cases the dielectric is air. The main difference between this and the fixed type of condenser is in mechanical construction. Because of limitations in insulation and in manufacture it is used only for receiving sets, laboratory instruments, and transmitters of low voltage. Variable condensers with air as the dielectric are made in capacities up to 0.005 microfarad, and with an oil dielectric up to about 0.010 microfarad. The breakdown voltage is increased considerably when oil is used as the dielectric.

A straight-line capacity condenser, such as is used in receiving sets, has semicircular plates. In this type the capacity varies directly with the setting of the plates. In a *straight-line wave-length condenser*, such as is used in wave meters, the stationary plates are semicircular and the movable plates have a special shape. The shape is designed to give a uniform wave-length scale in tuning. In a *straight-line frequency condenser* the stationary plates are semicircular and the movable plates are shaped to give a uniform frequency scale in tuning.

Rating of Condensers.—The manufacturer's name plate on a condenser must indicate the capacity of the condenser and its voltage rating. The voltage rating of the condenser must be greater than the full working voltage of the circuit to take care of surges of high voltage.

Electrolytic Condenser.—Certain metals such as aluminum, magnesium, and tantalum, when immersed in a solution called the *electrolyte*, allow electricity to flow in one direction but not in the other. *Two* electrodes of this kind practically prevent all flow of electricity and constitute an electrolytic condenser. Such condensers are usually constructed with aluminum electrodes. The disadvantage of this type compared with the dry type is that it has an appreciable energy loss.

The critical voltage of an electrolytic condenser is the maximum impressed voltage which it will stand without permitting an appreciable leakage current. The critical voltage for aluminum in an electrolyte of sodium sulphate is 40 volts, and for aluminum in ammonium phosphate, ammonium citrate, or sodium tetraborate, it is about 470 volts.

The blocking effect of the aluminum is due to a very thin oxide or hydroxide film on the aluminum covered by a thin layer of gas, the resistance of which may be several million ohms per square centimeter. In comparing this device to the ordinary solid condenser, the gas layer corresponds to the dielectric, and the aluminum electrode and the electrolyte correspond to the two plates of the condenser.

The capacity depends only on the voltage at which the electrodes are formed and the material of the electrode, and not on the nature of the electrolyte. The capacity decreases rapidly as the formation voltage is increased. Thus the capacity for aluminum is about 2 microfarads at a formation voltage of 50 volts, 0.4 microfarad at 200 volts, and 0.1 microfarad at 600 volts.

It is essential that the oxide film and the gas layer cover only the portions of the electrodes which are in the electrolyte. Otherwise considerable arcing may take place between the exposed surfaces and the electrolyte. The energy losses in condensers on continuous duty are greater at high than at low voltages. It is, therefore, desirable for such duty to use several low-voltage units in series.

Calculation of Capacity.—The capacity of a condenser consisting of two similar metal plates is

$$C = 0.0885\frac{KA}{d}$$

where C is the capacity in micromicrofarads, d the thickness of dielectric between plates in centimeters, A the surface area of one side of one plate in square centimeters, and K the dielectric constant (page 55).

For the multiplate condenser which, instead of one pair of metal plates, has N plates with the alternate ones connected in parallel, the capacity is

$$C = 0.0885\frac{KA(N-1)}{d}.$$

For a variable condenser with semicircular plates the maximum capacity when the movable plates are between the fixed plates is

$$C = 0.1390\frac{K(r_1^2 - r_2^2)(N-1)}{d}$$

where N is the total number of parallel plates, r_1 the outside radius of plates in centimeters, and r_2 the inside radius of plates in centimeters.

It is essential to remember that capacity exists between any adjacent conductors. Thus the capacity of two No. 8 wires of copper, which are 1,000 feet long and 1 foot apart, is 0.0032 microfarad.

Filters.—A filter is a device which allows the flow of currents having certain frequencies but blocks currents of other frequencies. It consists of a combination of inductances and capacities which offers a low impedance to a certain range of frequencies and a high impedance to others. In a radio receiving set a filter may be used to block the passage of undesired frequencies, and in a transmitting set for blocking frequencies which are not to be transmitted. Certain principles of design which are applicable to filters have been given under resonance (page 84).

Filter System for Rectifier.—The filter system in the rectifier unit of a receiving set is substantially as shown in Fig. 10. The choke coils (page 95) are made with a laminated iron core. The capacity of the last large condenser must be large enough to supply the full current requirement of the receiver on peak loads. The combination of coils and condensers serves to smooth out the variation of the input current and to maintain a steady direct-current output. As the incoming current *varies* it induces in the coils a counter-electromotive force in a direction such that it tends to oppose any changes of the current. The condensers, which are charged to a certain value by the voltage induced in the coils, will discharge when the voltage applied to them becomes less than that value; that is, the condensers tend to oppose any changes of the voltage. Filters are generally classified as (1) low-pass type, (2) high-pass type, and (3) band-pass type. A *low-pass filter* as shown in Fig. 11 allows the flow of currents of low frequencies but blocks those of higher frequencies. The *high-pass filter* (Fig. 11) allows the flow of currents having frequencies above a given value but blocks those of lower frequencies. The *band-pass filter* (Fig. 11) allows the flow of currents having frequencies within a given range but blocks those of other frequencies. The effectiveness of a filter system in eliminating the undesired frequencies increases as the resistance of the coils is reduced and as more units are added. The figures indicate one unit of each system.

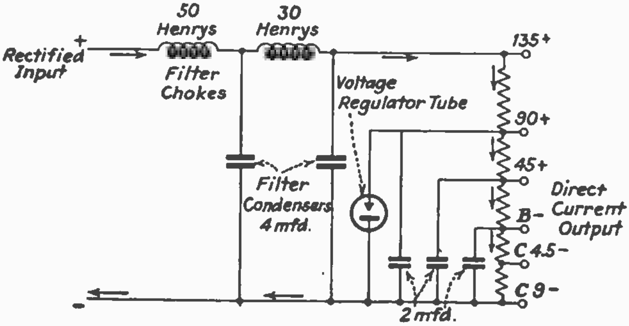


FIG. 10.—Filter system for rectifier.

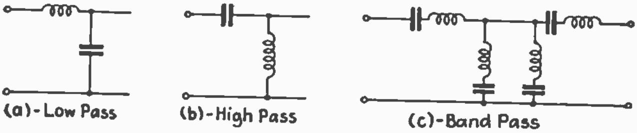


FIG. 11.—Types of filters.

Filter systems are applied for various other purposes such as the elimination of commutator (page 211); ripple elimination of interference to broadcast reception by the key clicks from the transmitters (page 455) used by amateurs; elimination of interference from electrically operated devices (page 445).

Part 2

PRACTICAL MEASURING INSTRUMENTS

Instruments are required for the measurement of electrical quantities in circuits. The instruments commonly used in transmission, reception, testing and laboratory work include ammeters and voltmeters for the measurement of direct and alternating currents, galvanometers, ampere-hour meters, wattmeters, frequency meters, radio-frequency ammeters—in general the action of such measuring instruments depends on either the magnetic effect of a current or its heating effect.

Galvanometer.—The operation of a galvanometer depends on electromagnetic principles. This instrument may be used to detect the presence of small electric currents less than a millionth of an ampere and to measure their *amounts* and *directions*. Its sensitiveness and frailty make it applicable mainly for laboratory work. Its action is based on the movement of a magnet placed in the magnetic field of a wire carrying a current. The magnet may be stationary and the coil movable or the magnet may be movable and the coil stationary. The moving element carries a pointer which passes over a graduated dial. In the most sensitive types there are no pivots or springs and the coil is suspended by a long thin wire, and instead of an indicating pointer, a small mirror attached to the coil shows its movements by the change in the direction of light reflected from it.

Direct-current Voltmeter.—A diagram of a voltmeter is shown in Fig. 12. This type, called a *moving-coil meter*, consists of a stationary magnet and a movable coil. A pointer attached to the coil passes over the scale, which is graduated to indicate voltage values. A spring attached to the shaft of the pointer resists the movement of the coil and brings the pointer back to zero when no current is flowing through the instrument.

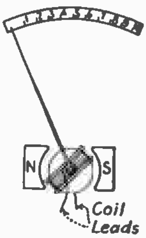


FIG. 12.—Direct-current voltmeter.

A voltmeter must be connected *across* the voltage which is to be measured. On this account a high resistance is placed within the device in series with the moving coil to prevent a short circuit. The positive terminal of a voltmeter should be attached to the positive side of the circuit. The range and value of voltage values depend on the design of the meter and the amount of the series resistance. Thus a millivoltmeter has a small resistance and can be used to measure small fractions of a volt.

An external resistance called a *multiplier* may be used with a voltmeter to increase its range. The meter reading is multiplied by a constant which depends on the resistance of the multiplier.

Direct-current Ammeter.—The action of an ammeter is the same as that of a voltmeter. Its construction is different because an ammeter is a device of low resistance which is connected in *series* in a circuit to measure the current. For this reason the series resistance in an ammeter is omitted. Ammeters of this simple type are made for small currents only. For large currents the instrument is provided with a resistance, called a *shunt*, connected *across* the terminals, as shown in Fig. 13. This shunt diverts a portion, usually one-tenth, of the main current to the coil. The meter is actuated by the small current which passes through its coil, but the scale is calibrated to indicate values of the total current. No shunt other than the one provided with an instrument may be used without a recalibration of the readings.

The scales of voltmeters and ammeters of the electromagnetic type used for direct-current measurements are calibrated in equal divisions with each unit having the same space value as the next. The scale of an alternating-current meter (page 109), however, has space divisions which are not equal but which increase as the square of the value.

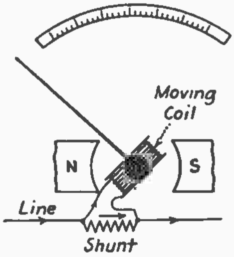


FIG. 13.—Shunt connection for ammeter.

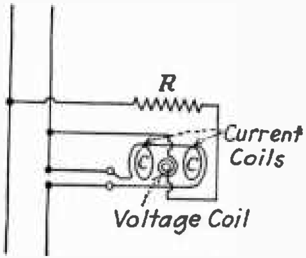


FIG. 14.—Wattmeter.

Wattmeter.—A wattmeter is an instrument which indicates the power taken by a circuit. In direct-current work the power is equal to volts times amperes, but in an alternating-current circuit the power is equal to volts times amperes times the power factor (page 10).

The wattmeter, as shown in Fig. 14, consists of a stationary *current* coil of low resistance, which is connected in *series* with the circuit, and a movable *voltage* coil, which is provided with a series resistance of high value and is connected *across* the circuit. Iron cores or permanent magnets are not used. The voltage coil is connected to a pointer and is provided with springs which bring the pointer to zero when no current is flowing through the meter. Connections to the line circuit are made through four terminal posts on the meter. Thus it performs the functions of an ammeter combined with a voltmeter.

Hot-wire Ammeter.—Another type of current-measuring device, the hot-wire ammeter, depends for its action on the expansion of a heated wire, instead of on the effect of a magnetic field on a coil. It may therefore be used on *either direct or alternating current.* As shown in Fig. 15, the resistance wire fastened between points A and B will stretch, as it is heated by a current. The change in length of the wire is taken up by the spring S and causes a movement of the pointer. The position of the pointer may be adjusted by a regulating screw.

Alternating-current Meter.—For alternating-current measurements a modified form of the magnetic-type instrument becomes necessary which utilizes the effect of a magnetic field on a small plate of iron. Two kinds of devices for the measurement of low-frequency alternating quantities are available, the moving-vane type and the inclined-coil type. The action of the moving-coil type, shown in Fig. 16, depends on the repelling effect between two magnetized plates A and B, one of which is fastened to a coil C and the other to a pointer. These instruments act on alternating current because, although the iron plates change in polarity when the current reverses, each has the same polarity as the other and consequently they still repel each other. In the inclined-coil type the field of the coil exerts a twisting action on a plate fastened to the shaft of the pointer.

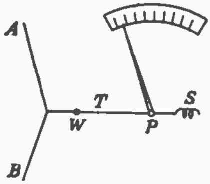


Fig. 15.—Hot-wire ammeter.

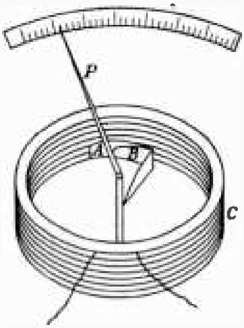


Fig. 16.—Alternating-current voltmeter.

A *voltmeter* of this variety has a coil with many turns of fine wire and a series resistance; an *ammeter* has a low-resistance coil with a small number of turns of heavy wire. For heavy currents a number of hot wires in parallel must be used to avoid heating the wire so much that its resistance changes. The disadvantage of the hot-wire measuring device is that it is slow in response and that the pointer must be adjusted to zero position frequently.

Thermocouple Ammeter.—A meter much used for the measurement of high-frequency currents depends on a thermoelectric effect and utilizes the voltage which is developed when the junction of two dissimilar metals is heated. The thermocouple consists of two wires of dissimilar metals such as steel and constantan, or manganin and constantan. Two ends of these wires are welded together and connected to a conductor carrying the high-frequency current. The other two ends are connected, as shown in Fig. 17, to a sensitive indicator such as a galvanometer. The heat of the conductor affects the junction of the thermocouple and generates in the wires a voltage which actuates the galvanometer. This voltage, which always acts in one direction, depends only on the amount of heat and not on the direction of the current in the conductor. The deflection of the galvanometer is proportional to the square of the current flowing in the conductor. Hence the divisions of the scale are not uniform, having a greater *space* value at the upper end of the scale than at the lower. For currents of more than a few amperes these instruments are made with several thermocouples in series. The disadvantage of the thermocouple ammeter is that the thermocouple corrodes readily.

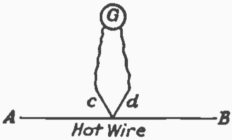


FIG. 17.—Thermocouple ammeter.

Current-transformer Ammeter.—For economy and accuracy, a more satisfactory device for the measurement of heavy currents of radio frequency consists of a combination of a galvanometer, thermocouple, and current transformer. The transformer has a primary (page 69) of one turn connected in the high-frequency circuit. The secondary (page 70) is wound on a laminated iron ring core and is connected through the thermocouple to the galvanometer. At high frequencies the secondary current is equal approximately to the primary current multiplied by the ratio of primary to secondary turns. One advantage of this arrangement is that only a change in the ratio of the number of turns in the primary and secondary windings is necessary to adapt the instrument for a different range of current values.

Ampere-hour Meter.—This is an instrument which indicates on a scale the condition of charge of a storage battery in ampere-hours. The pointer is moved by a small motor connected so that the current flowing in the battery circuit passes through it. The speed of the motor depends on the number of amperes of current flowing in the circuit. By connecting a revolution counter to the motor a direct reading in ampere-hours is obtained of the quantity of electricity which has passed through the meter.

When the battery is being charged, the pointer moves toward zero on the scale, and when the battery discharges, the pointer moves toward the high values on the scale. When the pointer reaches a mark on the scale at the value of the ampere-hour rating of the battery, the operator places the battery on charge. When the pointer approaches zero during the charging operation, it is arranged to open the charging circuit.

Frequency Meter.—Two common types of meters which indicate frequency are the vibrating-reed and the induction types.

The *vibrating-reed frequency meter* is provided with a number of steel strips each of which has a different natural frequency or period of vibration. The strips are placed so that a magnet carrying a current of a certain frequency sets into vibration the strip which has that particular natural frequency. A scale calibrated to frequency values is placed along the series of strips.

A modern *induction frequency meter*, illustrated in Fig. 18, consists of a moving disk which is actuated by two balanced coils each of which is connected across the circuit. One coil has in series with it a non-inductive resistance, and the other a reactance. The pull of each coil on the disk depends on the frequency and the square of the current. But the pull of the coil in series with the reactance decreases as the frequency increases, because less current flows through the coil on account of the increase in self-induction. The pull of the other coil, however, is increasing and consequently the disk moves until the forces are equalized. A frequency meter when used on a generator is connected across the generator terminals.

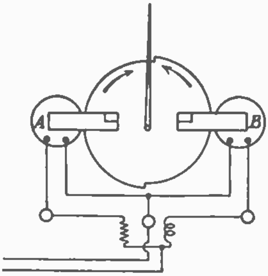


Fig. 18.—Induction frequency meter.

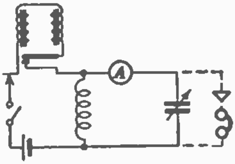


Fig. 19.—Circuit connections of wave meter including buzzer.

Wave Meter.—A wave meter is generally made with a fixed inductance in series with a variable capacity. The values of capacity and inductance depend on the range of the instrument. The circuit connections including a buzzer (page 34) are shown in Fig. 19. The direct-reading type of wave meter shows the wave length in meters or the frequency in kilocycles on a dial. The indirect-reading type is provided with a chart which shows wave length or frequency values corresponding to condenser settings.

The wave length or the frequency of the circuit of this device may be varied by changing the value of the capacity. If the wave length of the instrument is made the same as that of some oscillating circuit within its range the wave meter is in resonance with that circuit. The wave length of the instrument in meters is equal to 1,884 $\sqrt{LC}$ where L is the inductance in microhenrys and C the capacity in microfarads.

The condition of resonance is indicated by a maximum reading of a hot-wire or thermocouple ammeter placed at point *A* in the circuit marked *A* in Fig. 19. If the ammeter, instead of being inserted directly into the circuit, is coupled (page 87) to it, the coupling may be varied to allow a maximum meter reading. A less accurate method uses a crystal detector in series with a pair of head phones connected across the condenser as shown in the figure. Another method, seldom used, indicates resonance by the brilliancy of a lamp, such as a neon tube (p. 745), placed across the condenser. Neither of these other methods, however, gives any indication of the *relative* value of the current at resonance.

A wave meter, excited by a buzzer, as shown in Fig. 19, may be used as an oscillator or transmitter of waves of a known frequency, to calibrate another wave meter or a receiving set. Other uses of the wave meter include the tuning of a transmitter, the indirect measurement of the wave length of a transmitter by the calibration of a receiver, the measurement of decrement (page 91), degree of coupling, the fundamental wave length of an antenna, the capacity of a condenser, and the inductance of a coil.

Kolster Decremeter.—The decremeter (*Bur. Standards Scientific Paper* 235) may be considered as a wave meter in which the movable plates of the variable condenser carry a dial graduated in values of decrements (page 91). This device gives a direct reading of the decrement on a dial. The wiring diagram for this instrument is shown in Fig. 20. The first step in finding the decrement of a circuit is to set up a condition of resonance by changing the capacity of the variable condenser until the ammeter shows a maximum reading. Then the current is reduced to one-half the maximum reading by manipulating the condenser. The decrement scale is then fastened in its zero position. The next step is to turn the plates of the variable condenser continuously past the point of maximum current until the current falls to one-half of the maximum value. At this point a reading is taken of the value on the decremeter scale opposite the zero reference mark. This reading minus the decrement of the instrument itself gives the required decrement of the circuit.

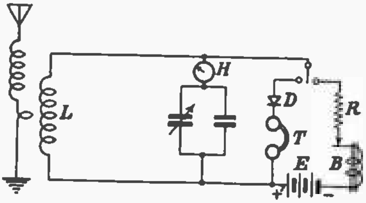


FIG. 20.—Kolster decremeter.

Hydrometer.—A hydrometer consists of a calibrated float enclosed in a glass tube. The glass tube is provided at one end with a piece of rubber tubing and at the other end with a rubber bulb which is used to draw the liquid into the tube. The float inside the tube is weighted at one end and has a graduated scale along the other. The specific gravity of the liquid is observed on the scale at the surface of the liquid in the tube. A commercial type of hydrometer is shown in Fig. 21.

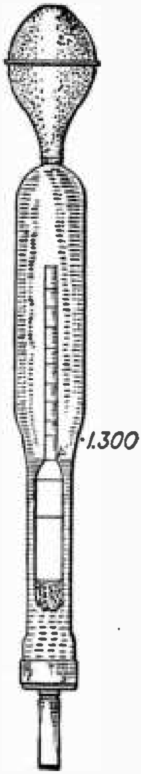


FIG. 21. Hydrometer

The specific gravity of a liquid is the weight of a certain volume of the liquid compared with the same volume of distilled water. The specific gravity of water is taken as unity or 1. In the case of a lead-cell storage battery the specific gravity of the electrolyte indicates the condition of the electric charge of the cells.

Wheatstone Bridge.—A circuit called the Wheatstone bridge is used to measure an unknown resistance in terms of known resistances. A diagram of this circuit is shown in Fig. 22. The voltage drop between points *a* and *c* is the same over the path *abc* as over the path *adc*. Hence some point *b* on the upper path must have the same voltage as a point *d* on the lower path. When such points have been located, a galvanometer *G* connected between *b* and *d* will show no deflection. With a current I_p (amperes) in the upper circuit, I_t in the lower, and r_1 and r_3 being the respective resistances in ohms, the voltage drop $I_p r_1$ is equal to the voltage drop $I_t r_3$ so that

$I_p r_1 = I_t r_3$ and $r_1 \div r_3 = I_t \div I_p$.

Similarly, in this figure, $I_p r_2 = I_t r_4$ and $r_2 \div r_4 = I_t \div I_p$.

Consequently $r_1 \div r_3 = r_2 \div r_4$ or $r_4 = r_2 r_3 \div r_1$.

An unknown resistance r_4 may be calculated from this relation.

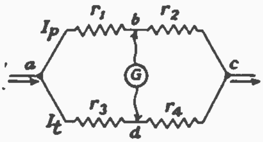


FIG. 22.—Wheatstone bridge circuit.

Part 3

RADIO RECEIVING SET TESTERS

The Weston tester, model 547, for radio receiving sets is designed for the service requirements of all ordinary types of radio receivers, whether operated by direct current or alternating current. This testing device measures the various alternating- and direct-current voltages used in receiving sets either at the vacuum-tube sockets or at any other part. It can be used to indicate continuity in the circuits of the set and also to test the vacuum tubes, including the alternating- and direct-current screen grid types (UX-224 and UX-222) and the power tubes (UX-250, UX-245, and UX-210), under the same conditions that exist when the tubes are in their sockets. All tests can be made with this instrument by using the voltages normally supplied to the receiving set by its batteries or by the so-called "socket-power" units (page 261), with no change in the connections, so that an auxiliary power supply is not required.

Instruments and Switches.—The **Weston testing set** has three instruments: (1) a direct-current milliammeter, (2) a direct-current volt-milliammeter, and (3) an alternating-current voltmeter. The arrangement for properly connecting the instruments to the circuits is shown in Fig. 23.

The alternating-current voltmeter has five ranges—750, 150, 16, 8, and 4 volts. Any of the three lower ranges can be connected directly across the filament terminals of the so-called "tester plug" by setting the alternating-current selecter switch to the desired range. These ranges are for the purpose of measuring the filament or heater voltages of tubes which have their filaments heated with unrectified alternating current, commonly called "raw" alternating current. The 150-volt range is provided for the purpose of measuring the voltage of the line and the 750-volt range for measuring the voltage of the secondary windings of the transformer. These two high ranges are available only at the binding posts marked "750," "150," and "+." The low ranges are also available at the binding posts marked "16," "8," "4," and "+."

The direct-current volt-milliammeter has eight ranges—750, 250, 100, 50, 10, and 5 volts and 100 and 2.5 milliamperes. The 750 and 250 ranges are for the plate- sometimes called "B" voltage measurements; the 250, 100, 50, and 10 are for grid-bias (page 36) voltages; the 50 range is also used for cathode-voltage readings; the 10-volt range is for filament voltage measurements, and the 5-volt range is also used for testing the *continuity* of the *circuits*. The 2.5-milliampere range is for use in measuring the "screen" current of screen-grid tubes (page 305), and the 100-milliampere range is for measuring the plate current of rectifier tubes (page 286).

The direct-current milliammeter has two ranges—100 and 20 milliamperes. Either range, as desired, may be used by throwing the "Ma." toggle switch to the 100-milliampere scale or to the 20-milliampere scale. Shunts can be obtained to add milliameter ranges of 2- and 10-ampere scales. The 2-ampere range is provided especially for measuring the current in a dynamic loud-speaker (page 129) and also in field coils, trickle chargers, etc. The 10-ampere range is for measuring larger currents such as are required of 5- or 7.5-ampere battery chargers and similar devices.

Two bipolar dial switches are provided to connect the direct-current milliammeter to the various circuits as designated on the dials. They are arranged in such a manner that the instruments cannot be connected across two circuits at the same time. For all readings on dial 2, dial 1 must be set to the position marked "switch 2." A smaller switch is provided and is marked "4," "8," "16," and "off." It is intended for use in selecting the desired ranges of alternating-current filament voltage for connecting the alternating-current voltmeter directly across the filament terminals.

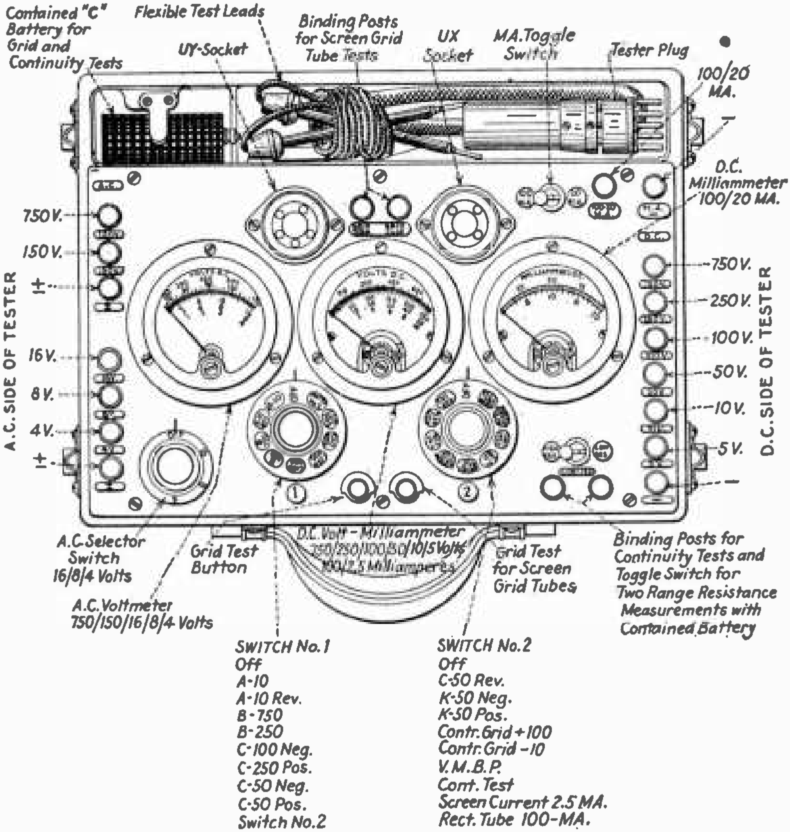


Fig. 23.—Weston testing set.

All ranges of the three instruments, except the 100- and 2.5-milliampere ranges of the volt-milliammeter, are brought out to binding posts for making voltage or current measurements directly on batteries, socket-power devices, continuity tests, or for any purpose for which the "cord and tester plug" device is not adapted.

General Tests.—When radio receiving sets having tubes operated with "raw" alternating current are to be tested, the alternating-current voltmeter may be left in the circuit during the tests for plate voltage, plate current, grid-bias (page 36) voltage, and the tube tests described later. This allows the operator to follow any changes which may occur due to variations in the filament voltage during the tests. The wiring for the 750- and 150-volt ranges of the alternating-current voltmeter is entirely insulated from the low-voltage ranges and all other circuits in the test set. Although only one range can be used at a time to obtain correct readings, no damage can result if high and low ranges are connected simultaneously. Either of the high-voltage ranges may remain in the circuit during any of the other tests. The low-range binding posts for alternating-current voltages must not be used when the "tester plug" is inserted in the radio set, on account of possible interconnections.

The alternating-current voltmeter switch should be placed in the "off" position when direct-current type tubes are being tested with the direct-current voltmeter and its associated bipolar switches. No harm will result, however, if this alternating-current meter is left in the circuit while direct-current measurements are being taken; but because the alternating-current voltmeter takes more current for its operation than the direct-current instrument, slightly inaccurate readings may result. The "tester plug" should be removed from the radio receiving set when the binding posts are used on account of possible interconnections in the radio set.

Resistance Measurements.—Resistances from 100 to 100,000 ohms may easily be measured without additional equipment, by setting the dial switches to "Cont. Test," connecting the unknown resistance to the binding posts marked "Cont. Test," and comparing the deflection of the central instrument with the instruction chart.

Capacity Measurements.—Capacity values from 0.25 microfarad to 10 microfarads may be determined by connecting a variable resistance in series with the voltage range of the alternating-current voltmeter, the condenser to be measured, and a 110-volt (60-cycle) alternating-current supply line. The capacity in microfarads is obtained by comparing the deflection of the voltmeter with the instruction chart.

Tests of Radio Receiving Sets.—The following tests are made with the "tester plug" in the radio-set socket and the tube in the tester socket.

Direct-current Filament Voltage.—Dial 1 is set at "A" or "A Rev." to obtain an up-scale deflection. The alternating-current selector switch must be at the off position. The voltage is read directly on the 10-volt direct-current scale.

Alternating-current Filament Voltage.—The alternating-current selector switch is set to the desired range and the voltage is read directly on the alternating-current voltmeter.

Plate Voltage.—Dial 1 is set at "B-750" or "B-250" and the voltage is read directly on the direct-current voltmeter.

Grid-bias Voltage.—Dial 1 is set at "Neg. C-100" or "Neg. C-50" and the grid-bias voltage (page 36) is read on the direct-current voltmeter; for the 100-volt range the 10-volt scale is used and the reading is multiplied by 10; for the 50-volt range the 50-volt scale is used.

When the filament voltage of direct-current radio receiving sets is being measured, if the voltmeter indicates up-scale with dial 1 at "A Rev.," the grid-bias measurement should be made with dial 2 at "C-50 A Rev.," dial 1 being first set to switch 2. The reading is then taken directly on the 50-volt scale.

Screen-grid Voltage.—The shorter lead is connected with a clip, between the binding post marked, "grid term," and the tip of the tube. The longer lead is connected with a clip between the binding post marked "grid clip" and the grid clip in the radio receiving set. Then dial 1 is turned to "Pos. C-250" or "Pos. C-50" and the voltage is read directly on the 50- or the 250-scale of the direct-current voltmeter.

Screen-grid Current.—Dial 1 is set to switch 2 and dial 2 at a screen-current value of 2.5 milliamperes. The current is then read on the 250-range of the central instrument, but this reading must be divided by 100 to get the value of the screen-grid current in milliamperes.

Cathode Voltage.—Dial 1 is set to switch 2 and dial 2 is set at "K Neg. −50" or "K Pos. −50," whichever gives an up-scale deflection. Then the voltage is read directly on the 50-volt scale of the central instrument.

Control of Screen-grid Voltage.—The short lead is connected with a clip between the binding post marked "grid term" and the tip of the tube, and the long lead is connected with a clip between the binding post marked "grid clip" and the grid clip in the radio receiving set. Dial 1 is turned to switch 2 and dial 2 to "Cont. grid −10" or "Cont. grid +100." If the tube is being used as a screen-grid amplifier (page 306) the voltmeter will give an up-scale deflection at the "Cont. grid −10" setting; if the tube is being used as a space-charge (page 285) amplifier, the voltmeter will give an up-scale deflection at the "Cont. grid +100" setting.

Plate Current.—The "Ma." toggle switch is set to 100 or 20 milliamperes depending on the range desired, and the plate current is read directly on the direct-current milliammeter which is connected in the plate circuit at all times.

Grid Current (for Other than Screen-grid Tubes).—If grid current is present in amplifier tubes, it will be indicated by a deflection to the left of zero on the central meter, when the switches are set for screen-grid current. If any grid current is present it may be due to a gaseous tube (page 280) or to oscillating (page 391) or unbalanced circuits.

Grid Test.—First the reading on the direct-current milliammeter is noted and then the push button marked "Press for grid test" is depressed. An increase in plate current will result because the grid-bias voltage is decreased by 4.5 volts (voltage of the small dry battery). The amount of increase in plate current indicates the condition of the tube. Grid tests may be made without the aid of additional adapters in the same manner on the UX-227-type tube when used as a detector.

Grid Test for Screen-grid Tubes.—The control grid voltage is measured by setting dial 1 to switch 2 and dial 2 at "Cont. Grid −10." If at this position the voltmeter moves the pointer in the wrong direction, it indicates that the tube is being used as a space-charge (page 285) amplifier. In this case the push button marked "Press for grid test" should be used instead of the one marked "Grid test on S. G. tubes." If the voltmeter gives an up-scale deflection, the push button marked "Grid test on S. G. tubes" should be used. An increase in plate current will result because of the change in grid-bias voltage from the normal value to zero. The way in which the tube is being used must be determined before the grid test is made. As stated previously, if the tube is being used as a screen-grid amplifier, the voltmeter will give an up-scale deflection when dial 2 is set at "Cont. Grid −10"; but if it is being used as a space-charge amplifier, the voltmeter will read in the proper direction when the dial is set at "Cont. Grid +100."

Testing Rectifier Tubes.—All rectifier tubes of the filament type may be tested with this instrument. For this kind of service, dial 1 is set to switch 2, dial 2 is turned to "Rect. Tube −100 Ma.," and the milliammeter toggle switch is set at 100 milliamperes. Then the "tester plug" is inserted in the socket of the rectifier and the tube is placed in the test set. If the tube is of the UX-281 type (half wave) the milliammeter will indicate the total plate current; but if the tube is a full-wave rectifier such as the UX-280 type, the milliammeter will indicate the current in one plate and the central instrument will indicate the current in the other plate. This gives the current in both plates simultaneously and the two readings should be added to get the total current. Both instruments should give the same reading. If they do not, it is an indication that the emission of one filament is lower than that of the other.

The tester plug must not be inserted in the socket of the rectifier and the push button must not be pressed until the dial switches are in their proper positions. Filament voltage may be measured in the same manner as for any other type of tube.

Testing Batteries and Eliminators.—The "tester plug" must not be inserted in any socket of the set when batteries or eliminators are being tested. For such testing dial 1 is set to switch 2 and dial 2 is turned to "Vm. B. P." The two flexible leads with the test prods should then be connected to the voltmeter binding posts—"black" to "minus," and "red" to the range desired. The instrument can now be used as a multi-range voltmeter to measure the voltage in any circuit or in any of its parts. The test leads may also be connected to the alternating-current posts so that measurements may be made of the line voltage as well as the high and low voltages of power transformers.

Continuity Tests.—When a continuity test is to be made of circuits, dial 1 is set to switch 2 and dial 2 is turned to "Cont. Test," and the two test leads are then attached to the two binding posts marked "Cont. Test." The voltage of the contained battery may now be checked by touching the two leads together—the voltmeter should indicate 4.5 volts which is read on the 50-volt scale, divided by 10. The two leads are then connected to the part of the apparatus in which the continuity of the circuit is to be checked. The indication on the direct-current voltmeter using the 10-volt scale can be compared with the chart supplied with the tester, which shows the resistance of the circuit directly in ohms. If the resistance of the circuit is below 5,000 ohms, the toggle switch marked "High Res.—Low Res." should be moved to the side marked "Low Res." For resistances higher than 5,000 ohms, however, the toggle switch should be moved to "High Res." When it is set at the "High Res." position, the voltmeter has a resistance of 1,000 ohms per volt, and at the "Low Res." position the voltmeter has a resistance of 100 ohms per volt. When continuity tests are being made, all power must be disconnected from the apparatus which is being tested.

With the addition of a small test panel the Weston model-547 instrument can be used as a vacuum-tube voltmeter, a resonance indicator page 667), an oscillator (page 38), a vacuum-tube reactivator (page 291), and an ordinary vacuum-tube tester (without the radio receiving set).

Part 4

RESISTANCE UNITS, INSULATORS, AND CRYSTALS

Resistors.—A resistance unit for radio-frequency use must be of sufficient size so that it will not be heated excessively by the current. Also, a resistance unit should have a low temperature coefficient, a constant resistance for a given range of frequencies, and a form of construction which allows a low value of distributed capacity and of inductance. Wire of the alloy called *manganin* is much used for this purpose. It is interesting to note that the inductance of a straight wire having a direct-current resistance of 40 ohms, a length of 50 millimeters, and a diameter of 0.025 millimeter (0.001 inch) is 0.15 microhenry. To minimize inductance and capacity effects a special form of winding is used. In this type of winding a wire is wound on a form of a suitable insulating material, as, for example, bakelite with a space between the turns equal to the diameter of the wire. Another wire parallel with the first is wound in the unfilled spaces in the form in a direction opposite to that of the first wire, as shown in Fig. 24. With this construction the currents in the two wires flow in opposite directions and adjacent wires are kept at nearly equal potentials. Units of resistance over 1,000 ohms are sometimes made in the form of a tape which has the resistance wire for the woof and cotton threads for the warp. This type is non-inductive but is suitable for small currents only.

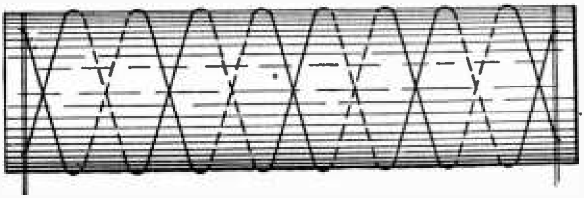


FIG. 24.—Winding to minimize inductance and capacity.

A resistance unit which is used merely as a load or to regulate voltage and current need not possess a constant value but must have ample radiating surface and a low temperature coefficient.

Resistance Units for Large Currents.—It is difficult to design a resistance unit which can carry a heavy radio-frequency current and at the same time have a constant resistance over a given range of frequencies. A unit of this kind may be made of wire or ribbon of manganin or nichrome wound on an asbestos tube in a way that will reduce the inductance and distributed capacity. The required current-carrying ability is obtained by connecting small units in combination.

Standard Fixed Resistances.—Standard resistance coils, accurately measured, are obtainable in a range from about one hundred thousandth of an ohm to several hundred thousand ohms. Likewise, any required current-carrying capacity and degree of accuracy may be specified.

Grid Leak.—A grid leak is a type of high-resistance unit used in the operation of a vacuum tube as a detector. It is made in various forms such as a length of high-resistance wire, a piece of high-resistance metal, a mark made with a graphite pencil on an insulator, or a pile of small carbon plates so arranged that a variation of the pressure upon them changes the resistance. Such units may be obtained in values from 0.25 megohm to 8 or 10 megohms.

Fixed Resistances for Small Currents.—The construction of fixed-resistance units for small currents depends considerably on the degree of resistance. Thus for resistances of a few thousand ohms the unit may be made of high-resistance wire wound on an insulating tube and covered with enamel. For resistances of the order of about 50 megohms the unit may consist of an insulating tube wound with a wire made of carbon and a special kind of clay. A resistance unit of several thousand megohms may consist of a small glass tube from which the air has been removed and which has a very thin coating of tungsten on the inside surface. A somewhat different type utilizes a strip of paper coated with India ink.

For small-current work it is essential that the resistance remain constant under variations of temperature and under mechanical vibration.

Center-tap Resistance Unit.—In the operation of vacuum-tube filaments on alternating current it is necessary in some circuits to use the mid-potential point of the filament. A resistance unit of about 60 ohms commonly used for this purpose is mounted across the filament terminals of a tube socket and has a connection which provides the center tap of the filament. In cases where unbalancing occurs it is desirable to have an adjustable center tap which may be varied to the exact neutral point.

Potentiometer.—This device is a variable resistance of about 500 ohms. The wire-wound type of potentiometer uses a resistance wire of a nickel alloy, wound on a non-absorbent strip backed with a bakelite insulating form. The resistance unit of a potentiometer may, however, be made of graphite with a sliding arm of carbon. A potentiometer (Fig. 25) is used to regulate the degree or the polarity of voltage applied to a circuit. This device is essentially an arrangement for subdividing a voltage and is more correctly called a *voltage divider*. The relation between the source of voltage, the resistance, and the divided voltage is shown in Fig. 25. It is apparent that the voltage of point *c* may be varied from a negative to a positive value, corresponding to the supply voltage.

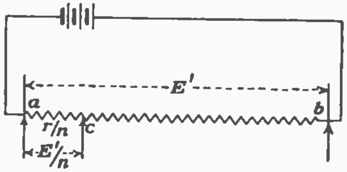


FIG. 25.—Potentiometer or voltage divider.

Rheostat.—In general, a rheostat is a variable-resistance unit having a considerable current-carrying capacity. A type of rheostat frequently used consists of a layer of wire wound on an insulating tube with a sliding contact which moves along the wire so that current may be made to flow through any desired portion. This type, however, is not suitable for heavy currents. Large rheostats usually consist of resistance units connected between switch points, with the wire of a unit embedded in enamel.

In very large rheostats the units consists of metal grids exposed to the air for cooling. The grid type of resistance is generally applied in commercial and industrial electrical equipment. Another type of rheostat for heavy currents is made of a pile of carbon disks or plates. The assembly is arranged so that a screw may be turned to vary the electrical resistance.

A type of fixed-resistance unit called an *amperite* has been used in series with the filament circuit of a vacuum tube instead of a rheostat.

Liquid Rheostat.—A compact form of rheostat for use with extremely heavy currents consists of two metal plates immersed to a variable depth in a conducting liquid. If water is used, its resistance may be decreased by the addition of a small quantity of salt to allow more current to flow. Such a rheostat may be cooled by the use of a metal container with radiating ribs or by circulating the liquid.

Starting Rheostat.—One type of starting rheostat or "starting box" for a direct-current shunt motor (page 225) is shown in Fig. 26. The resistance is made up of wires or grids mounted in an iron box which must be ventilated. The handle and the electromagnet *M* are mounted on an insulating panel of slate. The internal connections are indicated by dotted lines. The terminal *L* is connected to one side of the supply circuit, *F* to the shunt field post of the motor, and *A* to the armature of the motor. The other terminal of the motor is connected to the opposite side of the electric supply circuit.

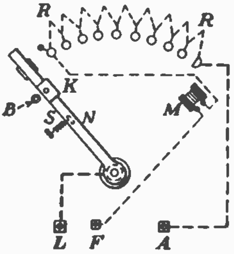


FIG. 26.—Starting rheostat for electric motor.

When the handle of the rheostat is moved to its extreme position to the right, the resistance is all cut out, the iron strip *K* touches the electromagnet *M*, and the handle is held in place. If the voltage is lost for any reason, the handle is released by the magnet and is pulled back by the spring *S* to open the motor circuit. The resistance units are in series with the armature at starting and are cut out one by one as the starter handle is moved. In the final position of the handle the full supply voltage is applied to the motor circuit.

Fuse.—A fuse may be considered as a resistance unit which is used to prevent the flow of excessive current in a circuit. The resistance portion is a piece of wire or strip of an alloy of lead and tin inserted in series with the wires of an electric circuit. The fuse is marked to indicate the value of current at which the resistance will melt and thus open the circuit. The size of fuse which can be used in a given wire without causing excessive heating, according to the National Electrical Code, is given on page 22.

Decade Resistance Boxes.—A resistance box of the decade type consists of a number of coils of wire and suitable switches which may be manipulated to introduce single coils or any desired combination of coils in a circuit. The range of resistances may be from a fraction of an ohm up to 100 or more megohms. Each resistance unit is marked with its resistance value to provide a means of quickly calculating the total resistance inserted into a circuit. The coils are wound with fine wire in a manner to reduce the magnetic field.

This type of unit is suitable for use with currents of low values. In a circuit of low inductance, however, a decade resistance box may change the inductance of the circuit, but a readjustment of the capacity of the circuit will compensate for the variation.

Insulators.—An insulator is essentially a device used to separate a conductor from nearby electrically charged bodies. It may be considered as a fixed condenser in which the dielectric is the material of the insulator, and the plates are the terminals of the insulator or the conductor and nearby conducting surfaces. Consequently the factors which must be considered in the selection of condensers, such as dielectrics, insulations, and power losses, apply also to insulators.

Power losses in an insulator appear in the form of heat and, if severe enough, will cause the insulator to fail. The losses in the solid dielectric may be reduced by a form of construction which diverts the path of the electric field from the solid dielectric to the air. The path must be long enough to prevent the voltage from jumping across, hence the length of an insulator is determined by the voltage at which the insulator is to be used.

Types of Insulators.—The two types of insulators are those for low-voltage work and those for high-voltage service. The insulation of a low-voltage circuit such as the antenna of a receiving set is just as important as that of a high-voltage circuit operating at 10,000 to 30,000 volts. Although the voltages and currents encountered in a receiving antenna are extremely small, the receiver is under a severe handicap if much of the electrical energy is allowed to leak away.

An insulator which is dusty, greasy, or sooty will allow leakage of electrical energy. If the dielectric is non-uniform or if it is cracked enough to permit the entrance of moisture, the insulator will soon become defective. Glazed porcelain or glass insulators are capable of withstanding high voltages but are not satisfactory where subject to severe mechanical vibration. A composition called *electrose* which is made with a shellac binder is often used for molded insulators. The purpose of ribs and petticoats on insulators is to lengthen the leakage path and to allow water to run off the body of the insulator. When an insulator is designed to stand the strain of the wire it supports, it is called a *strain insulator*.

A high-voltage insulator, in addition to the essential qualities of an insulator for low-voltage service, must provide sufficient support for the wire and must properly insulate the circuit. It is generally made with a shield designed so that the path of most of the lines of electric force is through the air rather than through the solid dielectric. High-voltage insulators for radio work are made in several types and in various sizes and shapes.

A transmitting antenna may have a high voltage imposed on it and must be carefully insulated to prevent leakage. A defective insulator will cause a marked decrease in the antenna current and the radiation, as may be noted from the ammeter reading.

Crystals.—Crystals of various kinds have long been used in radio communication. They played an important part as detectors in receiving sets, particularly those of the reflex type. Crystal detectors are still furnished as auxiliary equipment with commercial receivers for use in the event of a vacuum-tube failure. A quartz crystal which has piezo-electric properties (page 125) is widely used in frequency control circuits for radio transmitters.

Crystal Detectors.—The minerals, natural or artificial, which may be used as detectors in contact with a metal (steel) point are galena (lead sulphide), iron pyrites (iron sulphide), molybdenite (molybdenum sulphide), bornite and halcopyrite (combinations of iron sulphide and copper sulphide), zincite (zinc oxide), and carborundum (crystalline silicon carbide). In most cases a light contact with a fine wire gives best results, but some crystals are more efficient with a blunt contact point under pressure. Many crystals do not have a uniform sensitivity over the entire surface, while others lose their sensitivity in spots, deteriorating also with use, exposure to excessive heat, or exposure to air.

Crystal detectors must have either the property of unilateral conductivity (rectification) or the property of varying conductivity under different applied voltages. Almost all kinds of detectors which depend on contact between two dissimilar substances have both of these properties to some degree.

A crystal detector which acts as a unilateral conductor offers a greater resistance to the flow of current through it in one direction than in the opposite direction. If an alternating voltage is impressed on such a crystal detector, more current, therefore, will flow in one direction than in the other.

A direct-current ammeter in such a circuit will give a reading. The usual crystal detectors have a resistance of 1,000 to 10,000 ohms in one direction and about ten times as much in the other direction.

A crystal detector which has a variable conductivity under different applied voltages must be used in series with an auxiliary battery. Usually this arrangement is used only with carborundum. Crystals of silicon, iron pyrites, and galena are equally sensitive with or without the battery. The current-voltage characteristic curve of a carborundum detector is shown in Fig. 27. This curve illustrates the increase in conductivity as the voltage is increased. A mineral which does not possess this property has a conductivity which is constant under different voltages; consequently the current-voltage curve for such a mineral is a straight line. The voltage of the auxiliary battery is adjusted for operation at the bend of the curve. At this point a small increase of voltage in one direction results in a relatively large increase of current, but the same decrease in voltage results in a very small decrease of current.

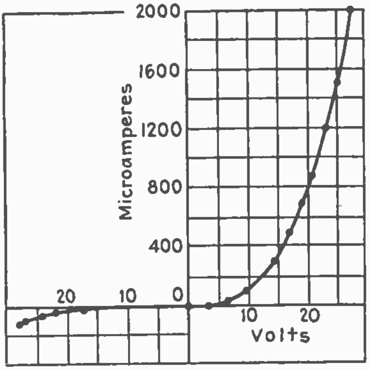


FIG. 27.—Characteristic curve of carborundum detector.

The relative sensitivity of a crystal detector as compared with a vacuum-tube detector may be shown by the minimum antenna current necessary to produce a given response in ear phones. Thus for the ordinary crystal a current of 500 units might be required; for one of unusual sensitivity, a current of 100 units; for a vacuum-tube detector, 100 units; for a "soft" tube, 10 units; and for an oscillating tube, 0.1 unit.

Piezo-electric Crystals.—Quartz and other crystals become electrically charged when compressed and change their shape slightly when charged electrically. If mechanically vibrated they will produce an alternating voltage and if subject to an alternating electrical field they will vibrate. These properties are known as *piezo-electricity*. A properly cut quartz crystal, if put under pressure, will show a difference of potential of several volts between its faces. A quartz crystal disk has a definite natural period of oscillation which depends on its size and shape and the manner in which it is cut from the body of the crystal. Furthermore, the disk will hold the original frequency of oscillation for long periods of continuous operation. The fundamental wave length of the crystal depends on its thickness and is approximately from 100 to 110 meters per millimeter of thickness. Crystals are ground with a mixture of carborundum and emery applied with the surfaces parallel. They are tested in a vacuum-tube oscillating circuit until the required frequency is obtained. If there is even a slight variation in the thickness of a quartz disk, it will not produce oscillations in a tube circuit, because the portions of different thicknesses attempt to oscillate at different periods of vibration.

The piezo-electric property of a quartz crystal is utilized to control the frequency of oscillation of a vacuum tube. An arrangement of a quartz disk and a vacuum tube in an oscillator used for producing standard-frequency service is shown in Fig. 28. The quartz disk is confined loosely between two metal plates *M* and *N*. If the plate circuit is tuned to a frequency approximately equal to that of the quartz disk, the circuit will oscillate. A hot-wire type of ammeter (page 108) placed in series with the condenser *C* will deflect only when the quartz is oscillating, and this provides a convenient means for a test. Tuning the plate circuit does not cause any change in the frequency of oscillation and serves only to increase the amount of energy which passes into the grid circuit from the plate circuit. In other words, the amplitude of the electric oscillations will be a maximum when the frequency of the tuned circuit is approximately equal to that of the crystal.

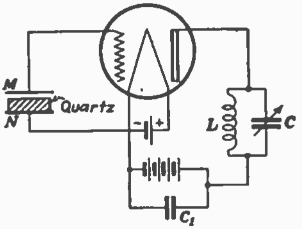


FIG. 28.—Oscillator for standard frequency.

Quartz crystals are used in circuits for producing oscillations of standard frequency and also for correcting, or for setting, the frequency of a transmitter. If a beat note (page 408) is observed between the frequency of a station and that of the quartz oscillator, the station frequency is adjusted until zero beat is obtained. Where a quartz oscillator is used to set the station frequency, it acts on the grid circuits of the power tubes through intermediate amplifiers.

The holder for the crystal is arranged so that the crystal is maintained at a fixed distance from the sides of the container and so that only a very light pressure is put on the upper contact plate. The container is hermetically sealed and kept at a constant temperature. At high frequencies of operation a variation of 10°C. in the temperature of the crystal will cause a variation in frequency of about 1,000 cycles. A crystal may become inoperative if it becomes greasy from handling. It must then be washed in a solvent for grease.

Part 5

TELEPHONE RECEIVERS, LOUD-SPEAKERS, AND MICROPHONES

The telephone receiver is used to convert into sound waves an alternating current which has superimposed on it a signal wave form of audio frequency. Two receivers (*ear phones*) of the type shown in Fig. 29 constitute a *head set*. The pole pieces *N* and *S*, of soft iron, are attached to the permanent magnet *H*. The two coils *M*, *M* are wound with fine wire and connected in series so that the received current flows through both. In the standard receiver there may be as many as 10,000 turns of wire with a direct-current resistance of 1,000 to 1,500 ohms, but special receivers may have a resistance as high as 8,000 ohms. At the high frequencies used in radio services the impedance is many times the direct-current resistance. A diaphragm *D* of thin soft iron is placed close to but not touching the pole pieces. The distance between them, usually a few thousandths of an inch, determines the sensitivity to a great extent. The permanent magnet exerts a steady pull on the diaphragm, and upon this is impressed the effect of the magnetic field of the coils. The variations of the current in the coils follow the sound variations directed toward the transmitter and produce corresponding variations in the magnetic field of the coils. Thus the diaphragm is put into vibration and reproduces the sound waves which strike the transmitter. This diaphragm has a natural period of vibration, resonant frequency, at which its response is a maximum. Special receivers of the "tuned" variety, in which the resonant frequency can be changed, have been made. The diaphragm can vibrate only at an audio-frequency rate. If it could vibrate at very high frequencies the sound would be beyond the range of the human ear.

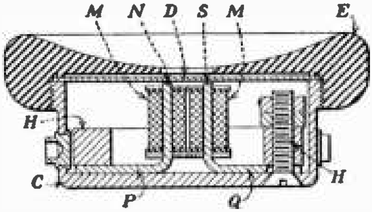


FIG. 29.—Telephone receiver (head set).

One disadvantage of this simple type of receiver is that the movement of the diaphragm with currents of high amplitude is so great that distortion results.

Balanced-armature Telephone Receiver.—In this type, illustrated in Fig. 30, a soft-iron armature is pivoted through the core of the coil *A* and is arranged so that its movement is transmitted by a lever and connecting rod to a mica diaphragm *D* located as in the standard receiver. Other non-magnetic materials, such as pressed paper, light wood, and "doped" cloth, have been used for the diaphragm. There is no pull on the armature until a varying current flows through the coil, because the path of the magnetic field is across the gap from one pole piece S to pole piece N. If a current flows in the coil, the magnetic field in the gap is diverted so that its path is *along* the flat pivoted armature. This forces the armature to move on its pivot. Consequently the vibrations produced in the armature by a signal current are of greater amplitude than if the armature is under an initial stress. The armature is mounted so that its movement is increased through the action of the lever. This receiver has the advantage that the high permeability (page 64) of the magnetic circuit results in a large force from a small signal current. A current of a fraction of a micro-ampere gives a satisfactory response in well-made head phones.

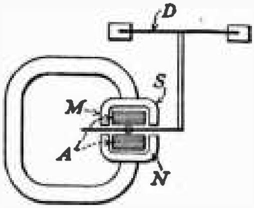


FIG. 30.—Balanced-armature telephone receiver.

Loud-speakers and Microphones. *Balanced-armature Loud-speaker*.—The first loud-speakers for radio work used an operating unit which was essentially the same as that of the balanced-armature head phone (telephone receiver). Horns of various sizes and shapes similar to the "bell" of a musical instrument were developed to improve the poor performance of such loud-speakers on notes of low frequency. Such an arrangement gave improved sound effects but it was of inconvenient size.

Exponential Horn.—This type of horn is intended to reproduce efficiently the vibrations of a diaphragm over a wide range of frequencies. The taper of this horn increases at an "exponential" rate such that the area of a cross-section through the horn is doubled for each unit of increase in its length. Such horns are seldom built in lengths of less than six feet because an increase in the rate of expansion raises the minimum frequency which the horn will reproduce.

Cone Speaker.—The type of loud-speaker illustrated in Fig. 31 utilizes a balanced armature which acts on a cone-shaped paper diaphragm through a lever and connecting rod. This diaphragm consists of a double cone fastened at its back to the frame. The adjoining edges of the two faces of the cones are glued together. The connecting rod must be centered in the front cone. The position of the rod may be changed by means of adjusting screws. Several types of the conical diaphragms have been developed. Among these are the single free-edge cone, the single cone fastened to the frame, the double-free-edge cone, the double reversed free-edge cone, and the double cone with adjoining edges fastened to the frame. A few of these conical diaphragms have been made with oval-shaped cones.

This type of loud-speaker gives a much better response on low frequencies, but below frequencies of about 100 its efficiency drops very sharply. Another disadvantage is that the armature strikes the poles on loud signals.

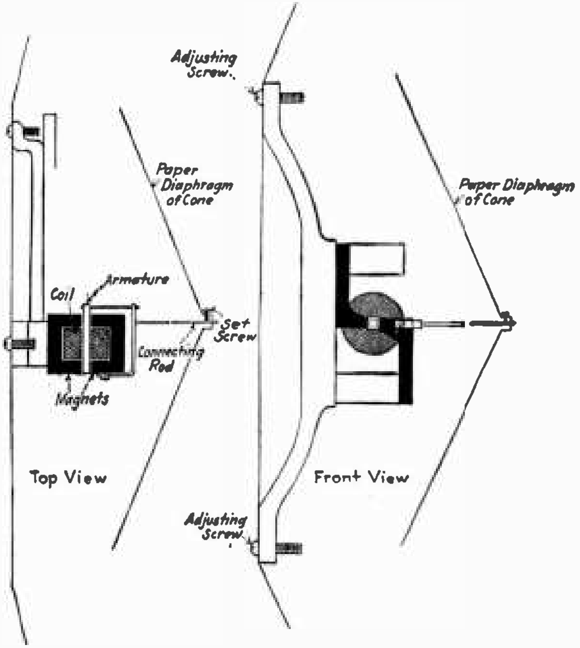


FIG. 31.—Cone type of loud-speaker.

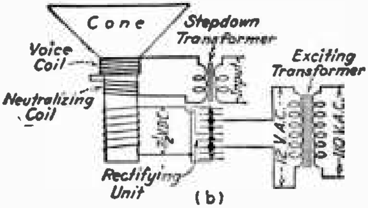


FIG. 32.—Moving-coil type or dynamic loud-speaker.

Moving-coil or Dynamic Loud-speaker.—The essential feature of the moving-coil or dynamic loud-speaker, as shown in Fig. 32, is a so-called *voice coil* placed in a magnetic field. The field coil is energized from an external source of direct-current power, usually the output of the rectifier in the power-supply unit, and requires from 4 to 15 watts. In other types the field current is obtained from the alternating-current light circuit of 110 volts through a step-down transformer and a dry-contact rectifier. The voice coil, consisting of about a hundred turns of fine wire, is centered in the air gap of the magnet and so mounted on the core that it is free to move *along* the core. The voice coil is fastened to a cone-shaped paper diaphragm. The interaction of the magnetic fields of the field coil and the voice coil forces the voice coil to move back and forth along the core corresponding to the variations of the current in the voice coil. This movement is transmitted to the diaphragm and reproduced as sound. The outer edge of the diaphragm is attached to a small metal ring faced with felt which bears against a baffle board. The hole in the board has a diameter equal to that of the outer edge of the cone. The moving coil is of low resistance and must be connected to the power tube through an output step-down transformer in which the ratio of turns in the primary to secondary coils is about 25:1.

The method of mounting will affect the quality of reproduction at low frequencies. "Free" mounting gives poor reproduction at frequencies around 400 cycles per second. Good response at 100 cycles may be obtained by mounting the loud-speaker in an enclosed cabinet. Difficulties due to mechanical resonance may be remedied by cutting holes in the back or bottom of the cabinet and covering the inside with sound-absorbing material. The best response to low frequencies of which the loud-speaker is capable is obtained by mounting it with the front edge of the cone close to the periphery of a hole in a baffle board which has a sufficient area. One recommendation is that the distance from the front of the cone, through the air, around the baffle, to the back of the cone should be one-quarter of the wave length of the lowest note desired. Thus, if the velocity of sound is taken as 1,083 feet per second, the wave length at 100 cycles per second is 130 inches and that at 50 cycles is 260 inches. One-quarter of these values gives the travel around the baffle as 32.5 inches for the 100-cycle note and 65 inches for the 50-cycle note.

This loud-speaker will reproduce frequencies as low as 40 cycles per second but may overemphasize the high audio frequencies. Some types minimize this over emphasis on high notes by the use of a *filter shunt*. Compared with the ordinary cone type, which is limited to a power input of about 1 watt, the dynamic loud-speaker can operate on a maximum of about 10 watts.

Inductor Dynamic Loud-speaker.—In this type two *U*-shaped permanent magnets are used to supply a fixed magnetic field. Instead of a moving voice coil, there is a moving armature. The armature, however, instead of rocking on a pivot, moves back and forth in a direction *along* the pole faces. The support for the armature is provided by the springs S, S, shown in Fig. 33. The voice coils C and C_1 are connected in series. When a current flows in the direction shown, the field between the poles P, P is increased while that between P_1, P_1 is decreased. Consequently a greater force is exerted on the armature bar A than on A_1 and the armature moves to the left. When the current reverses, the movement of the armature changes in direction. The outstanding advantage is that no direct-current excitation is required for the field.

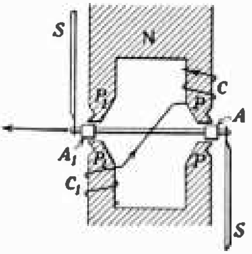


Fig. 33.—Inductor dynamic loud-speaker.

Phonograph Pick-up.—An electrical pick-up device in connection with the audio amplifier of a receiving set is used to reproduce phonograph records.

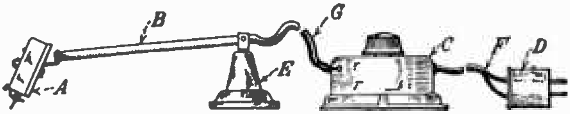


Fig. 34.—Phonograph pick-up.

One example of the magnetic type is the Bosch unit, as illustrated in Fig. 34. The reproducer A which carries a needle is fastened through a swinging arm B to a base E. The two leads G of the reproducer pass through the volume control C to a socket plug D. In order to use the device the detector tube is removed from its socket, the plug D is inserted, the receiver is switched on, the record on the turntable is rotated, and the needle of the reproducer is placed on the record.

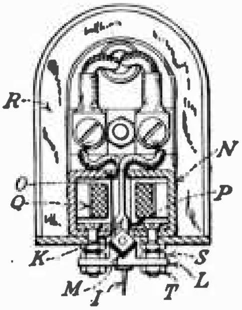


Fig. 35.—Phonograph reproducer.

A section of this *phonograph reproducer* is shown in Fig. 35. The needle I is held in the armature, which is pivoted on knife edges and vibrates in the air gaps O and P of the pole pieces N. The magnetic field is obtained from a permanent magnet. Movement of the armature induces in the coil Q an alternating voltage which varies in strength in accordance with the "curves" on the phonograph record. This voltage is impressed on the audio-frequency amplifier (page 355) of the receiving set through the socket plug.

Microphone Transmitter.—This instrument is acted on by sound waves to cause corresponding variations in an electric current. The carbon microphone transmitter of the *single-button* type as shown in Fig. 36 is essentially a speech-controlled variable resistance, because the resistance of the carbon varies with changes of the pressure upon it. The carbon grains *C* are confined between the hard carbon plates *E* and *F*, which are insulated from each other and serve as the electrodes of the device through the terminals *G* and *H*. The button *L* is fastened to the carbon plate *F* and is kept in contact with the aluminum diaphragm *D* by a metal spring *S*.

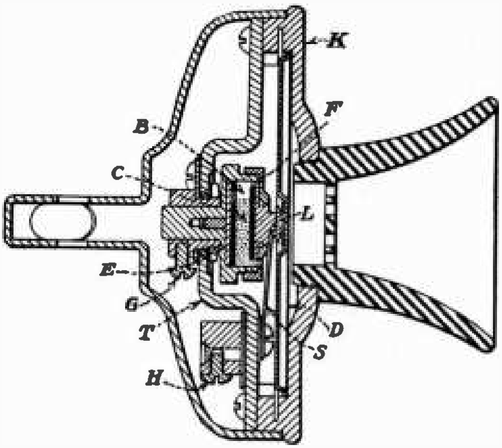


FIG. 36.—Carbon microphone transmitter (single-button type).

If a source of voltage is connected across the terminals, it will cause a current to flow from one carbon plate through the carbon grains to the other plate. A sound wave striking the diaphragm induces vibrations in it which are transferred to the carbon plate and thus varies the pressure on the carbon grains. This variation of pressure also varies the resistance between the carbon plates, and consequently the current in the external circuit has the same characteristics as the sound wave. One disadvantage of this type is that it introduces distortion on sounds of high intensity. Also, the flow of current through the carbon produces a hissing noise.

One type of carbon microphone takes a current of about 25 milliamperes and has a power consumption of about 0.3 watt on a supply of 12 volts.

Double-button Microphone.—In this type, the diaphragm has a cup of carbon grains called a *button* on each side and is connected into the circuit as shown in Fig. 37. When a sound wave strikes this diaphragm so as to increase the pressure on one set of carbon grains, the pressure on the other set is reduced. Consequently the current decreases in one branch of the circuit and increases in the other. The combined effect of these currents is to reduce distortion and to increase output. The resistances of the two buttons must be equal to avoid distortion. The transformer used with this microphone has a mid-tap on the primary winding. The response to frequencies over a range of from 1,000 to 6,000 cycles per second is quite uniform. This type of microphone is in general use in broadcasting stations.

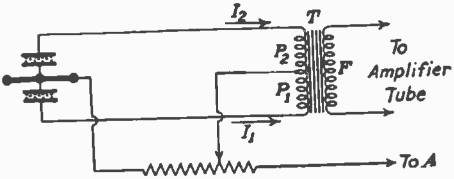


Fig. 37.—Carbon microphone transmitter (double-button type).

Magnetic Microphone.—This type depends on the action of a coil in a magnetic field. The construction is such that a sound wave striking a diaphragm causes it to vibrate and thus to vary the strength of the magnetic field around the coil. The varying voltage induced in the coil has a frequency characteristic of the same form as that of the sound wave. In another type the diaphragm is attached to a coil which is located in a permanent magnetic field. The movement of the coil in the field induces a voltage in the coil. A pair of head phones (telephone receivers) may be used as a magnetic microphone.

Condenser Microphone.—This type consists of a thin metal diaphragm placed close to but insulated from a thick metal plate. The diaphragm and plate together form an air condenser (page 55) of small capacity. This condenser, in connection with a battery and resistance units as shown in Fig. 38, is arranged so that a sound wave striking the diaphragm varies the capacity of the condenser and also the voltage across the resistance. This voltage drop acts upon a vacuum tube which serves as the input to a speech amplifier.

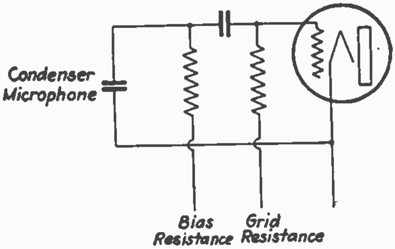


Fig. 38.—Condenser microphone.

The response to frequencies over a range of from 40 to 6,000 cycles per second is quite uniform. The condenser microphone gives more perfect reproduction than the other types but it is less sensitive and necessitates the use of a greater degree of amplification to produce an output of equal volume.

Part 6

TRANSFORMERS

General Principles.—The principle of induction is utilized in a transformer to change the voltage of an alternating current. In a "step-up" transformer the output voltage is higher than the input voltage; in a "step-down" transformer the output voltage is lower than the input voltage. A simple transformer as shown in Fig. 39 consists of two coils of insulated wire wound on a common core of silicon-steel sheets. The *primary coil* is considered the input side and the *secondary coil* the output side.

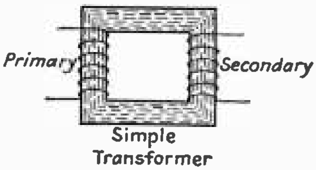


FIG. 39.—Simple transformer.

Operation of Transformer.—An alternating current flowing in the winding of the primary coil produces an alternating magnetic field in the core. The small current which flows in the primary when the secondary is "open" is called the *no-load* or *open-circuit* or *magnetizing current.* The magnetic field in the core induces in the primary winding a back voltage practically equal in value to the applied voltage. This magnetic field also induces an alternating voltage in the secondary winding. If the secondary circuit is closed, an alternating current will flow, producing a magnetic field which opposes that of the primary current, and consequently the magnetic flux of the core is reduced. This reduction decreases the primary inductance and allows a greater primary current to flow. In other words, if the secondary current increases, the primary current increases also.

A classification of transformers according to their construction consists of *air-core transformers* and *iron-core transformers.* Transformers are used in radio receiving circuits for coupling one stage to another in audio-frequency amplifiers, for coupling stages in radio-frequency amplifiers, for operating the filaments of vacuum tubes, and for producing high voltages for the plate supply of vacuum tubes. In radio transmitting circuits they are used for charging the condensers of a spark system (page 40) and for the plate supply of vacuum tubes in a tube type of transmitter.

Audio-frequency Transformer.—This is a device used to couple the output circuit of one vacuum tube in an audio-frequency amplifier to the input circuit of the next following tube. The transformer should have a nearly flat amplification curve (page 136) from about 150 to 5,000 cycles per second. A non-uniform curve results in sound reproduction which is distorted because certain frequencies are overemphasized. The core must be large enough so that it will not be saturated by the direct current in the plate circuit connected to its primary. If a core is saturated the variations of the plate current caused by the reception of a radio signal can produce but little additional magnetic flux; consequently all the plate-current changes are not transferred to the secondary circuit, and the quality of the signal is affected.

The impedance of the primary winding of a transformer is designed to match the impedance of the output circuit or the resistance of the plate circuit of the vacuum tube with which it is used.

Transformer Construction.—The greater the primary impedance relative to the plate impedance the larger will be the voltage impressed on the primary coil of a transformer and, consequently, also the amplification. A primary inductance of 100 henrys has an impedance of 628,000 ohms at 1,000 cycles and 62,800 ohms at 100 cycles, which is about six times the plate resistance of the tube. The reduction of impedance with frequency decreases the amplification at low frequencies. The primary inductance depends on the number of primary turns, the cross-section of the core, the length of the iron-core path, and the amount of direct current flowing in the primary circuit. High core losses diminish the amplification at all frequencies. The voltage amplification increases rapidly with an increase of the primary no-load reactance at low values of reactance, but more slowly at higher values. Beyond a certain point, then, there is little to be gained by increasing the reactance. The factors of size and cost must be considered, also, for an increase in the core increases the size of the unit, and if more primary turns are used, more secondary turns are necessary for a given ratio of secondary turns to primary turns.

Since the primary and secondary coils cannot occupy the same space, there is a certain amount of magnetic flux called *leakage flux* which does not link both coils. This produces the *leakage inductance* which decreases amplification at all frequencies.

The capacity effect between turns and between layers is small and affects amplification only at high frequencies. The capacity effect between the primary coil and the secondary coil also acts as a short circuit between the two windings at high frequencies and tends to decrease amplification.

If the *transformer ratio*, that is, the ratio of secondary turns to primary turns, is made high, and there are many turns on the primary, a very large number of turns are obviously needed on the secondary. This results in an increased internal capacity effect which, with the input capacity of the next tube, brings the natural frequency of the secondary circuit within the range of audio frequencies and causes a *resonance peak*. Amplification beyond this natural or *cut-off frequency* is very poor.

It has been shown that amplification of low frequencies requires a large number of primary turns and that a large number of secondary turns diminishes the amplification of high frequencies. Consequently a transformer is made with a rather low ratio of secondary turns to primary turns, a core having a large cross-section, a low internal capacity, and a low leakage inductance.

Amplification Curves.—The performance of a group of modern transformers is shown in Fig. 40. A UX-112A vacuum tube was used and operated with a plate voltage of 68 volts and a grid-bias voltage (page 36) of −3 volts. The specifications for the several types of transformers are given in the following table:

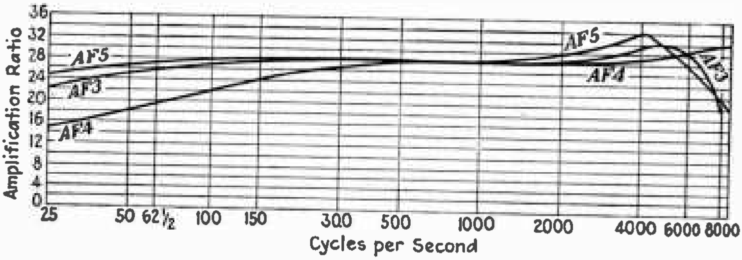


Fig. 40.—Amplification curves of modern types of transformers.

TABLE XVIII.—TRANSFORMER SPECIFICATIONS

Type of transformer	Ratio of secondary to primary windings, *n*	Maximum primary current, milliamperes	Resistance, ohms		Inductance, no direct current, henrys		Primary inductance with 3 milliamperes direct current
			Primary	Secondary	Primary	Secondary	
AF5........	1:3.5	10	2,400	34,000	190	2,330	110
AF3........	1:5	5	1,375	26,000	95	2,330	55
AF3........	1:3.5	5	1,900	26,000	190	2,330	85
AF4........	1:3.5	5	950	8,900	42	515	35

The effect of the lower primary impedance of the AF4 transformer is indicated by the decrease in amplification at low frequencies, as shown by the curves in Fig. 40. Both the AF3 and the AF4 transformers have a cut-off frequency at about 8,000 cycles per second. The small resonance peaks are due to the effect of internal capacity and leakage inductance.

The effect of a strong radio signal is to reduce amplification. This occurs because a strong signal causes an increased current to flow in the grid circuit of the amplifier tube. This current flows through the secondary winding of the transformer and acts so as to reduce the voltage developed.

A condition of *resonance* at 5,000 cycles or more does not produce a very noticeable effect on reception, because the efficiency of the loud-speaker at such frequencies begins to drop off. A condition of resonance at moderately low frequencies may be detected by laboratory measurements but, if small, does not perceptibly affect the performance of the amplifier.

The frequency characteristic of a multistage amplifier (page 355) may differ considerably from that of a single transformer. Interstage coupling may increase the effect of resonance conditions, and the coupling resulting from a common plate-voltage supply may cause a considerable change in amplification at low audio frequencies.

An audio-frequency transformer is of the step-up type with more turns of wire on the secondary than on the primary winding. The usual ratio of turns is three to one. The secondary winding, consisting of thousands of turns of very fine wire, must have a low value of distributed capacity to avoid by-passing currents of high audio frequencies around the winding. The maximum allowable primary current is about 10 milliamperes. Usually the secondary turns are wound over the primary but in one type of transformer both are made up in sections which are placed next to one another on the core. Some transformers are enclosed by a metallic shield which may be grounded.

Audio-frequency transformers should have a separation of several inches from each other, or they should be mounted so that the cores are at right angles. These precautions may minimize the difficulties caused by interaction of the magnetic fields of transformers.

Radio-frequency Transformer.—This unit is usually made of two single-layer coils on separate forms with the secondary outside the primary. The mutual inductance (page 68) between the two windings may be fixed or variable depending on the construction. The ratio of the number of turns in the windings is calculated for a maximum energy transfer and not primarily for voltage increase. The mutual inductance of such an *air-core transformer* is quite small. The impedance of the primary coil should be equal to the impedance of the vacuum tube with which it is used in order to get a maximum flow of current. Such transformers may have a primary inductance of about 10 microhenrys and a secondary inductance of 200 or more microhenrys. To prevent magnetic and static coupling, radio-frequency transformers may be shielded, or they may be so mounted with relation to each other that the interstage coupling is greatly decreased. In one arrangement (Fig. 41) three coils *A*, *B*, and *C* are mounted so that the axis of each is at 90 degrees to the others, and in another arrangement the axis of each coil makes an angle of about 58 degrees with the base.

Transformers used for alternating currents of radio frequencies are made with air cores. Iron is not so effective at radio frequencies in increasing the magnetic flux as at low frequencies. This condition exists because time is required for the magnetization to advance from the outside to the center of the core; that is, the current reverses so rapidly that the field is reversed before it penetrates an iron or steel core to any appreciable distance and is confined to the outer portion of the core.

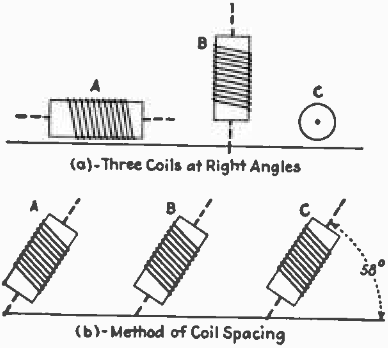


FIG. 41.—Method of coil mounting.

Power Transformers.—Transformers for use in circuits carrying considerable power, called power transformers, may be classified according to their construction as *open-core* and *closed-core* types. In the open-core type the magnetic lines of force are not at all confined to an iron core but it is intended that some will pass through the air. On the other hand, in the closed-core type the magnetic lines are confined as much as possible to the core. The *leakage flux* is that part of the magnetic lines due to one winding which does not link the other winding. The leakage flux may be reduced by the use of a closed core, or a core of large cross-section, or by winding one coil over the other.

In a transformer the ratio of the primary voltage E_p to the secondary voltage E_s is equal to the ratio of primary turns N_p to secondary turns N_s. Expressed as a formula, this becomes

$$\frac{E_p}{E_s} = \frac{N_p}{N_s}.$$

It may be shown also that the primary ampere-turns (page 63) are equal to the secondary ampere-turns, or $I_pN_p = I_sN_s$ whence

$$\frac{I_s}{I_p} = \frac{N_p}{N_s}.$$

The power in the primary circuit multiplied by its *power factor* (page 76) is equal to the secondary power times its power factor.

Transformer Losses.—The losses in a transformer consist of the heat lost in the wire, eddy currents, and hysteresis. The primary winding of a transformer must have a low *resistance* for direct current in order to keep down the I^2R loss. The core is laminated to reduce the heat loss due to *eddy currents* which are currents induced in the core. Silicon steel, which has a high permeability (page 64), is used to reduce the *hysteresis loss*, which is the heat developed by the changes of the flux density in the iron which accompany the flow of an alternating current. Alloys have been developed recently which have a higher permeability and consequently a lower hysteresis loss than silicon steel.

Commercial types of transformers may be classified into two types according to the relative positions of the iron and the windings, that is, the *core type* and the *shell type*, as shown in Fig. 42. The *distributed-shell* type of construction is used on single-phase transformers for service up to about 4,600 volts. Single- and three-phase transformers for higher voltages and medium power are made with a *rectangular core*, while high-capacity high-voltage transformers generally are of the *simple-shell type*.

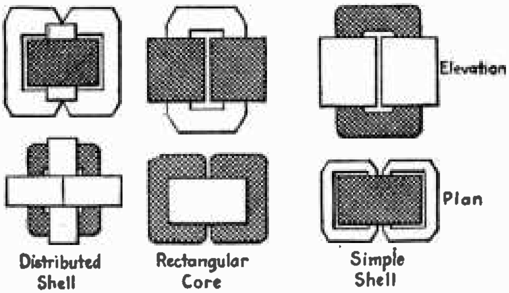


Fig. 42.—Windings of typical core and shell transformers.

Series Connections.—The two coils of a transformer winding, for either the primary or the secondary, may be connected in parallel or in series. Assume a "step-down" transformer, 10:1 ratio of turns, in which each coil of the primary winding is designed to carry 10 amperes at 1,100 volts without excessive heating, and in which each coil of the secondary is designed for 100 amperes at 110 volts. If the two primary coils are properly connected in series, they constitute, in effect, a single primary coil which can be connected to 2,200-volt mains to take 10 amperes without overheating unduly. If the two secondaries are properly connected in series, they constitute in effect a single secondary which will deliver 100 amperes at 220 volts.

Two coils of a transformer winding are properly connected in series when the current which flows through them follows around the core in the same direction in both coils. Figure 43 illustrates the proper and improper methods of making series connections. When two primary coils, improperly connected in series, are put on the supply mains, the current which flows through the two coils will have equal and opposite magnetizing action in the two coils, so that practically no magnetic field will be created and no "back voltage" will be induced in the windings to balance the applied voltage. The flow of current is therefore opposed only by the resistance of the coils, which is very low, and by the slight back voltage which is due to leakage. As a result, a very large current will tend to flow, producing short-circuit conditions. An improper connection of the secondary coils does not lead to short-circuit conditions but will result in zero voltage between terminals.

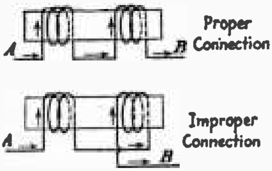


FIG. 43.—Right and wrong methods of making series connections of transformers.

Parallel Connections.—If the two *primary* coils of the transformer just mentioned are connected properly in parallel, they constitute in effect a single primary coil which is suited for direct connection to 1,100-volt mains and will take 20 amperes. If the two *secondary* coils are connected properly in parallel, they constitute in effect a single secondary coil which will deliver 200 amperes at 110 volts. The two coils of a transformer winding are connected properly in parallel when the current, which divides between them, flows around the core in the same direction in both coils, that is, so that both coils magnetize the core in the same direction. Figure 44 shows the proper and improper methods of making paralle connections. When two primary coils, improperly connected in parallel, are put on the supply mains, the currents in the coils oppose each other in their magnetizing action on the core. As a result, the core is not perceptibly magnetized and very little back voltage is induced in the coils. This allows a heavy flow of current and produces short-circuit conditions. Two secondary coils, improperly connected in parallel, give rise to short-circuit conditions. A voltmeter can be used to check transformer connections and may prevent serious damage to the windings.

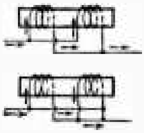


FIG. 44.—Right and wrong methods of making parallel connections of transformers.

Single-phase Connections.—As mentioned before, the primary coils of a transformer may be connected either in series or in parallel, and the secondary coils likewise may be connected in series or in parallel.

Two or more transformers may be *banked*, or operated in parallel. Figure 45 shows two transformers in parallel serving a single-phase two-wire line and also two transformers serving a single-phase three-wire line.

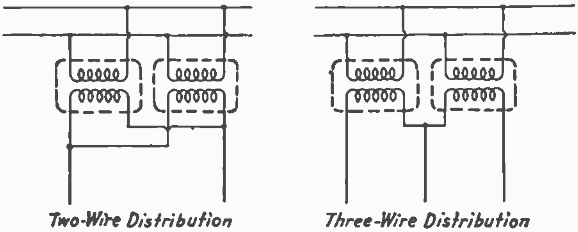


FIG. 45.—Transformers in parallel serving two-wire and three-wire lines.

Two-phase Connections.—In a two-phase or a three-phase system the step-up or step-down transformation (page 134) is accomplished, in general, by a separate transformer of the ordinary type for each phase.

In most cases the mains of a two-phase primary circuit are four wire (Figs. 46 and 47). The secondary or distribution circuits are generally four wire, although a few three-wire secondary circuits are in use. Figure 46 shows a two-phase system in which the power in each phase is received and delivered by a separate transformer in that phase. Both primary and secondary circuits are four wire. The two-phase three-wire system, in which one wire is used as a common return for both phases, is shown in Fig. 47 and indicates the use of two ordinary single-phase transformers.

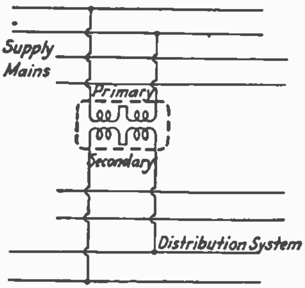


FIG. 46.—Transformer connections for four-wire two-phase supply to four-wire two-phase distribution.

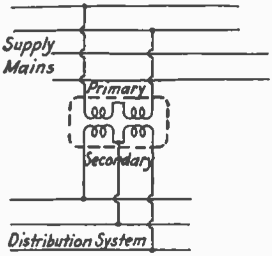


FIG. 47.—Transformer connections for four-wire two-phase supply to three-wire two-phase distribution.

Three-phase Connections.—The usual line for a three-phase system consists of three wires, *each* wire being in effect a common return for the current in the other two. Where three transformers are used, they may be connected in *delta* (Fig. 48) (also called *mesh*) or in *Y* (also called *star*) (Fig. 50). In a delta connection on the primary side, the three *primaries* are connected in series, and the *line wires* are connected to the three corners of the resulting triangle. In a Y connection on the primary side, one terminal of each primary is brought to a common point and the other terminal is connected to a line wire. The secondaries also may be connected either in delta or in Y, or they may be connected in a delta when the primaries are in Y, or *vice versa*.

It is necessary to keep in mind the distinction between *phase voltage* and *phase current*, and *line voltage* and *line current*. Thus, in a delta connection the *line* voltage equals the *phase* voltage, while the *line* current is equal to 1.73 times the *phase* current. Likewise, in a Y connection the *line* voltage equals 1.73 times the *phase* voltage, while the *line* current is equal to the *phase* current. Thus, in a balanced three-phase circuit the volt-ampere load is equal to 1.73 times the line current times the line voltage. In Fig. 48 there are shown three ordinary single-phase transformers with their primaries connected in delta to the three-wire, three-phase supply mains, and with their secondaries connected also in delta to the three-wire, three-phase distribution or service mains. The delta connection of both primaries and secondaries is preferred in practice, since with this arrangement the complete three-phase transformation still is effected even though one transformer may be entirely disconnected because of a burn-out or a breakdown. It

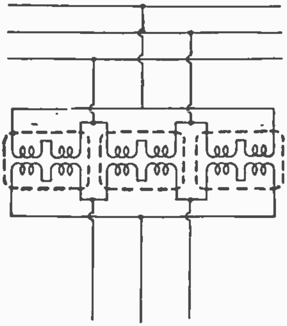


Fig. 48.—Transformer connections for three-wire three-phase delta connection of primary and secondary coils.

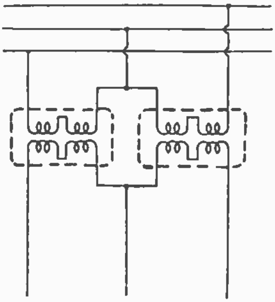


Fig. 49.—Open delta connections of transformers.

should be noted that when one transformer is disconnected, the arrangement is really a "V" or an "open-delta" connection, such as that shown in Fig. 49. Under these circumstances, line current and line voltage are equal to phase current and phase voltage. Thus, the volt-ampere capacity with a V connection is equal to the product of line volts and line amperes. This is 0.577 of the delta capacity, which is equal to 1.73 times line voltage times line current.

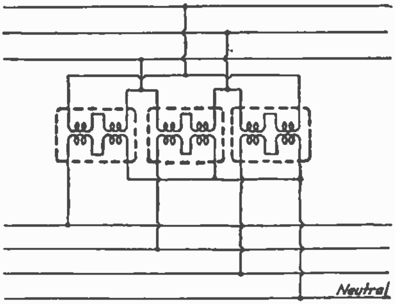


FIG. 50.—Transformer connections of three-phase three-wire delta supply to three-phase four-wire Y or star distribution.

The diagram of transformer connections using the primaries in delta in a three-phase, three-wire supply circuit, and the secondaries in Y in a three-phase, four-wire distribution circuit, is given in Fig. 50. The function of the fourth or neutral wire is to carry the unbalanced current, and, of course, with a balanced load, the fourth or neutral wire carries no current. This is similar to the function of the neutral wire in a direct current, three-wire system (page 215).

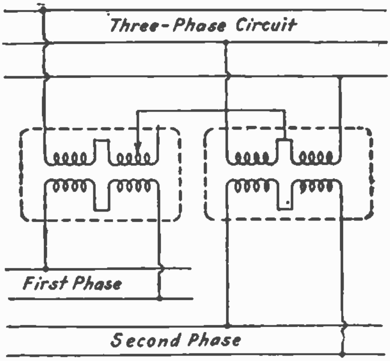


FIG. 51.—Scott connections of transformers for three-phase supply circuit.

Transformers may be connected with either their primaries or secondaries either in delta or in Y. With a delta-connected primary and a Y-connected secondary, the secondary voltage is equal to 1.73 times the voltage which would result from a delta connection. With a Y-connected primary and a delta-connected secondary, the secondary voltage is equal to 0.577 times the voltage which would result from a Y connection.

Phase-change Connections. Changes may be made from two to three phases, or from three to two phases, with or without a change in voltage, by means of special transformers which have the required ratio of transformation. This change is made by the use of the *Scott connection* on two single-phase transformers as shown in Fig. 51 which illustrates a three- to two-phase transformation.

Three-phase Transformers.—In general, a three-phase transformer has a common magnetic circuit for three sets of single-phase windings. As compared with three single-phase transformers, a three-phase transformer is lighter, smaller, more efficient, cheaper, easier to install, and lower in first cost. On the other hand, it is not so flexible and, in case of failure, causes more interruption to service. For these reasons the three-phase transformer is used mostly in large sizes.

Parallel Operation of Transformers.—In order that transformers may operate in parallel they must have the same ratings as to voltage, ratio of turns, and regulation. In this connection it is necessary to consider the polarity of the windings, as explained earlier in this section. A group of single-phase transformers having the same polarity and connected for parallel operation must have similar connections throughout. Under certain conditions, three-phase transformers cannot be operated in parallel. When such an installation is to be made, it is a good precaution to make thorough tests with a voltmeter before permanent connections are begun.

Autotransformers.—An autotransformer is made with but one coil. As shown in Fig. 52, part of this coil serves as both a high-tension and a low-tension winding (primary and secondary). A transformer made with two windings and a rating equivalent to that of an autotransformer requires more wire, more core iron, is higher in cost, and lower in efficiency. When the ratio of transformation is not large, an autotransformer may be used to good advantage.

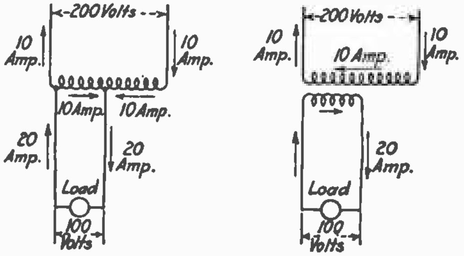


FIG. 52.—Autotransformer connections.

In the form of a *compensator*, the autotransformer is used to start alternating-current motors. The construction is such that at starting, a reduced voltage is applied to the machine.

Cooling Transformers.—The coils of a transformer may be immersed in oil to aid in dissipating the heat. Transformers of small size are cooled by exposure to the air. The secondary winding generally has a safety gap (page 238) for protection if the voltage increases beyond a certain value. The transformer case is grounded.

Hazards and Efficiency of Transformers.—Whether air or oil cooled, transformers are a source of both life and fire hazards. Care must be taken in choosing a location for them and in the method of mounting. By grounding a transformer case the danger from fire and the hazard to life from electric shock are reduced. The installation of a *ground connection* (p. 82) must receive the same care and consideration as any other part of the electrical system. The grounding of the case of an instrument transformer is desirable because it prevents danger from shock. All adjacent metal work also should be grounded as a protection against this danger.

The efficiency of a transformer is equal to the ratio of output to input. The difference between output and input is the amount of the various losses. In well-designed transformers the efficiency may be as high as 94 to 98 per cent, increasing with the size of the unit.

Part 7

RADIO-FREQUENCY RESISTANCE AND INDUCTANCE COILS

The method of measuring the coils of different shapes and of different kinds of wire as used in radio receiving sets is shown in Fig. 53. This method is described in detail in *Bureau of Standards Technologic Paper* 298. The effective resistance R of a coil may be found by direct comparison with a standard variable resistance R_s after the test coil and the condenser C are tuned to resonance. The *apparent inductance* L is calculated by the formula

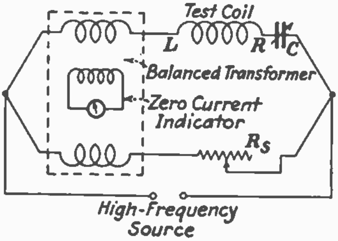


FIG. 53.—Method of measuring characteristics of coils.

$$L = \frac{25{,}350}{f^2C}$$

where the inductance L is in microhenrys, the frequency f is in kilocycles per second, and the measured *resonance capacity* C of the series condenser is in microfarads.

Characteristics of Coils.—The method employed is to compare, at radio frequency, several types of coils commonly used in radio receiving sets, the coils having been adjusted to the same self-inductance at a frequency of 1,000 cycles per second. This value represents the minimum of the apparent inductance, larger values being obtained at the broadcast frequencies. The direct-current resistance is, of course, different for the various coils, since some shapes require more wire than others for the same inductance at 1,000 cycles per second. The function of a coil in a receiving set is essentially to introduce inductance in the circuit, for practical reasons a given amount of inductance being introduced with the minimum possible length of wire and of resistance. On account of the capacity action of a coil the apparent inductance is usually much larger at broadcast frequencies, since the decreased inductance due to skin effect (page 88) is small in comparison. The capacity action of a coil tends to transfer more or less energy across the

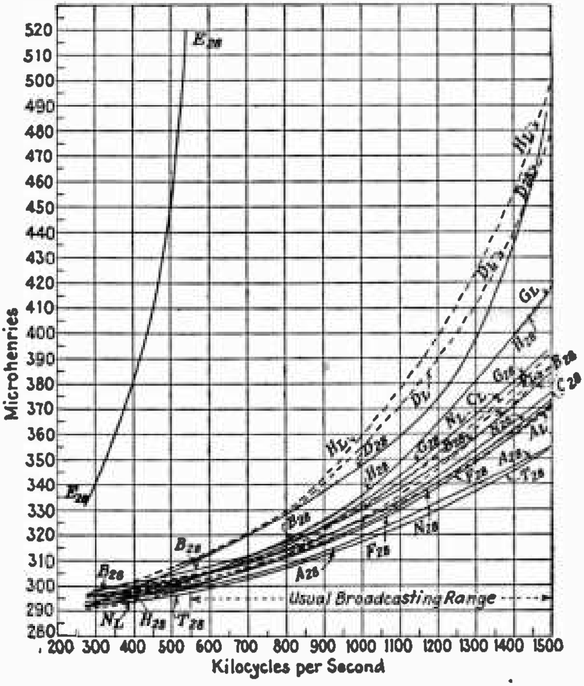


Fig. 54.—Curves for evaluating capacity of coil at different frequencies.

turns than along them, thus changing the effects of the coil with increasing frequency gradually into a condenser, with a resistance which is due to the insulation between the turns.

The quality of a coil can be considered in terms of a number of different properties, each of which is of importance in the use of the coil. For use in the tuned circuits of a receiving set the important characteristics are:

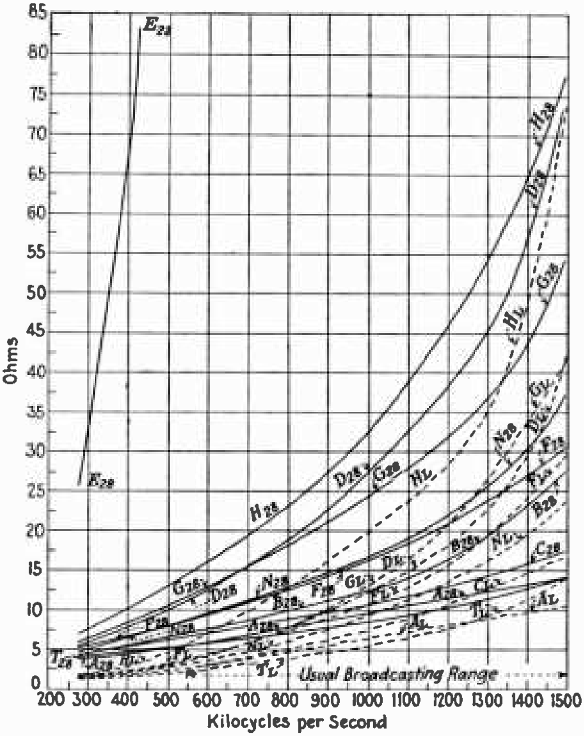


FIG. 55.—Radio-frequency resistance at different frequencies.

1. The radio-frequency resistance. A low rate of resistance at the actual frequencies used is desirable.

2. The magnitude of the ratio of the inductance to the resistance L/R should not be unreasonably small compared with the value obtained at 1,000 cycles per second. This ratio enters into the sharpness of *resonance* (page 83) which a circuit containing the coil would have.

It should be noted that the inductance L denotes here the *apparent inductance*, which is always larger at radio frequencies than at audio frequencies. This value increases very rapidly as the frequency of the circuit approaches the *natural frequency* of the coil; but, unfortunately, the approximate natural frequency of a coil corresponds to a frequency range within which the coil is of little practical value. The *apparent* increase of the inductance L of a coil is mostly due to the capacity of the coil, and this effect is, in general, much larger than the decrease of inductance due to a non-uniform current distribution in a wire or other conductor. There are several natural frequencies of a coil which do not bear definite *harmonic ratios* (page 72) to each other.

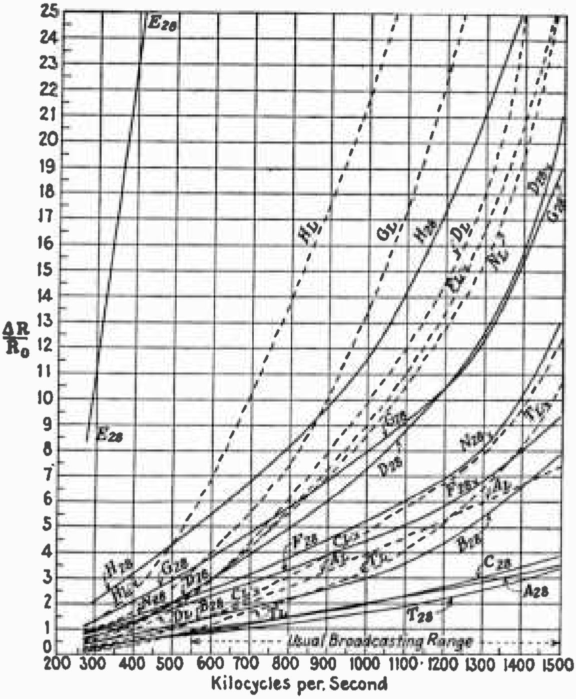


Fig. 56.—Ratio of increase of resistance over its direct-current value to its direct-current value at different frequencies.

3. The percentage increase of radio-frequency resistance to the direct-current resistance. This value should not be unreasonably large.

4. The percentage decrease of the ratio of the inductance to the resistance *L/R* at radio frequencies with respect to the value at audio frequencies at, for example, 1,000 cycles per second. This value should not be unreasonably large.

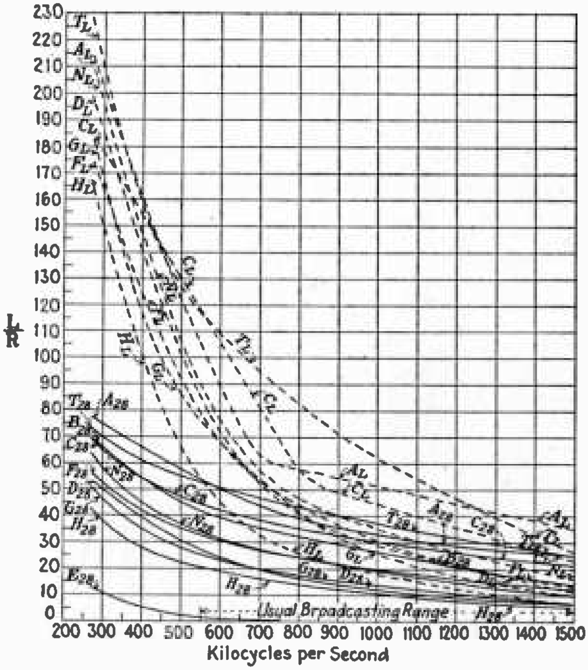


FIG. 57.—Ratio of inductance to resistance at different frequencies.

5. The apparent inductance. This value should not be too large compared with the value at 1,000 cycles per second, because the increase is mostly due to the capacity of the coil.

The above characteristics show certain merits of a coil, for which reason their variations with the frequency of the circuit are plotted in Figs. 54 to 57 and 63. It is of importance that a coil should have a comparatively low radio-frequency resistance if this requirement does not make necessary a shape and size of the coil which is unusually bulky. The curves for the characteristics given in paragraphs 1 and 2, and as shown in Figs. 55 and 57, are therefore of importance for rapid inspection of the results. The curves corresponding to paragraph 5, as shown in Fig. 54, give a means for evaluating the capacity of a coil.

Description of Test Coils.—The comparisons of coils given here apply to those of the so-called "low-loss" type and do not include shapes which are seldom used for radio work at broadcast frequencies. As an exception, an ordinary two-layer coil was measured in order to illustrate the unusual changes taking place in such a coil. The various shapes of test coils are shown in Fig. 58.

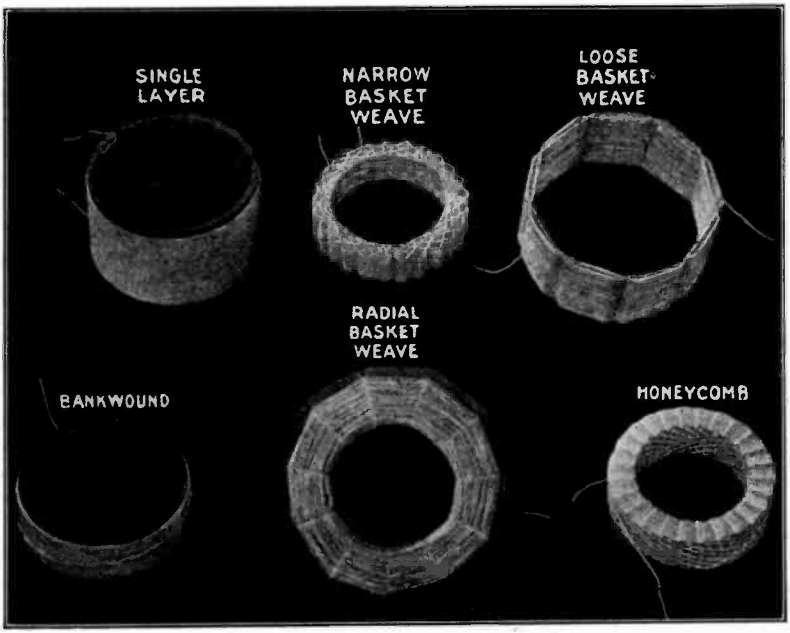


FIG. 58.—Various shapes of test coils.

To establish a basis of comparison, the inductance of all the coils is assumed to be adjusted to 291 microhenrys at 1,000 cycles per second, which is the approximate value of the inductance frequently used in receiving equipment for tuning to broadcast frequencies. For the sake of brevity the different shapes of coils are designated by capital letters, as is shown in the following tables. The kind of wire used is indicated by subscripts. Thus, D_{28} indicates a honeycomb coil using No. 28 American wire gage (A.W.G.) and double-cotton covered (d.c.c.) wire; T_{16} indicates a loose basket weave using No. 16 (A.W.G.) d.c.c. wire; and N_L a two-layer bank-wound (Fig. 59) coil using litz wire. All litz wire in the coils has thirty-two strands of No. 38 d.c.c. wire and corresponds roughly to the cross-section of No. 23 (A.W.G.) wire. In this wire thirty-two No. 38 (A.W.G.) enameled copper wires are braided together. In order to have comparative tests on various binders, six single-layer coils are of the same size as A_{28} and are coated with the materials indicated in the following table, which gives the designations used.

TABLE XIX.—KEY FOR TEST COILS, USING NO BINDER

Kind of coil	Symbol	Kind of coil	Symbol
Single layer	*A*	Two-layer	*E*
Radial basket weave on cardboard	*B*	Narrow basket weave	*F*
Radial basket weave on hard rubber	*C*	Loose basket weave	*T*
Honeycomb	*D*	Bank wound, two-layer	*N*
		Bank wound-three-layer	*G*
		Bank wound, four-layer	*H*

TABLE XX.—KEY FOR TEST COILS, USING BINDER

Binder used	Symbol	Binder used	Symbol
Shellac	K_{28}	Spar varnish	P_{28}
Commercial insulating varnish A	L_{28}	Collodion	Q_{28}
Paraffin	M_{28}	Commercial insulating varnish B	R_{28}

Detailed information of the coils is given in the following comprehensive table. The resistance of a coil at 1,000 cycles per second is, for those given in the table, practically equal to the direct-current resistance. For this reason the direct-current resistance is utilized for evaluating the ratio $L_0{:}R_0$ at 1,000 cycles per second.

TABLE XXI.—DETAILS OF CONSTRUCTION OF TEST COILS

Abbreviations: d. c. c. = double-cotton covered; d. s. c. = double-silk covered; mm. = millimeter.

Coil		Size of wire, A.W.G.	Core	Dimensions of winding, mm.	Direct-current resistance R_0, ohms	$\frac{L_0}{R_0}$ at 1,000 cycles in 10^{-6} henrys in ohms	Remarks
Symbol	Type						
A_{28}............	Single layer	No. 28 d. c. c.	Hard rubber	81 mm. diameter, 31.5 mm. long, about 55 turns	3.15	9.24	
A_{24}............	Single layer	No. 24 d. c. c.	Hard rubber	82 mm. diameter, 45 mm. long about 60 turns	1.44	20.2	
A_{16}............	Single layer	No. 16 d. c. c.	Hard rubber	163 mm. diameter, 67 mm. long, about 40 turns	.28	103.8	With about twice the diameter as A_{28} makes a coil of about the same proportions
A_L............	Single layer	No. 32–38 d. s. c. litz.	Hard rubber	81 mm. diameter, 59 mm. long, about 65 turns	1.25	23.27	
B_{28}	Radial basket weave	No. 28 d. c. c.	Cardboard 1.5 mm. thick, 11 spokes, with slots 2 mm. wide	Inside diameter 65 mm.	3.08	9.45	
C_{28}............	Radial basket weave	No. 28 d. c. c.	Hard rubber 3 mm. thick, 11 spokes, with slots 1 mm. wide	Inside diameter 64 mm.	3.59	8.11	
C_{24}............	Radial basket weave	No. 24 d. c. c.	Hard rubber 3 mm. thick, 11 spokes, with slots 1 mm. wide	Inside diameter 64 mm.	1.65	17.62	
C_L............	Radial basket weave	No. 32–38 d. s. c. litz.	Hard rubber 3 mm. thick, 13 spokes, with slots 2.5 mm. wide	Inside diameter 64 mm.	1.24	23.46	

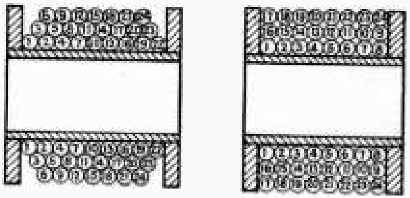
D_{28}	Honeycomb	No. 28 d. c. c.	Air, and just enough collodion to hold coil together	Inside diameter 57 mm.; four diagonal retarded winding; 25 pins 2 mm. in diameter	3.31	8.79	Pins are set on inside diameter and coil builds up along radius
D_{24}	Honeycomb	No. 24 d. c. c.	Air, and just enough collodion to hold coil together	Inside diameter 55 mm.; otherwise as above	1.35	21.55	Pins are set on inside diameter and coil builds up along radius
D_L	Honeycomb	No. 32–38 d. s. c. litz.	Air, and just enough collodion to hold coil together	Inside diameter 55 mm.; otherwise as above	1.11	26.21	Pins are set on inside diameter and coil builds up along radius
E_{28}	Double layer	No. 28 d. c. c.	Hard rubber	Inside diameter 81 mm.	2.75	10.58	Very poor coil
F_{28}	Narrow basket weave	No. 28 d. c. c.	Air, and just enough collodion to hold coil together	Outside diameter 76 mm.; 25 pins of 1.5 mm. diameter; four diagonal retarded winding	2.97	9.8	Pins are set on outside diameter and coil builds up along axis
F_{24}	Narrow basket weave	No. 24 d. c. c.	Air, and just enough collodion to hold coil together	Outside diameter 76 mm.; 25 pins of 1.5 mm. diameter; four diagonal retarded winding	1.30	22.38	Pins are set on outside diameter and coil builds up along axis
F_L	Narrow basket weave	No. 32–38 d. s. c. litz.	Air, and just enough collodion to hold coil together	Outside diameter 76 mm.; 25 pins of 1.5 mm. diameter; four diagonal retarded winding	1.07	27.2	Pins are set on outside diameter and coil builds up along axis
G_{28}	3-layer bank wound	No. 28 d. c. c.	Hard rubber, coil held together by collodion	Inside diameter 81 mm.; length of coil 10 mm.	2.70	10.78	
G_{24}	3-layer bank wound	No. 24 d. c. c.	Hard rubber, coil held together by collodion	Inside diameter 81 mm.; length of coil 14 mm.	1.17	24.87	
G_L	3-layer bank wound	No. 32–38 d. s. c.	Hard rubber, coil held together by collodion	Inside diameter 81 mm.; length of coil 17 mm.	.88	33.06	
H_{28}	4-layer bank wound	No. 28 d. c. c.	Hard rubber, coil held together by collodion	Inside diameter 81 mm.; length of coil 7 mm.	2.46	11.83	

TABLE XXI.—DETAILS OF CONSTRUCTION OF TEST COILS (*Continued*)

Coil		Size of wire, A.W.G.	Core	Dimensions of winding, mm.	Direct-current resistance R_0, ohms	$\frac{L_0}{R_0}$ at 1,000 cycles in 10^{-5} henrys in ohms	Remarks
Symbol	Type						
H_{24}	4-layer bank wound	No. 24 d. c. c.	Hard rubber, coil held together by collodion	Inside diameter 81 mm.; length of coil 11 mm.	1.14	25.51	
H_L	4-layer bank wound	No. 32–38 d. s. c. litz.	Hard rubber, coil held together by collodion	Inside diameter 81 mm.; length of coil 12 mm.	.86	33.85	
K_{28}	Single layer	No. 28 d. c. c.	Hard rubber, using shellac as a binder	Same as A_{28}	3.11	9.36	Used for binder test
L_{28}	Single layer	No. 28 d. c. c.	Hard rubber, using commercial insulating varnish A as binder	Same as A_{28}	3.20	9.09	Used for binder test
M_{28}	Single layer	No. 28 d. c. c.	Hard rubber, using paraffin as a binder	Same as A_{28}	3.14	9.27	Used for binder test
N_{28}	2-layer bank wound	No. 28 d. c. c.	Hard rubber, coil held together by collodion	Inside diameter 81 mm.	2.65	10.975	
N_{24}	2-layer bank wound	No. 24 d. c. c.	Hard rubber, coil held together by collodion	Inside diameter 81 mm.; length of coil 20 mm.	1.25	23.27	
N_L	2-layer bank wound	No. 32–38 d. s. c. litz.	Hard rubber, coil held together by collodion	Inside diameter 81 mm.; length of coil 25 mm.	.95	30.63	
P_{28}	Single layer	No. 28 d. c. c.	Hard rubber, using spar varnish as a binder	Same as A_{28}	3.14	9.27	Used for binder test
Q_{28}	Single layer	No. 28 d. c. c.	Hard rubber, using collodion as a binder	Same as A_{28}	3.11	9.36	Used for binder test

R_{28}	Single layer	No. 28 d. c. c.	Hard rubber, using commercial insulating varnish B as a binder	Same as A_{28}	3.21	9.07	Used for binder test
T_{28}	Loose basket weave	No. 28 d. c. c.	Air, and just enough collodion to hold coil together	9 diagonal alternating winding; 9 pairs of pins set on a circle of 92.5 mm. diameter; diameter of pins 2.5 mm. and small spacing between a pair of pins 10 mm.	3.19	9.13	
T_{24}	Loose basket weave	No. 24 d. c. c.	Air, and just enough collodion to hold coil together	9 diagonal alternating winding; 9 pairs of pins set on a circle of 92.5 mm. diameter; diameter of pins 2.5 mm. and small spacing between a pair of pins 10 mm.	1.42	20.5	
T_L	Loose basket weave	No. 32–38 d. s. c.	Air, and just enough collodion to hold coil together	9 diagonal alternating winding; 9 pairs of pins set on a circle of 92.5 mm. diameter; diameter of pins 2.5 mm. and small spacing between a pair of pins 10 mm.	1.21	24.05	

Figures 59 to 62 show how coils listed in the table are wound. Figure 59 shows the method used for winding a "three-layer bank-wound" coil in comparison with the winding of an ordinary three-layer coil. Figure 60 illustrates how the "narrow basket-weave" coil is made in which the coil is built up along a series of pins, which are removed after the coil is finished. Figure 61 shows the method used in winding the "loose basket-weave" coil, which requires a pair of pins for each corner. The spacing is 10 millimeters between the two pins of a pair. Figure 62 shows the method used in making the "honeycomb" coil. The zigzag winding is illustrated by the view of the entire cylindrical surface. The winding is built up along the radii of the coil.



Three-Layer Bank Winding

Ordinary Three-Layer Winding (Useless for Currents of the Broadcast)

Fig. 59.—Three-layer bank winding.

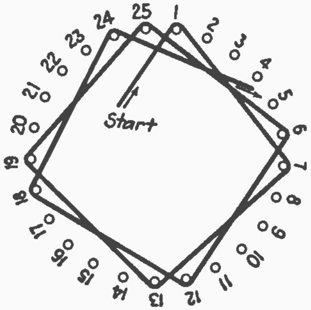


Fig. 60.—Narrow basket-weave winding.

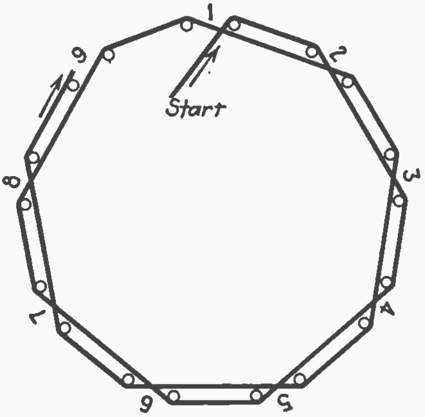


Fig. 61.—Loose basket-weave winding.

Explanation of Results.—Figure 54 shows the curves for the apparent self-inductance of the various test coils as a function of frequency. As on all the curve sheets, the dotted curves indicate the different coils for which litz wire having thirty-two No. 38 strands is used. The loose basket-weave type of coil and the single-layer coil give the lowest apparent inductance over the entire range of broadcast frequencies (500 to 1,500 kilocycles per second). This indicates that the coil capacity is comparatively low, while the ordinary two-layer coil (E_{28}) acts more or less like a condenser, since the coil is exceed-

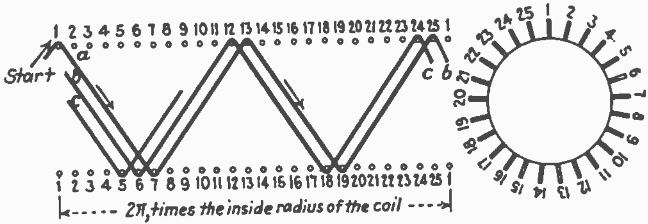


Fig. 62.—Honeycomb coil.

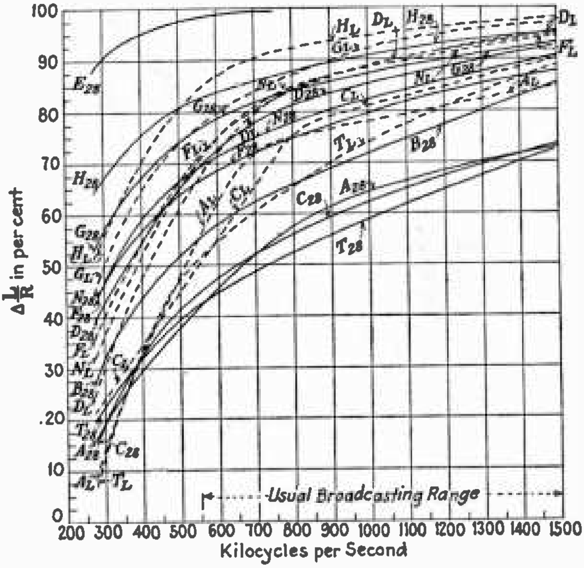


Fig. 63.—Curves for percentage decrease in ratio of inductance to resistance at different frequencies.

ingly large. Figure 55 gives the curves for the radio-frequency resistance of the coils. It is seen again that the values of the resistance vary greatly. Naturally, the ordinary two-layer coil (E_{28}) has very large radio-frequency resistance within the broadcasting range. Though its direct-current resistance is only 2.75 ohms, the effective resistance at 500 kilocycles per second is 162 ohms, at 580 kilocycles it is 465 ohms, and at 748 kilocycles it is 1,800 ohms. The resistance increases very rapidly until it is mostly due to the dielectric resistance across the insulation between the layers. A three-layer coil wound in the ordinary way (ordinary multilayer coil) and adjusted, like all the other coils, to 291 microhenrys at 1,000 cycles per second has a radio-frequency resistance of several thousand ohms at a frequency as low as 400 kilocycles per second. Figure 63 gives the curves for the percentage decrease in the ratio of the inductance to the resistance $L:R$ at different frequencies.

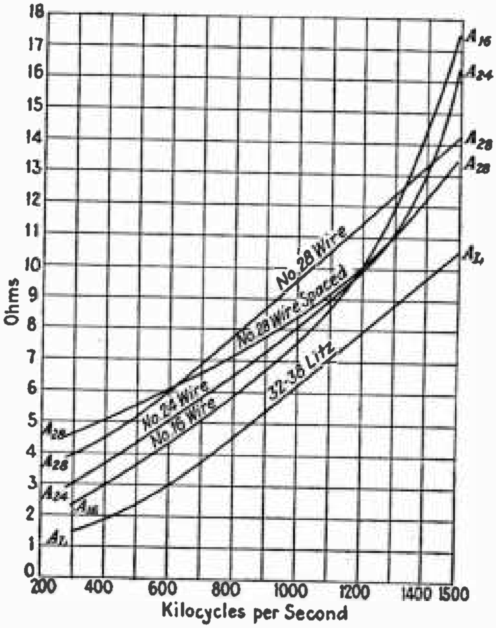


FIG. 64.—Radio-frequency resistance of single-layer coils at different frequencies.

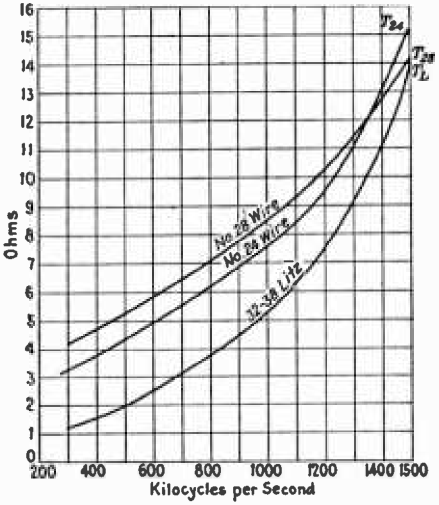


FIG. 65.—Radio-frequency resistance of loose basket-weave coils at different frequencies.

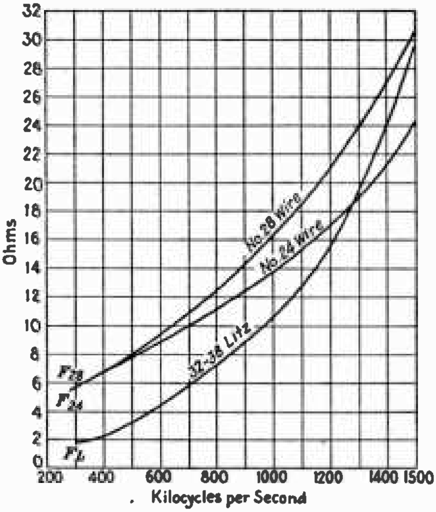


FIG. 66.—Radio-frequency resistance of narrow basket-weave coils at different frequencies.

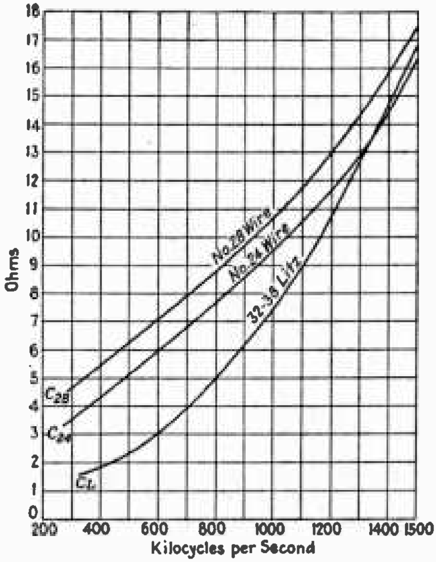


FIG. 67.—Radio-frequency resistance of radial basket-weave coils at different frequencies.

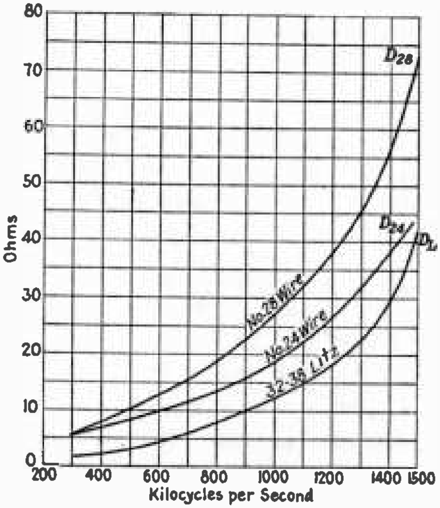


FIG. 68.—Radio-frequency resistance of honeycomb coils at different frequencies.

Effect of Wire Size on Resistance.—In order to show the effect of the size of the wire, curves for the resistance of No. 28, No. 24, and No. 16 d.c.c. wires are plotted and compared with each other and with litz wire which has thirty-two No. 38 strands. These comparisons are shown in Figs. 64 to 71. It will be noted that in all cases the litz wire, which corresponds roughly to No. 23 solid wire as regards its cross-section, has the lowest effective resistance. If solid wire is used, it appears unnecessary to use wire larger than No. 24, although No. 16 gives, for the lower frequencies, resistances which are slightly lower. Such a large size of wire would, however, make the winding of certain types of coils more difficult and the size of the finished coil too large for convenient use in receiving sets. Figure 64 shows a single-layer coil the turns of which are spaced by a distance equal to the diameter of the wire. There seems to be no large reduction in resistance except at the higher frequencies.

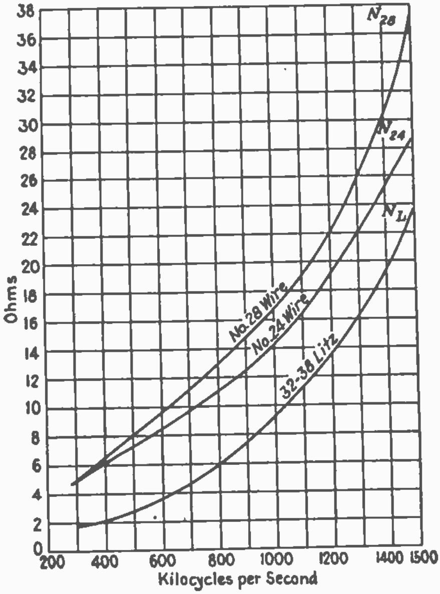


FIG. 69.—Radio-frequency resistance of two-layer bank-wound coils at different frequencies.

Effect of Broken Strands in Litz Wire.—The following table shows that there is no large change in the resistance of a coil of litz wire if a few strands are broken and the broken ends are not joined. The radio-frequency current apparently finds its way back across broken, disconnected strands; even if as many as six strands are broken, the radio-frequency resistance is only 3.4 ohms as compared with 3.1 ohms for unbroken strands.

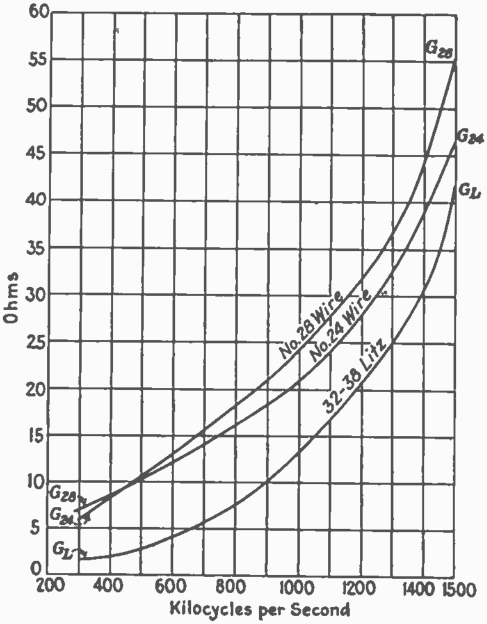


Fig. 70.—Radio-frequency resistance of three-layer bank-wound coils at different frequencies.

Table XXII.—Resistance of Broken Litz Wire (at 750 Kilocycles)

Broken strands	Resistance, ohms	Broken strands	Resistance, ohms	Broken strands	Resistance, ohms	Broken strands	Resistance, ohms
0	3.1	8	3.6	16	5.4	24	9.5
1	3.2	9	3.8	17	5.6	25	10.8
2	3.2	10	3.8	18	6.1	26	13.5
3	3.3	11	4.2	19	6.4	27	14.4
4	3.3	12	4.4	20	7.4	28	16.5
5	3.3	13	4.4	21	7.6	29	21.7
6	3.4	14	4.4	22	7.8	30	42.4
7	3.5	15	4.7	23	8.4	31	51.6

Litz wire used is "32 No. 38" which has thirty-two strands of No. 38 A.W.G. enameled wire braided together.

Effect of Binder on Efficiency.—The binders listed in table XXIII on this page apply to a single-layer coil, just enough of the binder being used to cover the entire surface of the wire. The varying nature of the different binders will probably result in slightly different thicknesses. After the application of the binder the coils should be thoroughly dried. The measurements of resistance are a little difficult when a binder is used, even though great care is taken that the binder is dry. For instance, in some cases the effective resistance of a coil on which a binder is used will be smaller by a fraction of an ohm than the resistance of the coil without a binder. The binder seemed to increase the difficulties of accurate resistance adjustments. The symbols are explained in table XX.

TABLE XXIII.—VARIATION WITH FREQUENCY OF RADIO-FREQUENCY RESISTANCE FOR DIFFERENT BINDERS, OHMS

Frequency, kilocycles	A_{28}, no binder	Q_{28}, collodion	R_{28}, commercial insulating varnish B	L_{28}, commercial insulating varnish A	K_{28}, shellac	M_{28}, paraffin
300	3.9	3.8	3.9	3.8	3.7	3.9
400	4.4	4.3	4.4	4.3	4.1	4.6
500	5.1	4.9	5.0	4.8	4.8	5.2
600	5.9	5.5	5.7	5.3	5.6	6.0
700	6.7	6.3	6.6	6.0	6.6	6.8
800	7.6	7.1	7.5	6.8	7.6	7.8
900	8.5	8.0	8.5	7.7	8.8	9.0
1,000	9.4	8.9	9.6	8.8	10.1	10.3
1,100	10.3	10.0	10.8	10.1	11.4	11.8
1,200	11.3	11.0	12.0	11.5	12.8	13.3
1,300	12.2	12.1	13.3	13.1	14.2	15.0
1,400	13.2	13.2	14.6	14.7	15.7	16.7
1,500	14.2	14.4	15.9	16.4	17.2	18.5

Conclusions.—The various curves in Figs. 64 to 71 can be used for comparing coils of six types at any frequency in the broadcast range. For these data to apply it is necessary that the coils be constructed in accordance with the information given in Table XXI. The dimensions are such that the coils are applicable to modern broadcast-reception equipment. A statement of the important characteristics of the coils is given on page 145.

The curves shown in Figs. 56 and 63 give the changes of resistance and of the ratio of inductance to resistance $L:R$ with changes of frequency. High values of these ratios do not in all cases correspond to high values of radio-frequency resistance. In some cases, for instance, a particular coil has a relatively high value for $R:R_0$, although the actual radio-frequency resistance is not large, because the direct-current resistance is comparatively low. The curves in Figs. 55 and 57 give the actual radio-frequency resistance and ratio of inductance to resistance at various frequencies.

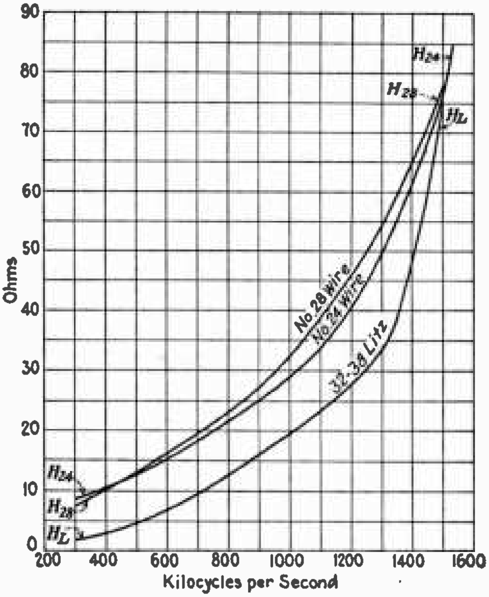


FIG. 71.—Radio-frequency resistance of four-layer bank-wound coils at different frequencies.

Of the coils measured the loose basket-weave coil and the single-layer coil, and next to them the radial basket-weave coil wound on hard rubber, have the lowest radio-frequency resistance. The four-layer bank-wound coil and the honeycomb winding have the highest resistance. This cannot, however, be generalized to other frequency ranges. For instance, for low-frequency sets (20 to 100 kilocycles per second), the multilayer bank-wound coil and the honeycomb coil have relatively low resistances, and they are besides, good coils mechanically, while the loose basket-weave coil has no special advantage and the single-layer coil cannot be used on account of excessive size.

There appears to be little reduction of resistance at the lower frequencies by increasing the length of the spaces between the turns of a coil, so that the advantage of getting a lower resistance is small compared with the disadvantage of requiring a longer coil.

The use of "32 No. 38" A.W.G. litz wire gives coils of somewhat lower resistance than coils wound with solid wire of the same cross-section. Number 24 (A.W.G.) solid wire has less resistance than No. 28 wire, and No. 16 wire, for a certain range, has less resistance than Nos. 24 or 28 wire. If solid wire is used it is not necessary to use wire larger than No. 24 (A.W.G.). This conclusion cannot, of course, be extended outside the broadcast frequency range; for instance, No. 16 solid wire would be better than any of the others for frequencies about 5,000 kilocycles per second.

All the insulating materials which were used as binders cause very slight increases in the resistance of the coils. Collodion seems best and also has the inherent advantage of drying rapidly after its application to the coil. This is of especial advantage in the construction of a bank-wound coil.

SECTION IV

FUNDAMENTALS OF RADIO COMMUNICATION

Radio Waves.—The action of wave motion is well known in everyday life. Thus, water waves are transmitted through water as the medium and are perceived by the eye. Sound waves are transmitted through the air as a medium and are perceived by the ear. Radio waves are transmitted through the ether which is the name given to a medium assumed to be present in space and in all matter. It is supposed that the ether has a very high degree of elasticity and that it can be affected only by electrons. A wave disturbance in the ether travels out from the source in all directions. The radio waves are detected by means of a receiving apparatus designed for this purpose.

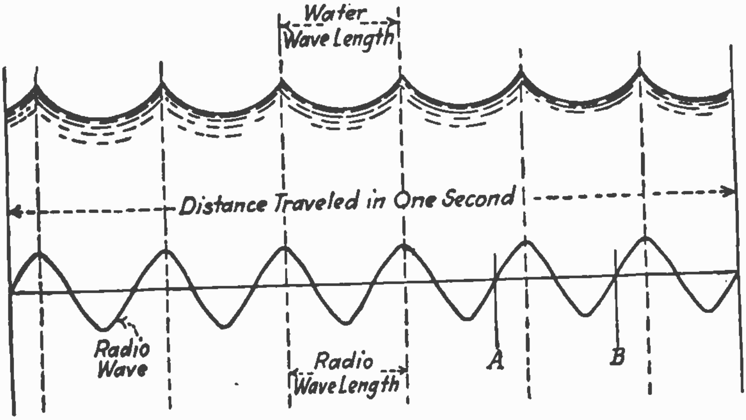


FIG. 1.—Radio waves.

The length of a wave is taken as the distance from the crest of one wave to the crest of the next wave, as shown in Fig. 1. The variations passed through during one such occurrence are said to constitute one *cycle*. The number of these cycles which occur in one second is called the *frequency*, The length of a radio wave is usually expressed in meters. The distance traveled by a wave in one second is its *velocity.*

The relation between wave length in meters, frequency in cycles per second, and velocity in meters per second is

Velocity = wave length × frequency.

The relations given above may be expressed also as

Frequency = velocity ÷ wave length, and

Wave length = velocity ÷ frequency.

The velocity of different kinds of waves varies very much, but any one wave has a definite velocity. Thus, a water ripple may have a velocity of a few feet per second; a long ocean wave has a velocity of thousands of feet per second; a sound wave has a velocity of 1,083 feet per second. It has already been mentioned (page 1) that *radio waves,* light waves, and heat waves are called *electromagnetic waves* and are transmitted at the same *velocity* of 300,000,000 meters per second, or about 186,000 miles per second, but differ in frequency. Obviously, therefore, if the velocity of radio waves (300,000,000) in meters per second is divided by the length of one wave (wave length) in meters, the quotient is the number of "waves" or cycles per second. A "rough-and-ready" rule is that the *frequency in kilocycles per second is obtained by dividing* 300,000 *by the wave length in meters.*

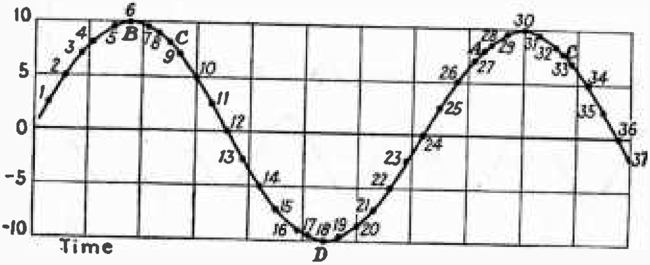


FIG. 2.—Sine wave.

Thus, the frequencies corresponding to wave lengths of 200 and 500 meters are 1,500 and 600 kilocycles, respectively, a *kilocycle* being 1,000 cycles.

The *amplitude of a wave* is its height measured from an average base line (assumed as along the position of rest) to the top of the wave. A wave may have a number of shapes or forms. The so-called *sine wave* is shown in Fig. 2. The *oscillating vacuum tube* furnishes a continuous wave, and a condenser discharging in a "spark" circuit (page 40) gives a *damped wave* (page 90).

In radio communication the electric energy is radiated in the form of waves by a device called an *antenna* (page 82).

Propagation of Electromagnetic Waves.—An electromagnetic wave is accompanied by a radiation field consisting of a *magnetic component* and an *electric component* which are at right angles to each other and travel *in phase* (page 73) at a velocity of 300,000,000 meters per second. The magnetic component of the field travels parallel to the ground, moving back and forth, while the electric component of the field travels in a direction perpendicular to the ground, moving up and down. Both the magnetic and electric components reverse their direction of travel once in each half cycle.

Such waves travel out from their source in all directions with the same velocity but may become modified in several ways. If they enter a space having a different *dielectric constant* (page 55), they are deflected in direction and reflected. Also, an absorption of energy occurs during their passage through any medium. The traveling lines of force (magnetic component), being grounded, are accompanied by earth currents. The lower part of the wave lags behind the upper part because of the resistance of the earth, and consequently the wave front becomes distorted. Such modifications may serve to explain many of the vagaries of radio transmission. It has been observed that the intensity of radio waves does not vary directly as the distance from the transmitter but decreases rapidly at first and then more slowly. A few of the factors which influence this diminution of intensity are the time of year, the geographical location, the character of the surface over which the wave passes, and the hour of the day or night; that is, the energy is lost in several ways such as in the earth's surface, in intervening conductors such as trees and buildings, and by reflection. Another factor causing a drop in intensity is the increasing length of the front of the wave. The length of the wave front is the circumference of a circle with the transmitting antenna at its center. If a given amount of energy is to be distributed over an increasing length of wave front, the intensity of distribution must obviously diminish. The reduction in power of a wave as the distance from the source increases is called *attenuation.*

Types of Radio Communication.—The type of radio communication which is employed determines to some extent the kind of radio wave which is transmitted. Thus, in naval work the type of communication called *continuous-wave* (C.W.) *telegraphy* is used. In this type, the power is supplied to the antenna only when the sending key is depressed and the form of the wave is as shown in Fig. 3. The amplitude of this wave remains constant.

Spark or *damped-wave telegraphy* is employed in other marine work. In this type, a *dash* or a *dot* corresponds to a series of wave trains. The form of each wave train is damped as shown in Fig. 4; that is, the amplitude of each succeeding wave is less than that of the wave preceding it.

In *interrupted continuous-wave* (I.C.W.) *telegraphy*, each dash or dot corresponds to a series of continuous-wave groups as indicated in Fig. 5.

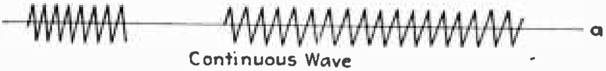


FIG. 3.—Continuous (undamped-wave) telegraphy.

In this type the amplitude of the waves in any group is constant, whereas in spark telegraphy, each wave train is quickly damped from a high amplitude to zero.

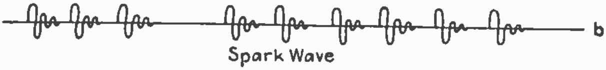


FIG. 4.—Spark (damped-wave) telegraphy.

In *radio telephony* the energy is supplied continuously to the antenna, and a continuous wave is radiated; but its amplitude is varied at a rate which corresponds to the characteristics of the sound wave entering the microphone (page 132). Such a modulated wave is shown in Fig. 6.

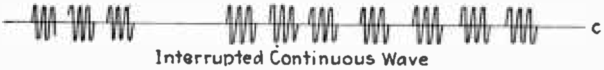


FIG. 5.—Interrupted continuous-wave (dash and dot) telegraphy.

FIG. 6.—Sound modulated wave.

Frequencies Employed in Radio Communication.—A standard wave length of 600 meters or 500 kilocycles has been adapted for merchant marine service. A range of from 5,000 to 20,000 meters, or 60 to 15 kilocycles is assigned for transoceanic service. Naval vessels use wave lengths from 750 to 3,000 or 4,000 meters, or 400 to about 100 kilocycles. Radio broadcasting is carried on from 200 to 550 meters, or from 1,500 to about 545 kilocycles. A number of broadcasting stations use *short waves* in addition to their regular wave length. A more detailed tabulation of the frequency assignments for radio communication is given on page 3.

Propagation of Short Waves.—The term "short wave" has been applied rather indiscriminately to waves less than 100 meters in length. Considerable work has been done in studying the behavior of short waves and particularly those of 60 meters and less. Their peculiar action is illustrated in the chart of Fig. 7 (Morecroft, "Elements of Radio Communication"). It is assumed that the transmitter is rated at 5 kilowatts and that a signal strength of 10 microvolts per meter (elevation of the antenna) is necessary to give an audible signal at the receiver.

The minimum transmission distance or range is apparently for the short waves of about 200 meters. The range of distance increases as the wave length increases above 200 meters and also as the wave length decreases below 200 meters. The greater increase is on the shorter waves and reaches a maximum for waves between 30 and 40 meters in length. Waves under 60 meters in length are audible up to the range indicated in the figure and marked "limit of ground wave"; but for ranges beyond, they are inaudible up to the distances represented by the curves of minimum range. Thus, a 30-meter wave is audible up to about 70 miles and, during the daytime, will not be heard in the region between 70 and 400 miles, which is called the "skip distance." During the daytime the signal would be audible from 400 to about 4,500 miles and, on a winter night, from 4,000 to about 12,000

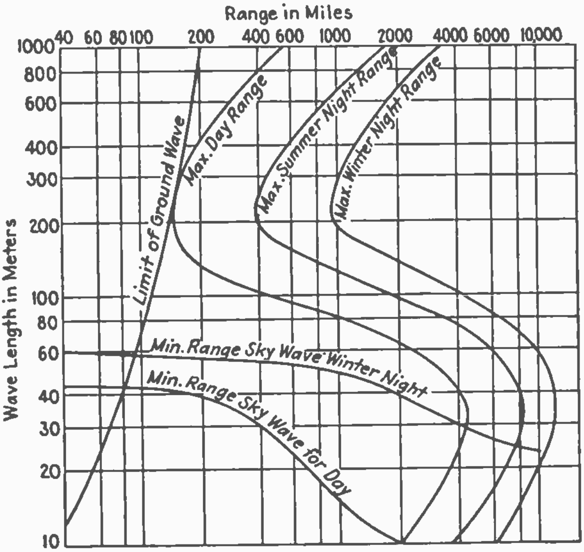


Fig. 7.—Propagation of short waves.

miles. These variations in behavior are considered to be caused by a layer of *ionized air* located several hundred miles above the surface of the earth. The reappearance of the wave is said to be due to a portion of the original wave which is reflected to the surface of the earth from the ionized region of the atmosphere.

For any wave length the skip distance is least at noon and greatest on a night in winter and decreases as the wave length increases. The skip distance depends also on the angle at which the wave is propagated, decreasing as the angle is made larger, up to a certain critical angle, at which it begins to increase again until finally the wave no longer hits the surface of the earth but goes off into space and is called a "space wave."

An antenna which is operated at its *natural or fundamental frequency* (p. 189) radiates a low-angle wave, and one which is operated on a *harmonic frequency* (p. 72) radiates a high-angle wave. The higher the harmonic the higher will be the angle of radiation.

Radio waves which pass around the earth's surface in a direction opposite to that between the transmitter and receiver, or those which pass around more than once, are known as "echo waves."

Classification of Wave Lengths.—At the Hague Conference held in September, 1929, the following nomenclature for the classification of wave lengths was adopted:

Long	3,000 meters up
Medium	200–3,000 meters
Intermediate	50– 200 meters
Short	10– 50 meters
Ultra short	Less than 10 meters

Oscillators for Short-wave Transmission.—Investigations have been carried out along a number of lines to produce electrical oscillations of the shortest possible wave length with vacuum-tube oscillators. Stable oscillations may be obtained with wave lengths as short as two meters by using standard types of tubes and reducing the constants in conventional types of oscillating circuits. Below the two-meter limit standard types of high-power transmitting tubes cannot be used because the dimensions of the tube elements are too large, even though the external oscillating circuit is reduced to the smallest possible mechanical dimension. It is necessary to use for the very short wave lengths, therefore, the low-power tubes, of the 5- or 7.5-watt transmitting type, or else the vacuum tubes designed for receiving sets.

A 201-type tube (page 290) with the base removed and a 0.001-microfarad fixed condenser between the grid and the plate leads as close as possible to the glass bulb can be used in the *ultraudion circuit* of Fig. 8, as a short-wave oscillator for wave lengths as short as one and one-half meters. The oscillating circuit consists of the capacity of the fixed condenser in series with the internal grid-plate capacity of the tube and the inductance of the two short straight wires, each possibly an inch long, making the connections with the grid and plate. The oscillations of this device are not very stable, and the wave length is not variable, since the tuning is fixed largely by the interelectrode capacity (page 303) of the tube. By extending the length of the grid and plate wires and moving the fixed condenser up and down these wires the wave length may be varied and adjusted, but, at the same time, it will be increased in length to two meters or more.

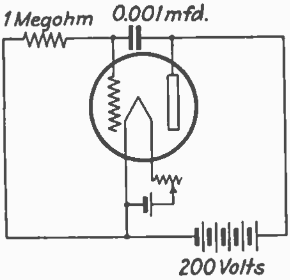


Fig. 8—Ultraudion circuit.

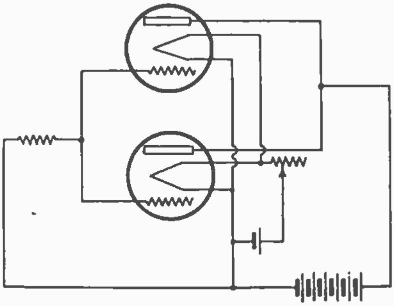


Fig. 9.—Mesny push-pull circuit.

The *Mesny push-pull circuit* shown in Fig. 9 produces more stable oscillations than the ultraudion circuit and allows a greater control than most other devices when short wave lengths are used. The grids and plates of the two tubes are placed in parallel by means of inductances, the central tap of each being connected to the filament. The grid and plate inductances consist of parallel straight wires joined by a so-called *shorting bridge.* Stable oscillations may be obtained with waves which are shorter than one meter. The wave length is varied by sliding the bridges along the grid and plate wires.

Positive voltages are applied to the plates; and grid-biasing (page 36) batteries, grid leaks, or straight wire connections to the filament are used. The wave length is determined by the inductance and capacity in the external circuit and also by the fixed grid-to-plate capacity of the tube. With ordinary vacuum tubes the lower limit attainable is a wave length of about one and a half meters. Although lower wave lengths have been obtained, almost no variation or control of frequency is possible, and the oscillations are sometimes unstable.

In the circuit of Fig. 10 the usual plate and grid voltages are reversed in polarity, a high positive voltage being applied to the grid and a small negative or zero voltage to the plate. This connection produces extremely high frequencies, wave lengths of one-half meter and less being obtained. The oscillations are claimed to occur entirely within the tube and consist of electron vibrations around the grid, the electrons from the filament being drawn at a high velocity toward the positively charged grid. Many of the electrons pass through the grid spaces, are repelled by the negative anode, are again attracted through the grid, and then repeat the process. The frequency of oscillation is determined largely by the time required for the individual electrons to cross the spaces between the electrodes. This of course depends on the applied field, and hence the frequency is affected considerably by the voltages used. There is no external oscillating circuit and the constants of the external circuit do not affect the wave length. The amount of energy radiated is very small.

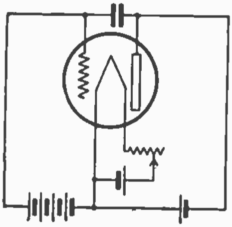


FIG. 10.—Reversed polarity circuit.

Another system for the production of very high-frequency oscillations uses the *magnetron vacuum tube*. *A two-element vacuum tube* (page 283) may be made to generate oscillations under certain conditions. If the anode is a circular cylinder and the cathode is a long straight wire filament at its center, the presence of an electromagnetic field of uniform strength with its direction parallel to that of the filament will prevent the filament electrons from reaching the plate (anode) and force them to move in circular orbits whose diameter is less than that of the cylindrical anode. A minimum wave length of 0.06 meter (6 centimeters) has been obtained. The wave length can be calculated approximately from the formula $W = 2ct$, where c is the velocity of light in meters per second, t is the time in seconds for an electron to travel across the anode-cathode space, and W is the wave length in meters.

Frequency Determination.—The most satisfactory method of measuring short waves is the arrangement devised by *Lecher*. By this method a pair of parallel wires are coupled to the oscillator and so-called *standing waves* are produced. A shorting bridge (page 173) on the so-called "Lecher wires" is adjusted to indicate the position of the *nodes* (page 184) and *antinodes* of the "standing" waves. The wave length is determined by the distances between these points. The indications of nodal points may be obtained by observing the deflection of the plate-current meter in the oscillator.

Reflectors and Beam Systems.—Investigations have demonstrated the practicability of using parabolic reflectors and wave directors on wave lengths shorter than five meters.

Applications of Short-wave Apparatus.—The applications and possibilities of high frequencies of the order of 500 megacycles at present are not established. The fact that the size of a complete directive transmitter and reflecting antenna system is comparable with the dimensions of a large-size searchlight would indicate possibilities in direction finders for navigation purposes.

Medical circles are interested in the possibilities of using intense high-frequency fields for the treatment of certain maladies. Investigations are being carried out on the effect of these frequencies on blood solutions (page 766).

The General Electric Company has developed a 6,000,000-volt oscillator operating at a frequency of 10,000,000 cycles per second, which is intended to raise the temperature of the human body to 105°F. This effect is to be used in the treatment of general paresis, a form of paralysis, which is an after-effect of several diseases.

Kennelly-Heaviside Layer.—The space through which radio waves are transmitted may be considered to be bounded on its lower side by the earth's surface, which has a varying conductivity, and on its upper side, at a distance of about 100 miles, by a region which also is conducting. This upper region, of rarified air, is a conductor because the air is ionized by the sun's radiation. The space between these conducting regions, however, is a good dielectric. The upper region is the *Kennelly-Heaviside layer.*

Certain conducting bodies such as tall steel buildings may absorb as much energy from a radio wave passing over them as to cause a so-called "radio shadow" to be made by the building. In the region of this shadow the intensity of the waves may be so low that no radio signals are received. A steel building also acts very effectively in shielding the interior space of the building from radio waves, the radio-signal strength measured within the building being only a small percentage of that outside.

The portion of a radio wave which travels as a space wave (page 172) is *reflected* at the lower and upper surfaces of the ionized layer of air, just as a light wave is reflected from a shiny surface. Reflected waves sometimes called "sky waves" may meet a *guided wave* in the Kennelly-Heaviside layer and either weaken or strengthen its effect depending on the time and weather conditions. Under the influence of the radiation of the sun, the air becomes partially ionized, so that the boundary of the upper conducting region is less in the daytime than at night. In the daytime, then, the space wave undergoes less reflection, and the guided wave is not increased to any great extent by the reflected portions. When, however, the boundary of the upper region is more definitely marked, as at night, the space wave undergoes more reflection, and the resultant effect of the reflected portions together with the guided wave is to increase the radio signal strength. Certain weather conditions, such as clouds, introduce great irregularities in the boundaries of the layer of conducting air which result in marked variations of the strength of radio waves. Again, when the sunset line passes between the transmitter and the receiver, the boundaries of the air layer are variable and affect the intensity of the radio signals.

Interference.—In a general way, interference with the reception of radio waves may be classified as that caused by (1) other transmitting stations, (2) static and other electrical disturbances, and (3) fading (page 36).

Interference from other stations is being minimized by the use of apparatus which maintains a constant frequency of transmission and, in some cases, by directional transmission and directional reception. Such interference may be classified in three general groups—that due to (1) an oscillating radio receiver, (2) to heterodyne interference, and (3) to code interference. An oscillating radio receiver sets up in its antenna a weak radio-frequency current which, nevertheless, radiates a wave that is strong enough to interfere with radio receiving sets located nearby. *Heterodyne interference* (page 36), which produces a more or less constant whistle, is caused by the interaction of the radio transmission from two stations operating at frequencies less than 10 kilocycles apart. Broadcast stations are assigned frequencies that are not less than 10 kilocycles apart because with such a separation there should be no interference.

Another form of heterodyne interference is due to the effect of a strong local station on a receiving set which has an untuned input (page 37). If the radio waves are strong enough to overload the first vacuum tube in the set, the frequency of the signal which is delivered by the set is twice that of the original. If, then, the receiving set is tuned to this higher frequency, considerable interference from the local station will result. Interference of this kind may be prevented by the use of a *wave trap* (page 96), tuned to the frequency of the local station. A transmitter which generates a harmonic (page 72) produces interference similar to the kind just mentioned except that the interfering frequency exists outside the receiver. The reception of a harmonic is avoided by the use of a wave trap tuned to the harmonic frequency. Interference which frequently is blamed upon harmonics may be caused by waves radiated from conductors near the antenna of the transmitter. Electric line circuits and steel buildings may produce such an effect by the radiation of a wave which has a frequency determined by the fundamental or natural frequency of the antenna. Code interference from radio transmitters on ships is observed occasionally at wave lengths near the upper limit of the broadcast range. A wave trap tuned to the interfering wave length may reduce the code signal to a "level" which is not objectionable. Interference from amateur radio transmitters is seldom experienced, because their range of operation is well below the lowest broadcast wave length.

Static is an electrical discharge of atmospheric origin which occurs at irregular periods and cannot be "tuned out." Radio waves which are weaker than the strength of the static at the time of reception are not intelligible and cannot be amplified, because the static is amplified at the same time and in the same proportion. Static comprises about 10 to 15 per cent of all forms of interference to reception.

In commercial work satisfactory results in the reduction of static have been obtained in some cases by the use of elevated antennas having directional characteristics (page 190), coil antennas (page 189), and ground antennas (page 190). Static is more prevalent in summer than in any other season and occurs less frequently in northern than in the southern latitudes. It has been observed that static produces less interference at high frequencies in the vicinity of 10,000 kilocycles per second than at lower frequencies.

Other electrical disturbances sometimes taken for static are caused by the turning on and off of electric lights, elevator motors, street-car motors, wheels of trolley poles, electric refrigerators, automobile ignition systems, and hundreds of other electrical devices. Methods for minimizing the effects of such interference are considered on page 448.

As yet, no device has been produced which will eliminate entirely the effect of static in reception, or even reduce it to any considerable extent. Most devices which reduce the noise also reduce the radio reception in the same proportion. The exceptions are found in the case of low, short antennas, or buried antennas, which will reduce local static effects.

Fading.—Fading is a variation of the strength of received radio signals at an irregular rate. That is, normal intensity may be maintained for a short while, then the signals may become loud, and finally the intensity may sometimes be so low that no sound at all is heard. These variations occur rapidly within a few seconds, or at intervals of an hour or more.

Several kinds of variations in signal strength may be due to the same causes which are responsible for fading. Thus, in transoceanic communication, there is a marked increase in signal strength when the entire path of travel is in darkness, compared to the strength during a period of daylight. During the day the signal strength is low but quite constant. At night, however, marked variations in strength accompany the increase in strength, but such variations are not considered as fading. Usually, fading is understood to consist of variations in intensity occurring at time intervals of several minutes. In another variety of fading the time interval may be as small as several seconds.

Fading is probably due to the interference between radio waves which arrive at the receiver along different paths. If the different waves are in phase when they reach the receiver, the result is an increase in signal strength. If they reach the receiver out of phase, they may so neutralize each other that the resultant intensity is very low.

Production of Radio Waves.—A wave of any kind may be produced by a body which is vibrating and which can pass on its vibrations to a medium capable of transmitting them. In a radio transmitter the oscillating electric charge of the antenna circuit passes on its oscillations to the surrounding space.

The radiation field which accompanies an alternating current is transmitted by wave motion. The intensity of this field at any distance from the transmitter is inversely proportional to the distance and directly proportional to the frequency.

Even a wire carrying a 60-cycle current radiates a weak electric wave, but to send out any considerable amount of power, both the frequency and the current must be increased. The amount of power radiated is proportional to the square of the current and the square of the frequency.

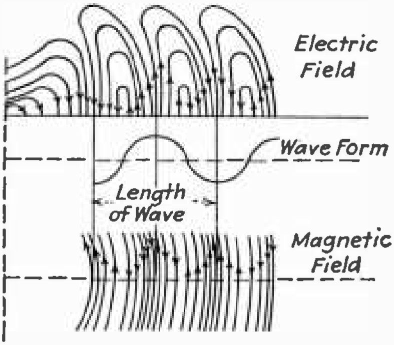


Fig. 11.—Radiation from a vertical antenna.

The action of radiation from a *vertical antenna* is illustrated in Fig. 11. Only half of the wave is produced, because the antenna is grounded. When an antenna is grounded, the resultant circuit has the same wave length as if the antenna is connected to a duplicate of itself. Thus the ground acts like an image of the antenna, and the wave length of the antenna from the free end to the ground is twice that of the antenna itself. That is, when the ground connection is removed, the wave length of the antenna is halved. The figure shows an elevation of the electric component (page 169) of the field, a plan view of the magnetic component (page 169) of the field, and the form of the wave. The magnetic field is parallel to the surface of the earth, while the electric field is perpendicular to it. When the wave has progressed some distance from the antenna, the lines of force may be considered as sections of planes. They may then be represented as in Fig. 12, which shows the electric component of the field and can be made to show the magnetic component also if the drawing is swung through an angle of 90 degrees about the horizontal base line. Both the magnetic and the electric components of the radiation field reverse as the current reverses. When the radio waves travel over an imperfect conductor, the electric lines of force are distorted as shown in Fig. 13.

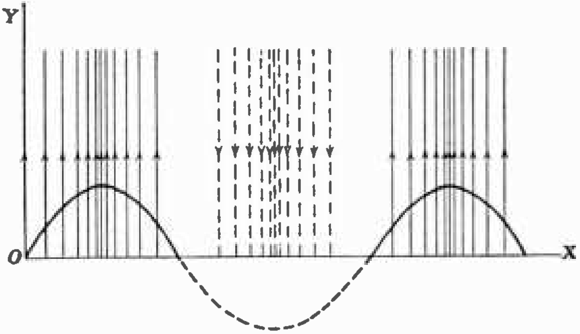


Fig. 12.—Electric component of radiation field.

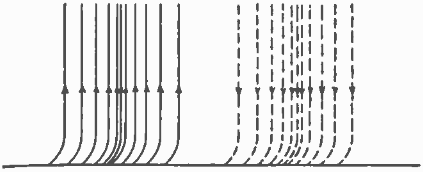


Fig. 13.—Distorted electric lines of force.

Action in Reception.—A simple explanation of the action of an antenna in radio reception is based on the principle that a voltage is induced in a wire when a magnetic field moves across the wire; that is, when the magnetic field of a radio wave moves past the antenna, a voltage is induced in the antenna and causes a flow of current.

Antennas.—The antenna is a necessary part of the apparatus for the reception or radiation of radio waves. Although a vertical-wire antenna is the most efficient form for radiation, it is limited to low values of current, because at high voltages the corona discharge (page 53) at the top of the wire dissipates considerable energy. There are difficulties also in the erection of a vertical wire which has sufficient inductance. The use of the condenser type of antenna avoids these difficulties. The general type which acts as a condenser is called simply an *antenna*, and the type which acts as an inductance is called a *coil antenna* or *loop*.

An antenna of the *condenser type* might consist of two parallel metal plates, but since the amount of energy radiated or received depends on the capacity of the system, such an arrangement would be expensive and bulky. A modification of this construction might consist of one metal plate elevated over the ground and parallel to it, the conducting surface of the earth acting as one of the condenser plates. It has been found, however, that an antenna of horizontal or inclined wires produces the greatest capacity for a given amount of metal. The capacity is determined by the number, length, and spacing of the antenna wires and their height above ground.

In certain cases, as when a good ground connection is not available, or when no variation of capacity can be tolerated, a *counterpoise* is used with the usual antenna but with no connection made to the ground. The counterpoise consists of a wire arrangement, similar to that of the antenna, located several feet above and insulated from the earth. Sometimes the wires of the counterpoise are joined by a system of connecting wires. The ground area covered by the counterpoise should be at least as large as that of the antenna.

When a counterpoise is used with an antenna, the electrostatic field is not confined between the two; actually the fields from both the antenna and the counterpoise act through the earth as a medium. The counterpoise is considered to be another antenna of large capacity and low height, and hence there is a voltage between it and the ground. The counterpoise when used is connected to the "ground" terminal of a receiving set.

A well-designed ground system or a counterpoise is necessary to avoid the concentration of earth currents with the resulting energy loss. It is apparent that lines of static force are set up between the antenna and the ground. The lines which pass through the air do not induce a current and hence do not cause an energy loss. But the lines which must pass through a conductor in order to complete the path from the antenna to the ground will set up currents and should be provided with paths of low resistance to reduce the energy loss to a minimum. A wire-network ground system or a slightly elevated counterpoise both serve to distribute the lines of force so that they enter the earth with no concentration.

Types of Antennas.—The type of antenna used depends somewhat on the frequency of the radio waves, the length decreasing as the frequency increases. Many broadcasting stations use a transmitting antenna consisting of a vertical wire which is several hundred feet in length connected at the middle point to a short single horizontal span, from 100 to 200 feet long. For short-wave, high-frequency work, at frequencies of thousands of kilocycles, only a vertical wire antenna is used with a small coil halfway along its length which is coupled to the oscillating circuit (page 91) of the transmitter. A transmitting antenna acts electrically in the same manner as a receiving antenna but the difference in the amount of power is so great that their physical characteristics vary considerably.

The characteristics of the receiving antenna depend on the degree of radio-frequency amplification of the receiving set and the distance from the transmitter. A receiver with several radio-frequency stages will give good pick-up from a station within about 50 miles on a short single-wire antenna 15 to 25 feet high. If the radio-frequency amplification is weak, and if the transmitter is at a considerable distance, the antenna wire should be 100 to 150 feet in length and located as high as possible. An indoor antenna is somewhat less effective than an outdoor one but gives satisfactory results. Reasonable reception is possible even with an antenna placed along the picture molding of a room, but a loop antenna does not give sufficient volume unless the receiver has several stages of radio-frequency amplification, or unless the transmitter is within 15 miles.

Several types of antennas which have met with favor are shown in Fig. 14. Special forms for amateur and short-wave transmitters are described in the section dealing with short-wave transmission.

The *T type antenna* is used commonly on ships. The lead-in (page 37) is taken off at the midpoint of the span. The natural wave length of this type is nearly one-half that of an inverted *L antenna* of the same length. The advantages of this type are that its construction is simple and it can be designed for large stresses. The *inverted L type* is the one most generally used and found on many of the smaller ships. The lead-in is taken off at one end. This type, like the T antenna, has the advantage of simplicity of construction, ease of erection, strength, and low cost.

The *umbrella type* has been used at shore stations and for portable work in government field service. The outstanding feature of this type is that only one support is required.

The *cage* or *hoop type* is similar to the L and T antennas, and the lead-in is taken off in the same manner. The wires in the span, however, are spaced at equal intervals around a hoop instead of along a straight spreader.

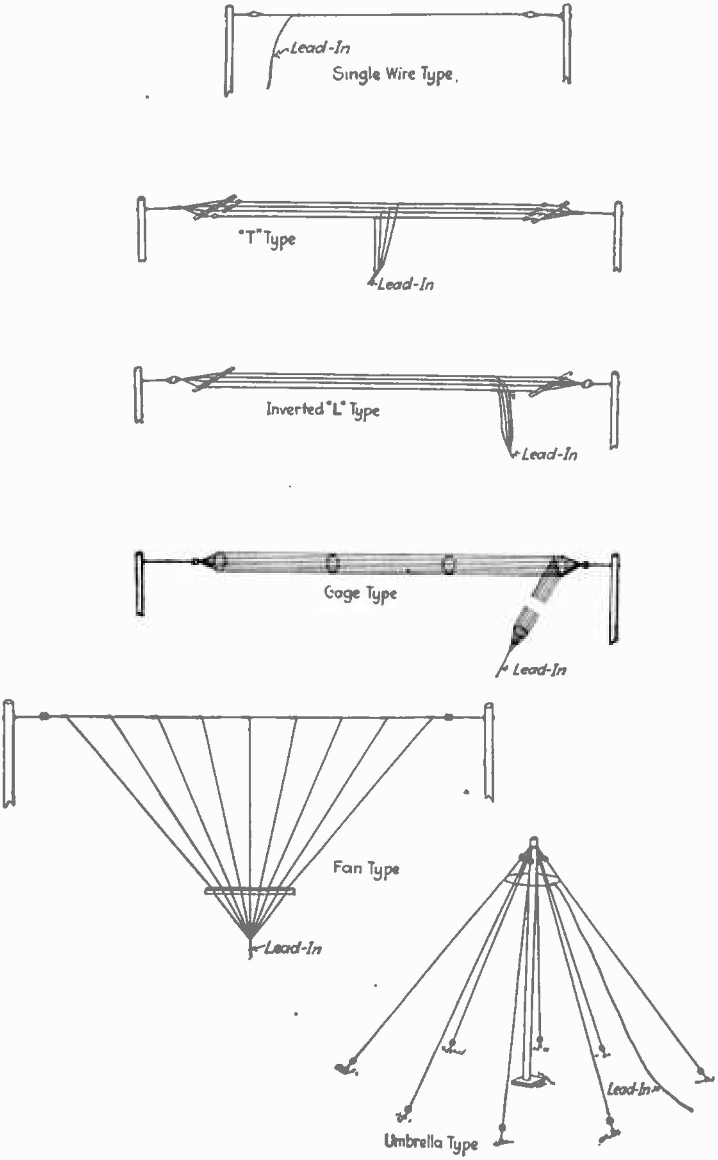


FIG. 14.—Types of antennas.

When the same antenna is used for both transmission and reception, the lead-in is brought to a transfer switch which connects the antenna system to either the transmitter or the receiver.

The multiple-tuned antenna has been developed to avoid the concentration of lines of force at the ground connection (page 82). A ground system providing short paths for the ground currents is obtained, as shown in Fig. 15, by placing along the antenna a series of coils through which the antenna current may flow. The coils are tuned so that the total reactance of the parallel paths is equal to the value required for a given wave length. This type of antenna has a marked directional characteristic.

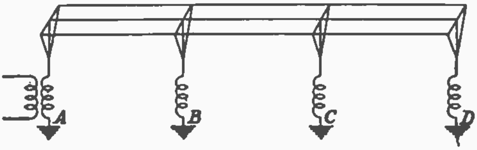


Fig. 15.—Multiple-tuned antenna.

The *Beverage* single-wire antenna provides a "resonant" antenna circuit in which a maximum value of current will flow at a given wave length. In this type the length of the horizontal portion of the antenna is made equal to the wave length of the signal, or a multiple thereof. The resonant circuit is obtained by grounding the far end of the antenna through a resistance equal in value to the impedance of the horizontal portion.

Beam Transmission.—The search for a type of antenna more directive than the multiple-tuned form led to the development of beam transmission, particularly for waves under 100 meters in length. The engineering difficulties involved in the production of a radio *wave beam*, on account of the large size of the reflector required, limit the method to short waves. This method is based on the use of a beam antenna (utilizing the principle of reflection), which consists of many vertical wires set up in the form of a *parabola*. When the transmitter is located at the focus of the parabola the radiated waves are reflected from the vertical wires in the form of a beam confined in a cone having an included angle of from 8 to about 15 degrees, depending on the arrangement and number of the wires. One advantage of beam transmission is that the wave amplitude is reduced only by the absorption of energy in the medium or in a reflecting surface, and not also by its distribution in space, as is the case with a wave transmitted spherically.

Antenna Current and Voltage.—The capacity of an antenna is not concentrated but is distributed, and each small portion of the antenna may be considered as forming a small condenser with the earth as the other plate. As electricity accumulates along the antenna wire, displacement currents will flow from the wire through the dielectric (air) to the earth, as indicated in Fig. 16. At the free end of the antenna the value of the current is zero, and at the grounded end it is a maximum. The voltage, on the other hand, has a maximum value at the free end of the antenna and zero at the grounded end. A large value of capacity concentrated in a part of the antenna results in an increased current in that part. Thus, the advantage of a long flat-top antenna is that the strength of current flowing to a radio receiver is increased.

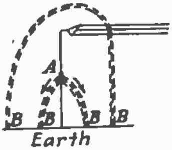


FIG. 16.—Displacement currents from antenna.

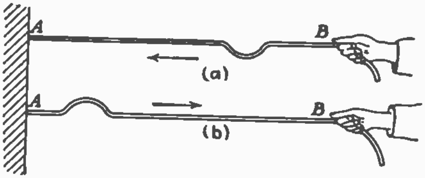


FIG. 17.—Oscillations of rope (traveling waves).

Harmonics.—The behavior of a rope which is oscillating will serve as an introduction to the action of an oscillating antenna. If a rope is shaken as shown in Fig. 17, a wave form will travel along the rope to the wall and back to the hand. If the rope is shaken slowly at a rate which corresponds to its mechanical period, the wave form appears as in Fig. 18. This vibration is the *fundamental wave*, or *first harmonic.* The portion of the wave from A to B consists of one-half of a cycle, and the *wave length* is equal to twice the length AB of the rope. It is apparent that no motion takes place at A and B where the rope is held and that the motion is greatest at point C. Points A and B are called the *nodes* of vibration, and point C is called the *loop.*

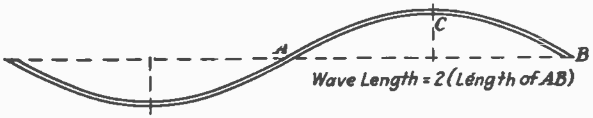


FIG. 18.—Oscillations of rope (fundamental waves).

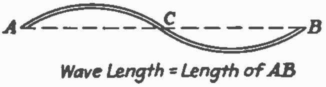


FIG. 19.—Oscillations of rope (second harmonic waves).

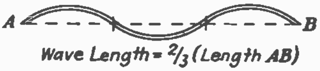


FIG. 20.—Oscillations of rope (third harmonic waves).

If the frequency of the motion imparted by the hand is doubled, the wave form appears as in Fig. 19, with nodes at *A*, *B*, and *C* and a loop on each side of *C*. The position of the loops changes as the wave travels back and forth. This vibration, called the *second harmonic*, has a frequency which is twice that of the wave shown in Fig. 18 and a wave length which is one-half of that of the other.

The *third harmonic* has the form of Fig. 20 in which there are *four nodes* and *three loops*. The wave length is equal to two-thirds the length of the rope.

Vibrations produced in a stiff spring, fastened at one end, have a wave form like that of Fig. 21. A node occurs at point *B*, and a loop at point *A* which is free to move. The portion of the curve from *A* to *B* is one-quarter of a cycle, and the wave length of such a vibration is equal to four times the length *AB*.

The voltage distribution curve for a *sine wave* on a vertical antenna, as shown in Fig. 22, is like that of Fig. 21. The grounded end of the antenna corresponds to point *B* of the spring, and the free end to point *A*. No voltage variation can take place at the grounded end and consequently a node occurs there, with a loop at the free end. Although theoretically the wave length is four times the length *AB*, the actual wave length is about 4.5 times the antenna length because of the effect of the electrical characteristics of resistance, inductance, and capacity.

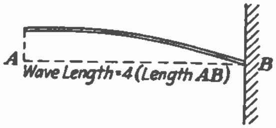


FIG. 21.—Vibrations in spring.

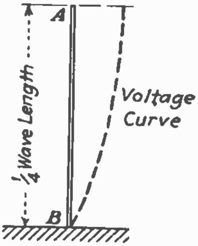


FIG. 22.—Sine-wave voltage distribution on vertical antenna.

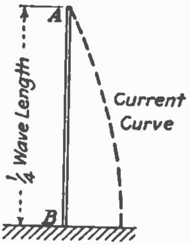


FIG. 23.—Sine-wave current distribution on vertical antenna.

The curve of current distribution, as indicated in Fig. 23, is opposite to that of the voltage and has a node at the free end with a loop at the grounded end.

The third harmonic, shown in Fig. 24, has a wave length which is one-third that of the first harmonic, or fundamental. In terms of the length of the antenna, the wave length is equal to four-thirds the length *AB*, or, conversely, the antenna length is three-quarters of the wave length.

Voltage curves of the second harmonic, for two types of vibration, are shown in Fig. 24a. The wave length is equal to twice the antenna length. By comparison with Fig. 22 it is seen that the second harmonic wave length is half that of the fundamental. In one of the curves there is a node at each end of the antenna and in the other curve there is a loop at each end. This means that the antenna must be grounded at each end, or free at each end. Since this is not possible, it is evident that oscillations at the second harmonic or any harmonic of an even number, cannot take place. An antenna which is free at one end and grounded at the other can oscillate only at the fundamental and at the odd-number harmonics having a wave length of one-third, one-fifth, one-seventh and so on, of the fundamental.

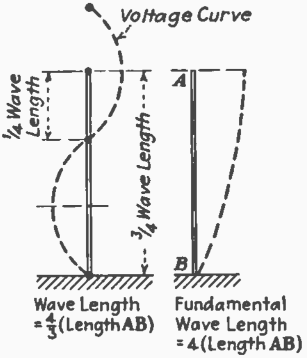


FIG. 24.—Third-harmonic voltage distribution.

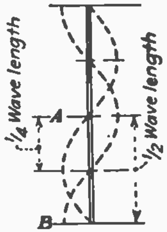


FIG. 24a.

Characteristics of an Antenna.—The length of waves radiated from an antenna depends on its capacity and inductance. The power which may be supplied to an antenna is proportional to its capacity, to the square of the charging voltage, and to the number of charges per second. The supply of power may be increased by increasing the capacity, raising the voltage, or increasing the number of charges per second. The limiting value of the voltage is determined by leakage and brush discharge; and, likewise, there is a definite maximum limit for the number of charges. The effectiveness of an antenna as a radiator of energy increases with its height because of the larger dielectric between the antenna and the ground, which produces a greater electrostatic field. Actually, the increase in the length of the lead-in wire (page 37) limits the height that can be used.

The antennas of high-power stations have a large capacity and consist of many long wires. The capacity of a wire is proportional to its length, but the capacity of a multiwire antenna is less than the sum of the capacities of the wires considered separately. In general, the capacity of antennas is of the same order as that of the usual variable air condenser. Antenna capacities range in value from a few hundred micromicrofarads for a small antenna to ten or fifteen thousand for a large transmitter. The *Austin formula* for the capacity of a flat-top antenna, not including the capacity of the lead-in wire, is

$$C = 40\sqrt{A} + 8.85\frac{A}{h}$$

where C is the capacity in micromicrofarads, A the area of the flat top of the antenna enclosed by the bounding wires in square meters, and h the average value of actual height of the antenna above ground in meters.

For a long antenna which has a *length* l greater than eight times the width W, this formula must be multiplied by a factor equal to $\left(1 + 0.01\frac{l}{W}\right)$.

The inductance of antennas may be from 50 to 100 microhenrys. Sometimes a loading coil (page 37) is inserted in the lead-in wire to tune the antenna system to a certain wave length. The wave length in meters of a loaded antenna is given by the formula

$$W = 1{,}884\sqrt{\left(L + \frac{L_0}{3}\right)C_0}$$

where L is the *inductance* of the loading coil in microhenrys, $L_0/3$ the inductance of the antenna at all frequencies in microhenrys, and C_0 the capacity of the antenna at all frequencies in microfarads.

The total resistance of an antenna is made up of several different parts. The total power supplied is dissipated in the (1) ohmic resistance, (2) dielectric resistance, and (3) radiation. The power used in overcoming the ohmic resistance is lost as heat in the antenna, the ground wire, and the antenna condensers. The power used up in the dielectric is lost as heat in the dielectric around the antenna, in that of the condensers, and in adjacent imperfect dielectrics such as guy wires, metal masts, metal stacks, and trees.

The total resistance of an antenna is taken as equal to the power supplied to the antenna, divided by the square of the antenna current; that is,if I is the current in amperes measured at the base of the antenna, and R is the total resistance, then the power P in watts supplied to overcome antenna resistances is I^2R, or $R = P \div I^2$.

The radiation resistance depends on the frequency of operation as well as the physical characteristics of the antenna, being a maximum at the fundamental or natural frequency and decreasing sharply at frequencies lower than the fundamental.

The power used in overcoming the radiation resistance determines the radiating power of the antenna. A measure of the efficiency of the antenna system is given by comparing the relation of the power supplied to the power radiated. By finding this ratio at various operating frequencies it is possible to determine the most efficient frequency for radiation.

The change in total resistance of an antenna as the wave length is varied is shown in Fig. 25. Curve 1 shows that the radiation resistance decreases as the wave length is increased, since the radiation resistance is proportional to the square of the wave length. Curve 2 shows that the ohmic resistance is approximately constant over the entire range of wave lengths. Curve 3 shows that the resistance of the dielectric increases directly as the wave length. If the dielectric losses are small, the curve 4, which is the sum of curves 1, 2, and 3, will drop gradually beyond the point *A* instead of rising as shown in the drawing. The effective resistance of an antenna on land may range from a minimum of about 5 ohms, to as much as 30 ohms at the fundamental (page 172) frequency.

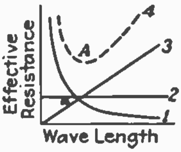


FIG. 25.—Change in antenna resistance with wave length.

The advantage of a *multiwire antenna* is that the effective resistance is reduced by using several wires instead of one, and the ratio of antenna capacity to inductance is increased. The spacing of the wires should be at least 0.02 of the span. Methods of measuring antenna resistance, capacity, and inductance are described on page 639.

Radiated Power.—The effective watts of radiated energy *W* supplied by a transmitter are given by the following equation assuming a uniform distribution of current which is equal in value to the maximum current obtained in an actual antenna:

$$W = \frac{1{,}600h^2 \times I^2}{l^2}$$

where *W* is the radiated energy in effective watts, *l* the wave length of antenna in meters, *h* the effective height of antenna in meters, and *I* the maximum current, or current at the base of the antenna in amperes.

An accurate determination of the radiated power necessitates the consideration of the *antenna form factor* which takes into account the physical characteristics of the antenna. Generally the *output of a transmitter* is expressed in terms of *meter-amperes*, which is the product of the effective height of the antenna in meters and value of the raido-frequency current in amperes in the antenna at its base.

Wave-length of Antenna.—An antenna operates at its fundamental wave length when no inductance or capacity is added to the antenna circuit. The *fundamental* or *natural wave length* of an antenna depends on its shape, the number of wires, and their length and height. The wave length of the waves radiated by an antenna is increased by the addition of inductance (loading coil) and is decreased by the use of a condenser in series with it.

As the capacity is reduced, its reactance increases, until at zero capacity the reactance is infinite and corresponds to an open circuit. It has been shown (page 178) that the wave length is halved when an antenna is ungrounded or opened. It follows then that the wave length of an antenna cannot be reduced to less than half the fundamental wave length by the use of a series condenser. The use of the condenser is objectionable because it decreases the overall capacity of the antenna and hence the amount of power which can be supplied.

An approximate *calculation* sometimes used is that the *fundamental wave length* of an antenna in meters is somewhat more than four times the length of the wire. This relation applies to a *vertical*-wire grounded antenna and also to a *flat-top* antenna, if the length is measured from the transmitter or receiver along the lead-in to the end of the flat top. An easier and more accurate measurement of fundamental wave length, however, is obtained by the use of a *wave meter* (page 111).

The fundamental frequency of an antenna is the lowest at which the current reaches a maximum with no loading inductance (page 37) or capacity. If this frequency is designated as *f*, the antenna has other resonant frequencies at values of 3*f*, 5*f*, 7*f*, and so on, which are called *harmonic frequencies*. Ordinarily an antenna radiates only the waves having a frequency equal to that of its fundamental wave length, but if a voltage which has harmonic frequencies is applied to an antenna, the harmonics may also be radiated.

Directional Effect of Antenna.—A simple *vertical-wire antenna* has no directional effect, but an antenna with a long, low top transmits and receives best in a direction *opposite* to that in which the top of the antenna points.

The *loop or coil antenna* is more directional than any other type. The strongest signal is received when the transmitter being received lies in a direction along the plane of the coil. This characteristic is applied in the operation of a *direction finder* as described on page 789. The actual direction characteristic, however, is distorted because of the effect of the capacity which exists between the loop and ground. As a result of this distortion the position of the weakest signal is not exactly at right angles to the plane of the loop.

Antenna Construction.—Wooden, latticed metal and tubular metal telescoped *masts* may be used as the supports of a transmitting antenna, the type depending mostly on the size of the installation. Guy wires or ropes are usually needed, but such masts should have some freedom of movement. A single-wire antenna for a receiving set needs no special form of support, but if it is swung from a tree the end of the antenna itself should be kept well away from the tree. The wires of a ship antenna are usually stretched between two spreaders which are fastened to the masts of the ship. Each end of an antenna must be insulated from its support by means of suitable insulators such as those described on page 123. The supporting masts of high antennas must also be insulated from the ground. In general, a satisfactory insulator must have adequate mechanical strength as well as good dielectric (page 53) properties. The importance as well as the difficulty of suitable antenna insulation for high-power stations is apparent, of course, because of the high voltage used, which may be over 50,000 volts. The *lead-in wire* should be soldered to the antenna wire and located away from adjacent conductors such as walls of buildings and pipes. All connections in the antenna and ground systems should be soldered to avoid *corrosion* which offers a high resistance to the weak radio current.

An antenna wire must have good tensile strength, low ohmic resistance, light weight, durability under weather conditions, and a reasonable cost. Some materials which have been used are aluminum, galvanized iron or steel, steel coated with copper, enameled solid copper, and enameled stranded copper. For an ordinary antenna the enameled solid or the stranded copper wire is satisfactory.

The *ground connection* may be made to a water pipe, gas pipe, or radiator pipe. On ships the ground connection is made to the steel hull or to a large copper plate placed below the water line. If an insulating compound is used in making the joints in a pipe line, the electrical path to the ground is interrupted and a good ground connection is not obtainable unless made at a point where the pipe line joins the underground system. Under some conditions it is necessary to run ground wires to one or more metal plates buried in the ground. The plates should have an area several times the projected area of a multiple-wire antenna and may be arranged in a circle around the transmitting station. A *counterpoise*, used instead of a ground connection, as described on page 35, must be taut and well insulated from its supports. In aerial communication the ground connection is made to the metal frame of a motor, an engine, or a supporting structure.

A *ground antenna* usually consists of a single wire, with an insulating and moisture-proof covering such as rubber, located on the surface of the ground or buried about 6 to 12 inches, or under water. With a ground antenna, reception is due to that portion of the radio wave which penetrates the ground. Although the power received by a ground antenna is much less than that received by a raised antenna, this form of construction has several advantages. It has a *directional characteristic* such that the signal is strongest when the wire points in the direction of the wave travel. Also, the ratio of signal strength to atmospheric static is greater than for an elevated antenna. For transmission, however, there is not much advantage in its use.

Care of Antenna.—The *insulators* of an antenna should be cleaned at least twice a year, and more frequently if the location is in a sooty, smoky district. At this time it is advisable to examine the system for loose nuts, frayed wires, and rusted parts.

Field Strength.—The intensity or strength of a radio wave is taken as the intensity measured in volts per meter of the electric field, which is approximately perpendicular to the surface of the earth. The strength of the field measured within several miles of a transmitter is of the magnitude of thousandths of a volt per meter, and at distant points may be so small as millionths of a volt per meter. An explanation of the term *volts per meter* may be made by a consideration of the field of a charged condenser. In a two-plate condenser, charged to a voltage of say 0.001 volt, with the plates separated a distance of 0.01 meter, the electric field between the plates has a strength of 0.001 volt in 0.01 meter, or 0.1 volt *per meter of height*. Thus, the field intensity of a transmitter may have a value of 10 millivolts at a distance of 10 miles. Then the energy acting upon a receiving antenna 5 meters in height is 5 × 10 or 50 millivolts.

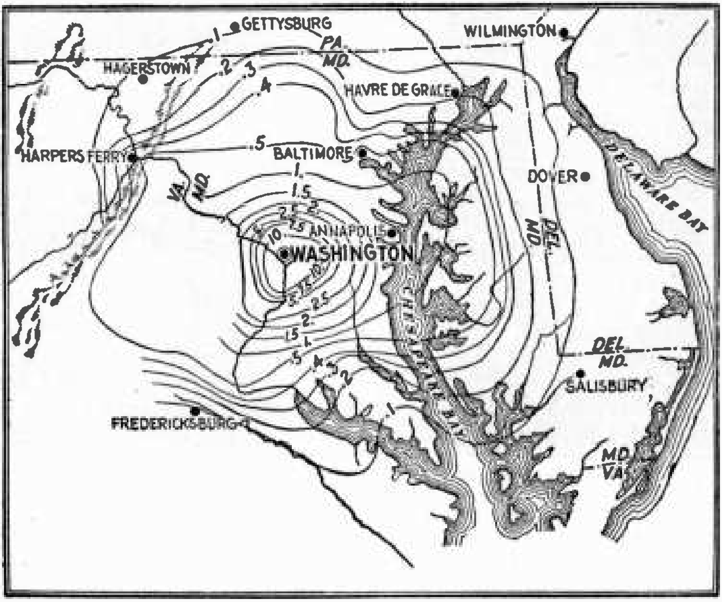


Fig. 26.—Map showing lines of equal signal strength.

The map shown in Fig. 26 and the radio air chart in Fig. 27 indicate the lines of equal signal strength; that is, all points at which a certain intensity—for example, 100 millivolts per meter—is observed are connected by the line marked "100." In order to obtain the data for such a map, a portable measuring device is taken over the region surrounding the transmitter and values of field strength are observed at many points. The map shows clearly how rapidly the field strength decreases as the radio waves pass over the section of the city occupied by high buildings of steel construction. The elongation of the curves over a region of water indicates a less rapid drop in intensity. By means of the information obtained from studies of this kind it is possible to determine the best location for a transmitting station which is to serve a certain area.

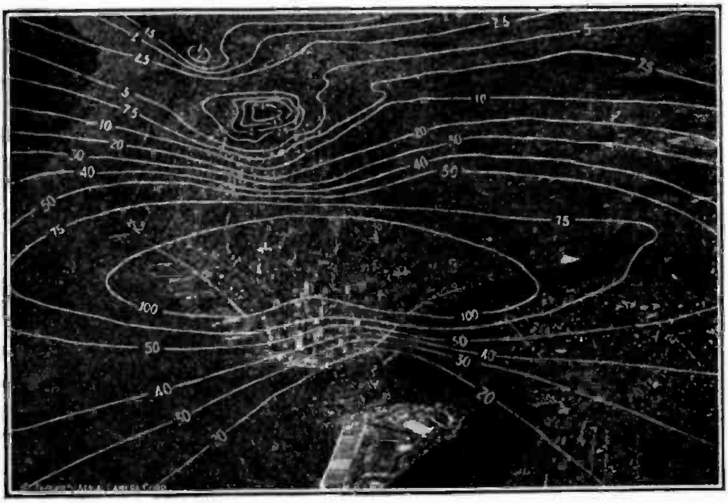


FIG. 27.—Radio air chart of New York City.

A field intensity of about 5 millivolts per meter of elevation of the "receiving" antenna gives loud volume on a good receiving set, and an intensity of 1 millivolt may be taken as the minimum for satisfactory volume above the "static level." An intensity of a few microvolts, however, is not strong enough to bring the volume of the signal above the "static level," which may have a strength of from several to a few hundred microvolts per meter of elevation of the receiving antenna.

The amount of power needed at the transmitter depends primarily on the range of transmission and also on the strength of static at the receiver and the frequency of transmission. A field intensity that is sufficient in one locality may be inadequate in another. Transoceanic telegraph communication has been carried on at frequencies around 20 kilocycles per second (15,000 meters) with a range of thousands of miles on a power input to the antenna of several hundred kilowatts. For longer distances better results have been observed on high frequencies in the vicinity of 20,000 kilocycles with power inputs of less than 50 kilowatts.

Calculation of Field Strength.—A formula which is generally used to determine the field strength E in millivolts per meter of elevation of the receiving antenna at a distance d in kilometers from a transmitter is

$$E = \frac{188hI}{Ld}$$

where h is the effective height of the antenna in meters, I the current in antenna in amperes, L the wave length of signal in meters, and d the distance from transmitter to receiver in kilometers. The above formula, however, is for transmission at distances of a few wave lengths through free space only, and does not take into consideration the decrease in intensity due to absorption of energy in the surface over which the wave travels, or the effect of reflection. The effective height is taken as the height of the equivalent single-wire, vertical antenna which gives the same field strength with the same current throughout its entire length. In a transmitting antenna the current increases from a minimum at the far end to a maximum at the base. By increasing the height, the current distribution is improved and the radia-

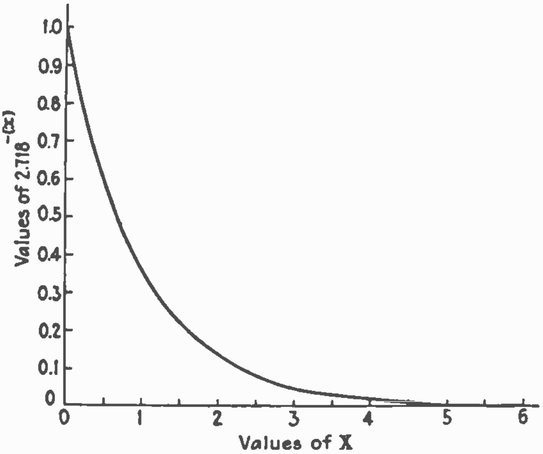


Fig. 28.—Attenuation factor for values of ("term").

tion is increased. The effective height of a loop is taken as the height of the equivalent single-wire, vertical antenna in which the same value of voltage is induced.

The absorption effect for daytime transmission over considerable distances on sea water is taken into account by multiplying the value of E by the *attenuation factor* f, thus:

$$f = 2.718^{-\left(\frac{0.000047d}{\sqrt{L}}\right)}$$

where d is the distance from transmitter to receiver in meters and L the wave length in meters.

Values of the attenuation factor which correspond to various values of the "parenthesis term" in the formula are shown in Fig. 28.

Measurement of Field Strength.—A commonly used method for the determination of field strength is based on the measurement of antenna voltage by substitution. In this method an input voltage having the same frequency as that of the unknown field is impressed on a radio receiver. Then the strength of the applied voltage is adjusted until the output of the receiver is equal to that produced by the unknown field strength. It follows that the value of the voltage induced in the antenna by the unknown field is equal to the applied voltage.

The applied voltage is determined (Radio Field Strength Measuring System, *Proc. Inst. Radio Eng.*, August, 1926) by measuring the flow of a current through an impedance. Special circuits are used to attenuate (page 169) currents by definite amounts to obtain a convenient deflection of an ammeter in the output circuit. The attenuator circuit must be shielded from the generator circuit or it will pick up energy from the latter of a magnitude comparable with that of the induced voltage.

SECTION V

POWER-SUPPLY SYSTEMS AND APPARATUS

Electric Power for Radio Apparatus.—The voltage range of electric power required by radio apparatus may be considered in three parts: (1) the filament supply, (2) the plate supply, and (3) the grid-bias (page 36) supply. The current and voltage required for this purpose must be non-fluctuating.

Dry and storage batteries are, of course, sources of non-fluctuating direct current. The alternating-current mains, usually at 110 volts and 60 cycles, will supply a non-fluctuating direct current, provided a rectifier (page 39) and filter (page 105) are used. If the voltage is to be increased, or decreased, a step-up or a step-down transformer (page 134) is required also. The direct-current mains, usually at 110 volts, will supply non-fluctuating direct current provided that a filter is used to smooth out the ripples. In this case the voltage can be reduced but not increased. A transformer will not operate on direct current. Non-fluctuating direct current obtained from a motor-generator (page 235), dynamotor (page 237), or rotary converter (page 237) may require the use of a filter. It is also essential with almost any kind of supply to provide a control by which the voltage can be varied to meet the requirements. The general arrangement of apparatus for obtaining a "pure" direct current from an alternating-current circuit is indicated in Fig. 1.

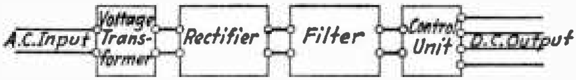


FIG. 1.—Apparatus for obtaining "pure" direct current.

Filters.—A filter consists of an arrangement of choke coils (page 95) and condensers. The choke coils are required to smooth out fluctuations in current, and the condensers to smooth out fluctuations in voltage. These condensers and choke coils have different values and locations depending on how much "smoothing" is necessary and how much voltage and current are to be handled. The output condenser (page 38) need not be large if only smoothness is required, but, unless a relatively large one is used, the low notes in radio reception will be missed. The greater the current value to be smoothed out the larger the choke coils must be, and the smaller the voltage the larger the condensers must be to reduce the fluctuations. Similarly, large choke coils and condensers would be required to smooth out the relatively large fluctuating direct current and the small fluctuating direct voltage required for the filament supply of vacuum tubes.

Part 1

BATTERIES

A battery consists of several cells which change chemical energy into electrical energy. The essential parts of a cell are two unlike *electrodes*, such as zinc and carbon, immersed in an electrolyte in a container. The *electrolyte* is a water solution of certain acids, hydroxides, or salts, depending on the type of cell.

Cells are classified as *primary* and *secondary*. The most familiar example of the primary type is the *dry cell*, and that of the secondary type, the *storage battery* or *accumulator*. The difference between primary and secondary cells depends on the character of the chemical reactions which occur in them. A primary cell cannot be charged by a current of electricity. When it is exhausted it is useless, unless provided with new electrodes and a new supply of electrolyte. A storage cell, however, changes chemical energy into electrical energy by a process which is reversible, meaning that a storage battery may be charged by passing an electric current through it in a direction which is opposite to that of the discharge current. During this process electric energy is changed to chemical energy and stored as such in the battery.

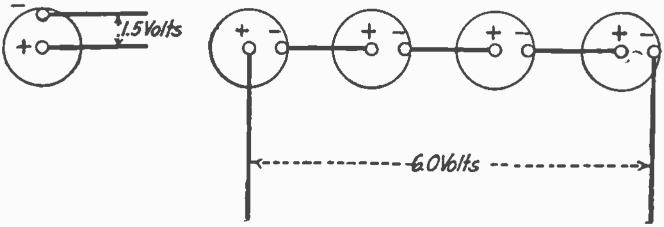


FIG. 2.—Cells connected in series.

The *capacity* of a battery is the quantity of electricity which it will deliver under given operating conditions. It depends, among other factors, upon temperature, current, allowable voltage at the end of service, and the nature of the service. The capacity of a storage battery under specified operating conditions is usually given in *ampere-hours* (page 110).

Cells may be connected together in series or in parallel. When cells are connected in *series*, as shown in Fig. 2, the positive terminal of one cell is connected to the negative terminal of the next cell. The voltage of this combination is the sum of the voltages of all the cells. The *ampere-hour capacity* of the combination is no greater than that of a single cell.

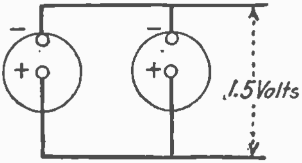


Fig. 3.—Cells connected in parallel.

Cells are connected in *parallel*, as shown in Fig. 3, when all the positive terminals are connected to one common line and all the negative terminals are connected to the other line. The voltage of this combination is equal to that of one cell, but the ampere-hour capacity is the sum of the capacities of all the cells. Cells which are used in a parallel combination must be of the same type and voltage. In a *series-parallel* arrangement, groups of cells are connected in series and these groups are connected in parallel.

Simple Primary Cell.—The simple form of primary cell consists of a piece of copper and one of zinc placed in water containing a small amount of sulphuric acid, as shown in Fig. 4. The pieces of metal are at different potentials with respect to each other, and when they are joined by a wire, an electric current will flow in the wire. It is assumed that the current flows from the copper through the wire to the zinc and from the zinc through the liquid to the copper. The current is carried through the liquid electrolyte by particles called *ions* (page 279) which carry electric charges. As this action continues, the zinc gradually dissolves and gas bubbles gather on the copper. The copper terminal is positive and is indicated by a plus (+) sign, and the zinc terminal is negative and is indicated by a minus (−) sign. The external circuit is connected to the cell across its terminals. The ions which carry positive charges move to the positive terminal, while the ions with negative charges move to the negative terminal. When a voltmeter is to be connected to a battery circuit, the voltmeter terminal which is marked "+" must be connected to the plus terminal of the battery.

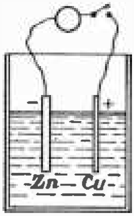


Fig. 4.—Simple primary cell.

Polarity.—The direction of current flow in a wire or other conductor, that is, the polarity of a conductor, must often be determined in order to get the proper connections for certain services, such as batteries, and devices for making and breaking a circuit. Most of the methods for determining polarity depend on either chemical action or magnetic action.

The most commonly used test is the one shown in Fig. 5. If two wires in a direct-current circuit are held about ½ inch apart in a glass of water in which a teaspoonful of salt has been dissolved, bubbles will form on the negative (−) wire. No bubbles, or very few, will be seen on the positive (+) wire. If the two wires in a circuit are held about ¼ inch apart on a small piece of moistened blueprint paper, the paper around the *negative* wire will turn *white*. Another test, in which two wires in a circuit are held against a peeled raw potato, as in Fig. 6, indicates the polarity by the blue color which appears on the potato at the point of contact with the *negative* wire.

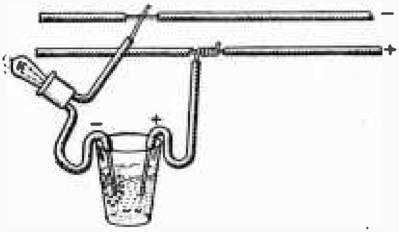


Fig. 5.—Salt-water test for polarity.

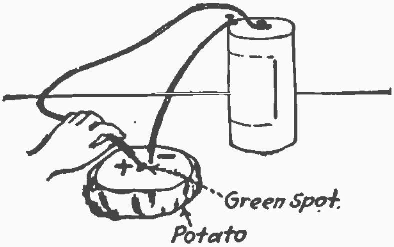


Fig. 6.—Testing polarity with a potato.

A test depending on magnetic action can be made with a compass needle. Figure 7 shows the relation between *direction of current flow*, direction of magnetic field (page 59), and position of the compass needle. Magnetic action causes the north pole of the compass needle to point in the direction of the magnetic field.

Another method of determining polarity of a circuit is by the *voltmeter test*. When the positive wire in a circuit is attached to the positive terminal of a voltmeter, and the negative wire to the negative terminal, the needle indicator of the instrument will swing in the right direction over the scale. If the needle swings in the wrong direction, the connections must be reversed.

Local Action in Batteries.—In the operation of a zinc and copper cell, certain difficulties arise which are caused by conditions known as "local action," "polarization," and "internal resistance." Pure zinc passes into a solution only when the cell supplies a current to an external circuit. Commercial zinc, however, contains impurities which act with adjacent zinc particles to form small cells. At such places zinc is always passing into solution, causing small currents of electricity which are wasted. This loss of zinc is called local action. Such local action is reduced considerably if the surface of the zinc is amalgamated with mercury.

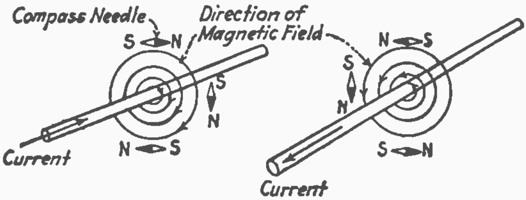


Fig. 7.—Testing polarity with compass needle.

Polarization.—The most familiar form of polarization is the formation of hydrogen bubbles on the copper when the cell is in operation. This gas layer reduces the output of the cell because it produces a voltage opposing that of the cell and also it diminishes the area of the surface of the copper which is in contact with the electrolyte. Both of these conditions increase the resistance of a cell. This condition may be avoided or minimized by the use of substances called *depolarizers* in the form of solids, liquids, or gases.

Internal Resistance.—The internal resistance of a battery must be considered as part of the resistance of the whole circuit. That is, the resistance of the entire circuit is the sum of that of the external circuit and that of the battery. The internal resistance of any cell varies with the type of cell and its condition. A lead storage battery has a low internal resistance and can, therefore, supply a heavy current. A lead storage battery should never be short-circuited because of the damage which may result to the battery when a heavy current flows.

Dry Cells.—A primary cell must have a large capacity for voltage and current, a low internal resistance, and freedom from polarization. Dry cells have these advantages, are portable, but subject to local action. Primary batteries are convenient but expensive to operate. The most common form of primary cell is the dry cell, which has been described on page 197. The open-circuit voltage of the dry cell is about 1.5 volts and the short-circuit current depends on the type of cell. A so-called "No. 6" cell passes from 25 to 35 amperes on short circuit. The voltage test is much less harmful than the short-circuit current test as an indication of the condition of the cell. Dry cells are intended primarily for intermittent use but can supply a continuous current of small value. Deterioration takes place even when the dry cell is not in use and is greater for the smaller sizes than the larger. Batteries which are located in a cool, dry place show little deterioration, but freezing temperatures must be avoided. The capacity of a dry cell is about 30 ampere-hours. A 22.5-volt dry battery for radio service has an ampere-hour capacity of about 3.5 and an internal resistance of approximately 300 ohms.

Closed-circuit Cells.—This type of cell is intended for use where a continuous current is required and must, therefore, have a large ampere-hour capacity and freedom from polarization. One example of this type, called the *gravity cell*, consists of a copper electrode in a saturated solution of copper sulphate, above which is a lighter solution of zinc sulphate surrounding a zinc electrode. This cell has a voltage of about one volt, but the internal resistance is considerable. It has been largely replaced by the *caustic-soda cell* which has a lower internal resistance. This latter type has one electrode of zinc and the other of copper and copper oxide which serves as the depolarizer in an electrolyte of a 20 per cent solution of caustic soda (sodium hydroxide). The working voltage is from 0.6 to 1.0 volt depending on the rate of discharge and length of service. The battery may be renewed by supplying new electrodes and electrolyte.

Other Wet Cells.—The wet cell, sometimes called the *Leclanche cell*, uses as an electrolyte a solution of sal ammoniac in a glass jar and is intended for light and intermittent service. The carbon-cylinder battery, which is a form of this type, consists of a zinc rod and a cylinder of carbon without any depolarizer in a solution of sal ammoniac. This cell has a voltage of about 1.4 volts, and the polarizing action, although quite rapid, is intermittent because the collection of gas diffuses when the cell is idle.

Storage Batteries.—The type called a storage battery may be charged or discharged a great many times with one set of electrodes in the same electrolyte. The positive terminal of a storage battery may be marked with a plus (+) sign, the letters "POS," a spot of red paint, or a red bushing around the terminal post. A voltmeter may be used to determine the polarity of an unmarked battery. The discharge current flows from the positive terminal through the external circuit to the negative terminal. When, therefore, the voltmeter is connected so that the pointer swings in the right direction, the positive terminal of the voltmeter is connected to the positive terminal of the battery.

The open-circuit voltage of a storage cell depends on its chemical construction and not upon the size or number of plates. Its capacity is given in terms of ampere-hours at a certain discharge at normal temperature. A *capacity* of 100 *ampere-hours* means that the battery can give 20 amperes for 5 hours. If the rate of discharge is more rapid the capacity is less, and if the rate of discharge is lower the capacity is greater.

Types of Storage Batteries.—The two general types of storage batteries are the *lead-plate battery*, containing an acid electrolyte, and the *nickel-iron* or *Edison battery*, containing an alkaline electrolyte.

A lead battery consists of lead plates immersed in a dilute solution of sulphuric acid. Most portable batteries are kept in containers made of a rubber compound; but large batteries are placed in glass or lead-lined tanks. The lead plates of portable batteries are of the pasted type in which the active material in the form of a lead oxide paste is pressed into a frame or *grid* made of a lead and antimony alloy. These plates must be "formed" by charging them with a direct current. This charging process, by oxidizing the positive plates, changes the active material into *lead peroxide*, which is brown in color. The negative plates are changed from the oxide to *pure sponge lead*, which is gray in color. The required number of positive plates are welded to a connecting piece to form the positive group of plates, and the negative plates form another group which meshes with the plates of the positive group. The negative plates are one more in number than the positive plates so that the two outside plates of a group are negative. *Separators* consisting of thin sheets of wood are generally placed between the positive and negative plates to prevent contact. In some types, a perforated or slotted sheet of rubber is added between each positive plate and the adjacent wooden separator to prevent oxidization of the wood. A cell of the lead-plate type is shown in Fig. 8.

The nickel-iron battery uses frames or grids made of steel. The active material in the positive plates is nickel oxide in the form of round tubes. The material in the negative plates consists of iron in a finely divided state placed in thin rectangular pockets. The *electrolyte* is a solution of *potassium hydroxide* together with certain other substances, and the container is made of steel. The cells are connected together by means of nickel-plated copper connectors. The cells must be insulated from each other because the steel containers are electrical conductors.

Electrical Characteristics.—The ampere-hour capacity of a storage cell indicates the number of ampere-hours which can be delivered at a certain temperature and a final discharge voltage. Thus a certain storage cell may have a capacity of 100 ampere-hours at 25°C., when a discharge current of 20 amperes continues to a final discharge voltage of 1.75 volts. If the discharge rate is above normal, the rated ampere-hour capacity will not be obtained. On the other hand, if the discharge rate is low, the ampere-hour capacity is somewhat increased.

Lead-plate Cells.—The open-circuit voltage of a lead-plate cell is about 2.0 volts. As the cell discharges at its normal rate the terminal voltage drops to about 1.75 volts at practically complete discharge. Such cells should not be discharged beyond this point except when the discharge rate is considerably above normal. The average voltage over the period of discharge varies with the rate of discharge, being about 1.95 volts at normal discharge rates and about 1.75 at high rates.

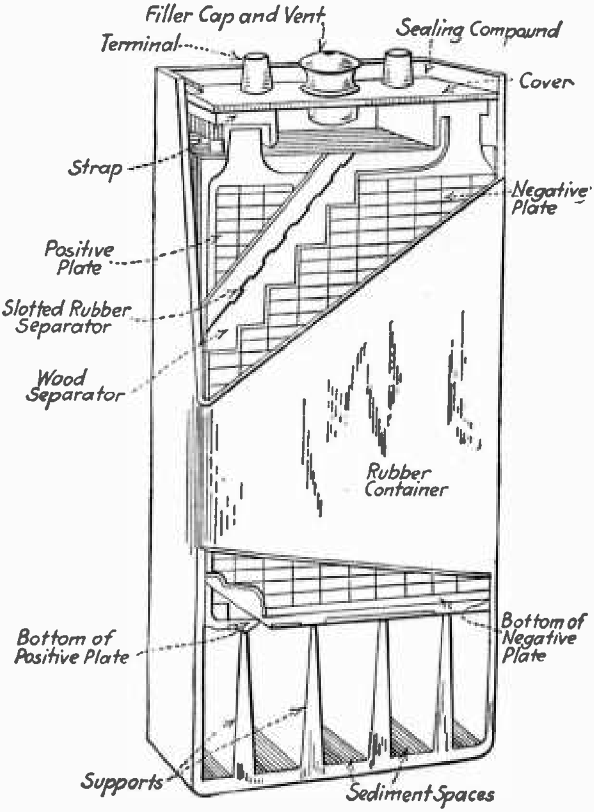


FIG. 8.—Lead-plate cell.

During the discharge of the battery the *specific gravity* of the electrolyte decreases because of the water resulting from the chemical action when lead sulphate is formed on the positive and negative plates. The specific gravity of the electrolyte of a lead-plate cell serves to indicate the state of charge and may be determined with a syringe *hydrometer* (page 112). The cell is considered to be discharged when the specific gravity falls to 1.10.

Nickel-iron Cells.—During the discharge of nickel-iron cells the voltage falls from the open-circuit value of between 1.45 and 1.52 volts to a final voltage which is about 0.9 volt per cell. The average voltage over the period of discharge is about 1.14 volts per cell at normal discharge, and 1.05 at higher discharge rates. The state of charge of these cells cannot be determined by the specific gravity of the electrolyte. The voltage of a nickel-iron cell falls more rapidly during discharge than that of a lead-plate cell. Consequently, lead-plate cells are better suited than nickel-iron cells for use where a constant terminal voltage is essential.

Charging and Maintaining Storage Batteries.—The purpose of charging a storage battery is to pass a current through the cells in a direction opposite to that of the discharge current, in order to reverse the chemical action which occurs during discharge. During this process the acid absorbed by the plates during discharge must be driven out. Direct current must be used for charging storage batteries, and if alternating current is to be used for charging, it must be changed into a direct current by means of a motor-generator set (page 235), a synchronous converter (page 237), or some type of rectifier (page 39). The charging current may be adjusted by means of a suitable control resistance or rheostat (page 121) to the value designated as the constant charging rate on the name plate of the battery.

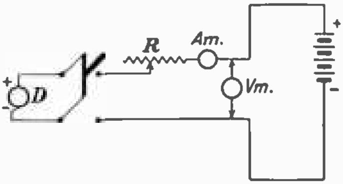


FIG. 9.—Direct-current charging circuit.

A charging circuit utilizing a direct-current line is shown in Fig. 9, the positive terminal of the charging circuit being connected to the positive terminal of the battery. During the period of charge, the control resistance may be decreased to keep the current at a constant value because the terminal voltage of the battery itself gradually increases. The value of the current flowing depends on the difference between the charging voltage and the battery voltage. The charging voltage must be *at least* 2.5 volts for each lead-plate cell and 1.7 volts for each nickel-iron cell, because the voltage of the battery acts in opposition to the charging voltage. The amount of resistance in ohms required in the charging circuit may be calculated from the equation $R = \frac{E_1 - E_2}{I}$ where E_1 is the voltage of the line in volts, E_2 is the voltage of the battery, and I the charging rate in amperes.

The *control resistance* may consist of a *bank of lamps* connected in parallel or of resistance coils for insertion into lamp sockets. In such a device, the charging rate is increased by connecting into the circuit more lamps in parallel. To prevent a discharge of the battery through the generator in case the charging voltage drops or fails, it is necessary to insert into one side of the charging circuit an *underload circuit breaker*. This is a device which acts to open one side of the circuit when the current falls below a given value. In usual practice the charging period lasts from five to eight hours; and near the end of this period, large batteries begin to emit gas so that the current should be reduced to about 40 per cent of the normal charging rate to avoid excessive *gassing* and a rising temperature. A charging rate of several times the normal discharge rate may be maintained until gassing begins. Continuous overcharging may result in dislodging some of the "active" material from the positive plates. During the charging period of nickel-iron batteries, no change in the charging rate is made. They emit gas throughout the entire charging period of about seven hours. The charging rate should not be less than the normal amount. Frothing during the charging of a nickel-iron or Edison battery is an indication that the charging rate is too high or that the level of the solution is too high. The temperature of any storage battery during charging or discharging should not be allowed to exceed 110°F.

The gases emitted during the charging period of a storage battery consist of oxygen and hydrogen, which may collect in the right proportions to form an explosive mixture. Good ventilation should be provided in battery charging rooms, and open flames of any kind must be avoided. Even the spark caused by a momentary short circuit of the battery wires may serve to ignite the gases. The bubbles of gas thrown off from the batteries into the atmosphere carry with them minute particles of the electrolyte which, in the case of the lead-plate battery, become apparent as choking fumes. The gassing also causes the loss of water from the cells which must be replaced by "pure" and preferably distilled water.

Sometimes batteries are charged by the *constant-voltage* or *tapering-charge* method in which the voltage at the battery terminals is kept constant throughout the charging period. The charging current decreases automatically as the charging process continues, and the period of charge is about the same as in the constant-current method. The advantages of the constant-voltage method are that a large portion of the ampere-hour capacity (page 201) can be put into the battery during a short period. Further charging current may be regulated automatically and may be adjusted to prevent gassing. In this method the charging voltage for lead-plate cells is about 2.3 volts per cell at its terminals and 1.7 volts per cell for the nickel-iron type. A variable resistance may be placed in series with the batteries to avoid an excessive initial current. When a lead-plate cell is discharging, lead sulphate forms on both the positive and the negative plates and will harden if the battery is idle for a considerable time. This sulphated condition is removed only with difficulty on the next charging. Sometimes it is helpful to pour out the electrolyte, fill the cells with water, and recharge the battery. If the battery is not then in a normal condition, it may be discharged and the process repeated. A nickel-iron cell, however, will not be damaged if it is left in a discharged condition.

In *trickle* or *floating charging* of a lead-plate battery, a small current is passed through the battery continually. If gassing occurs, the current is too large; and if the specific gravity is below the normal value, the current rate is too low and should be increased.

A temporary loss of capacity results if either the lead-plate or the nickel-iron cell is idle for any length of time. This loss of capacity is caused by local action within the cells. It is then necessary to charge, discharge, and recharge the batteries several times at a low rate to restore them to their normal state.

Effect of Temperature on Storage Batteries.—Both lead-plate and nickel-iron batteries suffer a temporary loss of capacity at low temperatures. The decrease in capacity of a lead-plate battery is approximately proportional to the reduction in temperature. A nickel-iron battery has a critical temperature which changes with the discharge rate. At a normal rate of discharge the critical temperature is slightly above the freezing point of water. Full capacity can be obtained above this temperature, but the output below it is small. In very hot weather either type of battery may be used successfully, but the specific gravity of the electrolyte in the lead-plate battery should not be so high after charging as in cool weather; in other words, the battery should not be charged so fully in hot as in cold seasons. For use at temperatures near freezing the lead-plate battery is preferred.

Internal Resistance of Storage Batteries.—The internal resistance of a storage battery is very small. At the end of discharge period, however, it increases to about double its normal value but falls to the normal resistance when the battery is again charged. The lead-plate battery has a lower internal resistance than a nickel-iron battery of the same capacity.

Electrolyte.—The electrolyte in a storage cell must always be kept at the proper level, so that no overflow occurs during charging. The lead-plate battery uses an electrolyte of *sulphuric acid* and water consisting of one part of acid to about four of water. The specific gravity varies with the kind of battery and the use for which it is intended; for portable batteries it is 1.280.

Acid should be added only to make up a loss due to spilling or leakage or a complete removal, but never to raise the specific gravity or to make up for evaporation. The electrolyte is prepared by pouring the acid slowly into the water and stirring constantly. Water should never be poured into the acid because of the danger of personal injury. The mixing must be done in a glass or porcelain container and not in any metallic vessel unless it is lined with lead.

The nickel-iron battery uses an electrolyte which consists of a water solution of potassium hydroxide including a small amount of lithium hydroxide and other substances. Sodium hydroxide is sometimes used instead of potassium hydroxide. This electrolyte may be obtained from the manufacturer of the cells in either a liquid or a dry state. The density does not change during charging and discharging, but there is a gradual reduction with use. The electrolyte when fresh should have a density of about 1.220 and should be replaced when the density drops to 1.160.

Only *pure water* should be used, and *distilled water* is to be preferred. Water which has not been distilled usually contains impurities and may impair the battery. The specific gravity of distilled water at 70°F. is 1.000.

Charging Panel.—A panel of the Exide type is shown in Fig. 10 as arranged for charging a 60-cell emergency radio battery in two "banks," because the voltage of the complete battery is higher than the 110-volt supply of the generator. The voltmeter circuit shown in the drawing is closed by means of the push button to take readings. A reading across circuit 1 indicates the battery discharge voltage; across 2, the charging voltage; across 3, the voltage of bank *A* of the battery; and across 4, the voltage of bank *B* of the battery.

Charging.—The first step in the use of the panel for charging batteries is to close the reversing switch, check the charging voltage across voltmeter circuit 2, and reverse the switch if no reading is obtained. The connections to the battery banks are checked by observing the voltage across voltmeter circuits 3 and 4. Then, with the six-pole switch open, the *circuit breaker* is closed, the low-voltage release plunger is held up, and the six-pole switch is closed. The charging current for the two banks of batteries then flows through the charging resistance units.

The *ampere-hour meter* is used to control the charging. The red pointer is set for the rated ampere-hour capacity of the battery for the existing charge. During the charging period the black pointer moves in the direction toward zero capacity. At zero the charging should have been completed and the charging circuit is opened through the action of the black pointer which trips the circuit breaker. If an overcharge is desired the black pointer must be shifted backward the necessary amount. A low-voltage release attachment is provided to open the circuit breaker in case the generator fails, in order to prevent the battery from discharging.

Floating the Battery.—When the six-pole switch is closed in the position for charging and the circuit breaker is open, the charging circuit through the resistance unit of the panel is open but the battery receives a *floating charge* through the two lamps mounted near the upper corners of the panel. This is intended to be the normal condition of operation; that is, the battery is fully charged and floating on the line, the circuit breaker is open, the six-pole switch is closed, and the radio equipment supplied by the battery is connected to the main wiring of the panel.

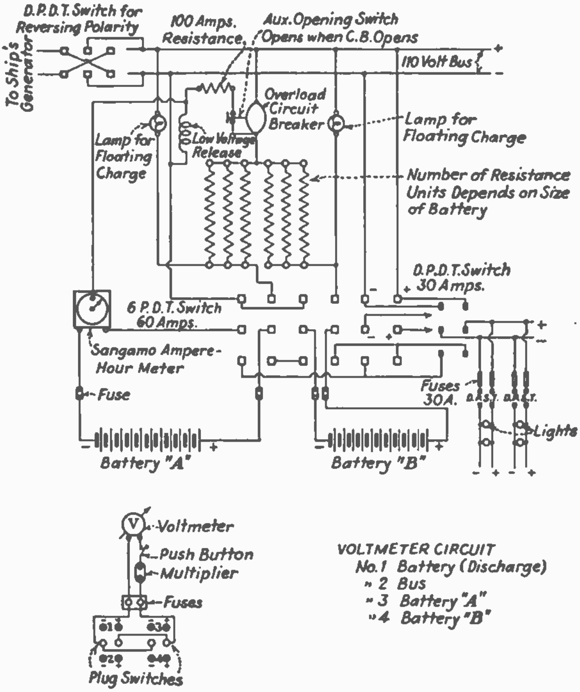


FIG. 10.—Charging panel.

Discharging the Battery.—The battery is connected for discharging by opening the circuit breaker and closing the six-pole switch in the direction opposite to that for charging. When the charging generator is not operating, the switches on the battery panel should be opened. During such periods, lights should not be operated from the batteries except in case of emergency.

Part 2

ELECTRIC GENERATORS

Electric generators and motors are used to convert energy from one form to another. When the conversion is from mechanical to electrical energy, the machine is a *generator;* and when the conversion is from electrical to mechanical energy, the machine is called a *motor*. The theory underlying these two machines is essentially the same. In fact, the usual types of motors may be used as generators with slight changes, and generators are easily adaptable for uses as motors.

How an Electric Generator Operates.—The movement of a wire across a magnetic field causes an *electromotive force* (*e.m.f.*) or voltage to be generated in the wire. The magnetic field may be set up by a permanent magnet or by an *electromagnet* which is wound with wire in which a current is made to flow. The value of the electromotive force or voltage generated depends on (1) the strength of the magnetic field and (2) the speed of the moving wire. The generation of the electromotive force causes a flow of current through the wire if it is in a closed circuit.

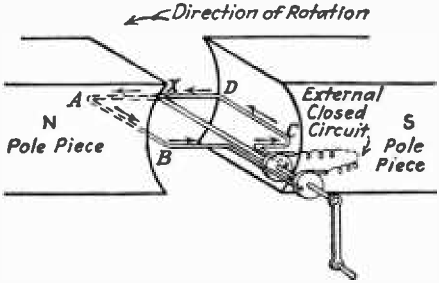


FIG. 11.—Simple elementary electric generator.

The relation between the direction of motion of the wire or conductor, the direction of the magnetic field, and the direction of current flow is important in order to understand the action of an electric generator.

Figure 11 shows the simplest form of electric generator, consisting of a loop of wire arranged to rotate in a magnetic field. It will be observed that the field poles are marked *N* and *S*, to indicate opposite polarity which causes a magnetic field to be established. The direction of this magnetic field is from *N* to *S*. If the loop is rotated in a counterclockwise direction about its axis *X*, the sides *AB* and *CD*, which cut across the magnetic field, will have generated or induced in them an electromotive force. If the terminals of this loop are connected by means of an external closed circuit, a current will flow in the direction indicated by the arrows.

The *right-hand rule*, used to determine the direction of the induced electromotive force *in a generator*, is illustrated by Fig. 12. The so-called "left-hand" rule for motors which is theoretically the same as the "right-hand rule" as applied to generators may be used to explain the operation of electric motors as described on page 221. In the application of this rule, the forefinger, the thumb, and the middle finger of the *right hand* are set at right angles to one another as shown, the hand being held so that the thumb points

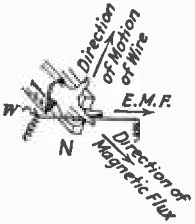


FIG. 12.—Right-hand rule for induced electromotive force.

FIG. 13.—Wire-loop positions with respect to pole pieces.

in the direction of motion of the wire *W* and the forefinger in the direction of the magnetic field. The middle finger, extended, will then point in the direction of the *induced electromotive force*. The application of this rule to Fig. 11 will show that the current in the right-hand wire flows from *C* to *D* and that the current in the left-hand wire flows from *A* to *B*, as indicated by the arrows. It will be understood, of course, that this movement of the wire through the magnetic field causes the generation of an electromotive force only when the conductor is cutting across the *flux lines* (page 59) of the magnetic field. For example, at the instant when the rotation of the loop of Fig. 11 carries it into the dotted position of Fig. 13, the wires *AB* and *CD* are moving parallel to the flux lines of the magnetic field and are not cutting across it. At this instant, therefore, no electromotive force or voltage is generated. When the loop is in the horizontal position shown in Fig. 11, the maximum electromotive force or voltage is induced. As it continues to revolve, it cuts across less and less of the magnetic field until it reaches the vertical position of Fig. 13, called the "neutral position," at which point the induced electromotive force or voltage is zero. The motion of the loop is then from a vertical into a horizontal position in which *AB* and *CD* are interchanged in position. During this period, the electromotive force or voltage increases again from zero to a maximum value, but now its direction is opposite to that shown in Fig. 11. The maximum value is reached when the loop has revolved 180 degrees from the original position. The application of the right-hand rule in this position indicates the reversal of the electromotive force or voltage because the wire *AB* is now cutting across the flux lines of the magnetic field in an upward direction, and *CD* in a downward direction. From this point on, the electromotive force or voltage again begins to decrease, reaches zero at 270 degrees, reverses, and then rises to its original value.

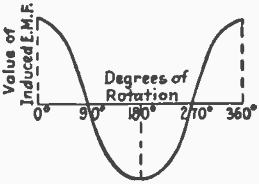


FIG. 14.—Induced electromotive force in simple generator.

From this it is seen that a loop of wire rotating at a uniform rate of speed in a uniform magnetic field generates an electromotive force or voltage which varies from a maximum to zero and then reverses its direction, one reversal taking place each half revolution. With but few exceptions all generators operate on this principle, thus generating an *alternating voltage*.

The electromotive force or voltage generated at each instant during the rotation of the loop of wire is shown in Fig. 14. In this chart the horizontal axis gives the position of the loop in degrees, starting from the position shown in Fig. 11 taken as zero. The vertical axis of the chart shows the amount of the induced electromotive force and its direction. The part of the curve above the horizontal axis represents the direction of the current which is obtained with the loop as shown in Fig. 11; and that below the axis, the direction when the loop is reversed.

Alternating-current (A.C.) Generators.—In order that the terminals of a number of loops of wire like the one in Fig. 11 may be attached to an external circuit, and to provide for their rotation, some form of sliding contact must be used. As shown in Fig. 11, the ends of the loop are connected to *slip rings*, which are usually mounted on the shaft with suitable insulation under the rings. The external circuit is then connected to *brushes* of carbon or copper, which rest on the rings and collect the current which is generated. These slip rings are also called "collector rings." With this construction the voltage and current delivered to an external circuit by the generator will vary through cycles as indicated by Fig. 14. A machine which delivers a voltage and current of this kind is an *alternating-current generator*.

Direct-current (D.C.) Generators.—Most generators designed to deliver direct current really generate an alternating current which is converted to a direct current by a *commutator*. In its simplest form, a commutator consists of a metallic tube slit lengthwise into two equal parts, mounted on the shaft, and insulated from it by mica or similar material. Figure 15 shows a simple form of commutator connected to a single-turn loop of wire. Two brushes located directly opposite each other make contact with the two segments of the commutator; and as the loop rotates, they serve to conduct the current from the loop to the external circuit. In order that the alternating induced electromotive force or voltage may produce in the external circuit a *rectified* or direct current, the brushes must be set as in Fig. 16. In this position, one segment of the commutator moves *out of contact* with one brush and *into contact with the other* at the instant when the loop of wire is passing through the *neutral position*, in which the induced electromotive force or voltage is practically zero. In other words, the current in the external circuit is kept in one direction at all times, because the commutator segments change from one brush to another at the same instant that the induced electromotive force or voltage changes its direction.

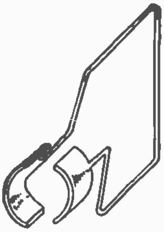


FIG. 15.—Simple commutator.

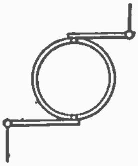


FIG. 16.—Neutral position of brushes on commutator.

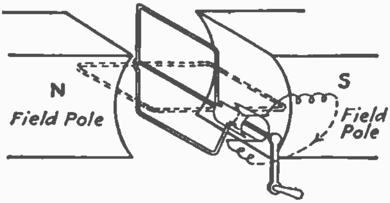


FIG. 17.—Wire-loop commutator and brushes.

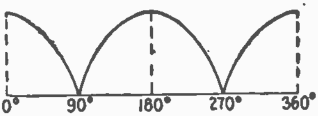


FIG. 18.—Commutated current.

Figure 17 shows a simple direct-current generator, and Fig. 18 shows the variations in the direct current delivered by such a generator. Comparison of Figs. 14 and 18 shows that the only difference is that the latter figure has the middle curve reversed in direction. This reversal is produced by the action of the commutator. Such a curve represents a *pulsating direct current* with its magnitude varying from zero to a maximum. In order to reduce the pulsation, and produce a steady flow of current, it is necessary to wind a great many separate loops of wire on the rotating part of the generator and connect each loop to a separate commutator segment as in Fig. 19. The effect of this arrangement of loops is shown in Fig. 20, which represents the variations of the current generated by two loops of wire at right angles to each other. When one loop of wire is cutting the magnetic field under the middle of each of the poles, the other is in the neutral position; that is, the first coil is generating its maximum when the second is generating its minimum voltage. The two effects are combined by connecting the loops in series as well as by bringing each end out to a commutator segment so that the resulting voltage C is the sum of the voltages A and B of the separate loops. It can be seen from Fig. 20 that the magnitudes of the voltage pulsations are thus greatly reduced. By the use of several hundred separate loops, each connected to a separate commutator segment, the direct current produced will have only a slight commutator ripple.

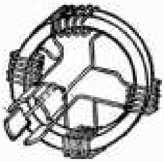


Fig. 19.—Armature with four loops and attached commutator.

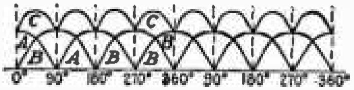


Fig. 20.—Voltage and current curves generated by four-loop armature.

Voltage of Generator.—The voltage generated by a single-turn loop of wire rotating at a slow speed is very low. In order to produce the voltages used commercially, it is necessary to wind a great many turns of wire (many loops in series) in each coil, and the total voltage is then the sum of the voltages induced in the turns of each coil. In addition it is necessary to rotate the coils at a high speed, often as high as 3,600 revolutions per minute (r.p.m.). In order to provide a magnetic field of great flux-line intensity, the field poles N and S of the generator are made very powerful, and the rotating coils are wound on an iron armature. Iron is used for supporting the coils of the armature as it gives a path of low resistance to the flow of the flux lines of the magnetic field through it. All of these points bear out the previous statement that the electromotive force or voltage generated depends on the strength of the magnetic field, the speed of rotation, and the number of turns of wire cutting the magnetic field. These several factors are governed by mechanical as well as by electrical features of the generator.

The size of the field poles N and S is determined by the size of the wire used in the field winding, the number of turns in the winding, the necessary insulation, as well as the allowable size of the generator. From an electrical standpoint, there is a limit to the strength of a magnetic field with a given amount of iron because of the *saturation* of the iron if too little metal is used.

DIRECT-CURRENT GENERATORS

Self-excited Generators.—A self-excited direct-current generator is one in which the current for the field winding is supplied by the generator itself. When a generator is started by an engine, turbine, or other prime mover, at first only a small electromotive force or voltage is generated, because the magnetic field of the field poles N and S is very weak, being that due only to the "residual magnetism" of the field poles. In other words, the field poles are permanent magnets as well as electromagnets. As the armature revolves, it generates a low voltage, which is impressed across the field windings of the machine, thereby causing a small field current to flow, which in turn increases the magnetic field. As this process continues, the generator gradually builds up the normal magnetic field of the field poles until the armature generates its rated voltage. When a generator is to be shut down, the load resistance in the line circuit is reduced to zero and the generator is slowed down by cutting off the power supply of the prime mover. Under certain conditions, if a generator is shut down while carrying a large resistance load, or by accident, it may happen that the residual magnetism of the field poles may become reversed. As a result of this reversal, the generator will build up a voltage of the wrong polarity when it is again started.

Separately Excited Generators.—If the field poles of a generator are supplied by a battery or by another electric generator, the voltage which is generated may be controlled independently. In this case, the reversed polarity mentioned above is not possible unless the separate source of excitation has been reversed. A separately excited generator thus does not depend on residual magnetism for starting.

Generators may also be classified according to the type of winding on the field poles. In this classification are (1) series-wound, (2) shunt-wound, and (3) compound-wound generators.

Series Generators.—Figure 21 shows a series-wound generator, in which all of the armature current passes through the winding of the field poles. As the load (current) of this type of machine increases, the voltage rises because the larger field current causes the magnetic field to strengthen. This generator is used for some street-lighting and railway purposes where a varying generator voltage and *constant current* are desirable.

Shunt Generators.—Figure 22 shows a self-excited, shunt-wound generator, in which the field winding is connected in parallel or is in "shunt" with the loops of wire on the armature. In this way, the *field current and, consequently the magnetic field, are practically constant,* which causes this type of machine to generate a fairly *constant voltage.* As the field winding carries only the small current necessary to excite the machine, it is made of small wire compared with the series machine, in which all the current passes through the field winding. As the current load of a shunt generator is increased, there is a reduction of armature voltage, and this voltage drop in the armature causes the terminal voltage of the machine to drop also. This then causes a slight drop in the field current, which causes a still further drop in the terminal voltage of the generator.

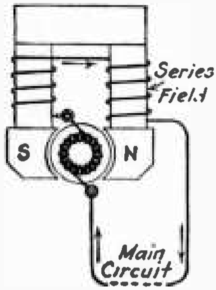


FIG. 21.—Series field coils.

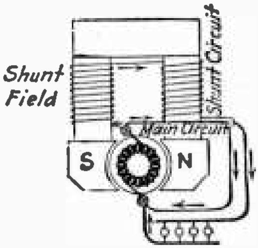


FIG. 22.—Shunt field coils.

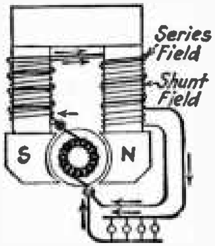


FIG. 23.—Compound field coils.

Compound Generators.—In order to compensate for the drop in voltage of a shunt generator, a series field is often added, forming a generator with a *compound* winding as shown in Fig. 23. As the current load increases, the magnetic field due to the series winding adds more and more to the strength of the magnetic field of the shunt winding, thereby holding the *terminal voltage approximately constant.* This type of generator is called "accumulative," because the effects of the series and shunt fields are added. By making a generator *overcompounded,* the voltage at full load may actually be made higher than at no load. In the *differential* type of the compound generator, the shunt and series fields are wound in opposite directions. In this latter type, the voltage on heavy overload or short-circuit conditions becomes very low, thereby reducing the stresses in the loops of the armature when the generator is overloaded.

Some generators which have a compound field winding have a switch arranged to short-circuit the series field when it is desired to operate simply as a shunt generator. Generators which are designed for power and lighting have usually compound field windings.

Three-wire Direct-current Generators.—To supply a three-wire 110–220 volt or the so-called Edison system of direct-current distribution, two generators are commonly used, which are connected as indicated in Fig. 24. The two generators are mounted on the same shaft with an engine or turbine for driving them. The neutral connection between the generators is used to supply the "unbalance" current of the system. It is also a common practice to operate a 220-volt, single-unit generator in parallel with double units as described, allowing the double-unit generator to take care of the unbalance current for all the generators.

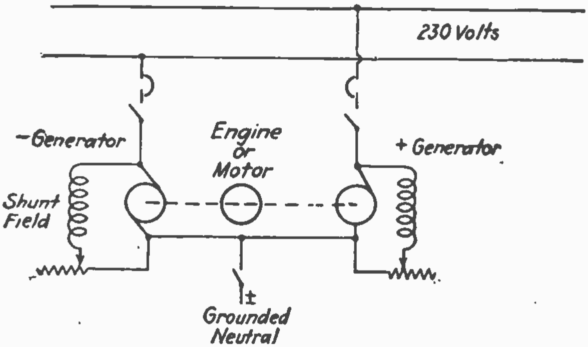


FIG. 24.—Parallel operation of direct-current generators for three-wire distribution.

Voltage Controls.—In order to raise or lower the voltage of a shunt-wound or compound-wound generator, it is necessary to vary the field excitation. This is done by placing a *rheostat* (page 121) or some other type of *variable-resistance box* in series with the shunt-field winding. By increasing or decreasing the resistance of the rheostat, the field current and hence the generated voltage is lowered or raised.

Automatic Regulators.—An automatic voltage regulator may be used to hold the generator voltage constant. This is accomplished by an iron plunger moving inside a coil of wire, connected across the generator terminals, the plunger and coil being so designed that the upward pull of the magnetic field of the coil is balanced by the downward pull of a spring. Contacts actuated by the plunger moving in the coil operate a remote-controlled field rheostat which adjusts the voltage.

Lamp Resistances.—Where protective resistances are necessary in connection with automatic rheostats, incandescent lamps may be used, provided they do not carry or control the main current nor constitute the *regulating* resistance of the device. When lamps are used as resistance in this way, they must be so arranged that they cannot have impressed upon them a voltage greater than that for which they are rated.

Protection of Direct-current Generators.—A distributing system connected to a direct-current *bus* (page 34) may supply current to a number of feeders at the switchboard, each feeder being supplied by a tap from the bus which is connected to fuses or circuit breakers for protection. If this protection fails to operate properly or if a short circuit occurs, overload protection for the generators must also be provided to prevent serious damage at the point where the short circuit occurs, as otherwise, without protection, the armature of the generator might be burned out.

Switchboard Instruments.—Certain switchboard instruments are required for the operation and regulation of generators. A *voltmeter* with a throw-over switch can be arranged to measure the voltage of the wiring connected to a group of generators or any one of them. An *ammeter* installed in one wire from each generator shows the amount of current being delivered. As the product of the ammeter and voltmeter readings in direct-current circuits is the watts being generated, no *indicating wattmeter* (page 108) is required. A recording *watt-hour meter* is of value if records of generator and plant efficiency are kept. Figure 25 shows the arrangement of meters commonly employed for the operation of direct-current generators.

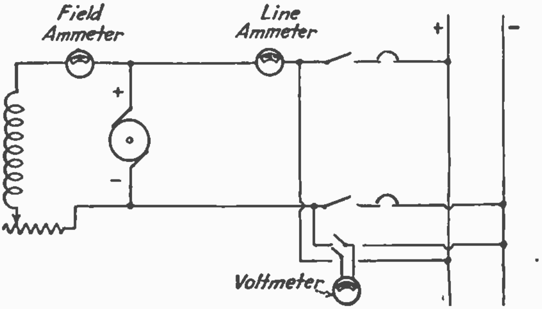


FIG. 25.—Meters for direct-current measurements.

ALTERNATING CURRENT GENERATORS

Because of the large capacities in which alternating-current generators are usually constructed, it is of advantage to have them operate at high speed. The rated revolutions per minute is, therefore, one of the most important factors in the determination of the size of the generator. For the reason that a commutator is not required for alternating-current machines, there are not the same limitations of speed as with direct-current generators. To obtain the best balance, lowest wind resistance, best insulation, and minimum of slip-ring difficulties, the field winding is on the *rotor* of practically all commercial alternating-current generators and the armature winding is on the stationary part or the *stator*. In a design of this kind the magnetic field is rotating, and the armature loops do not cut the magnetic field but rather are cut by the magnetic field. The effect, however, is the same as that discussed previously, for it is the *relative motion* between the magnetic field and the armature loops which induces the electromotive force.

In order to provide a uniform magnetic field, direct current must be applied to the field winding on the rotor. The alternating-current generator can of itself supply no direct current, so that an *exciter* is usually mounted on the shaft of the main generating unit or is separately driven. Figure 26 shows an alternating-current generator and its direct-current exciter with the necessary wiring. The rotating field of the main generator receives the direct current for its excitation by means of two slip rings mounted on its shaft. The alternating current generated in the stator windings is usually taken from the main generator by wires carried through insulated bushings in the frame of the generator.

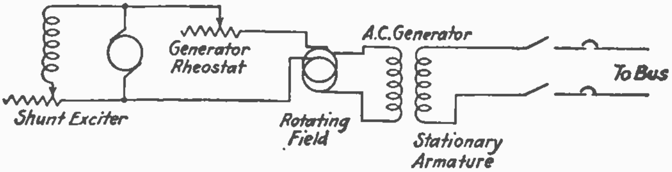


FIG. 26.—Alternating-current generator with exciter.

Single-phase Generators.—For lighting purposes a single-phase, two- or three-wire generator is often employed. Figure 26 shows this type of generator. In alternating-current operation it is desirable to have a constant frequency or a definite number of cycles per second. Figure 14 illustrates the variations in voltage which occur during one cycle, from a maximum to zero, to a maximum in the opposite direction, to zero, and to the original value. If the speed of the generator is such that 60 cycles are generated in one second, the *frequency* is 60 cycles per second. This is the common frequency used for lighting purposes. For certain purposes in radio telegraphy, 500-cycle generators are used, and special machines have been developed for generating frequencies as high as 200,000 cycles per second, to be applied to radio circuits. The frequency of an alternating-current generator is determined by the expression

$$\text{Frequency} = \frac{\text{number of field poles} \times \text{revolutions per minute}}{120}.$$

Example.—A 24-pole alternating-current generator is operating at 3,500 revolutions per minute. What is the frequency?

Solution.—

$$\text{Frequency} = \frac{24 \times 3{,}500}{120} = 700 \text{ cycles per second.}$$

Inductor Alternators.—The inductor type of alternator is used for the generation of currents having a frequency of from 500 to 200,000 cycles per second. Alternators of this kind when used for radio-telegraphy systems generate a current having a frequency of 500 cycles per second.

The principle of operation of an inductor alternator is illustrated in Fig. 27. Both the armature and the field magnets are stationary, and a considerable air gap separates the armature core C_1C_2 from the faces of the field poles N and S. The masses of iron I called *inductors* revolve about the axis m n. When the inductors are in the position shown, between N and C_1 and S and C_2, there is a certain magnetic flux between the field poles and the armature core due to the field excitation. When the inductors are not in that position, the flux is decreased because there are long air gaps in the magnetic circuit which have a smaller *permeability* (page 64) than the iron conductors. The variation of the flux through the coils AA sets up an alternating voltage in the coils. In this type of alternator the passing of each *inductor* causes a complete cycle of voltage because the voltage is built up in one direction while the flux is increasing and in the opposite direction while it is decreasing. In alternators of either the revolving field or revolving armature type (page 217) the passing of *two* poles causes a cycle of voltage.

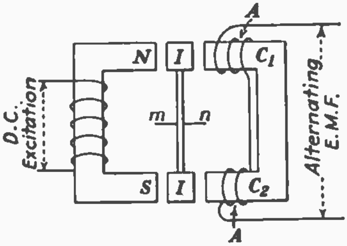


Fig. 27.—Inductor alternator.

Three-phase Generators.—For large lighting requirements and particularly for power supply, three-phase generators are quite commonly used. In a three-phase generator there are three independent windings, the maximum voltage being generated in each of the three windings at different instants. In a 60-cycle, three-phase generator the maximum voltages occur 1/180 second apart, as indicated in Fig. 28. The three-phase current is particularly well suited for power services.

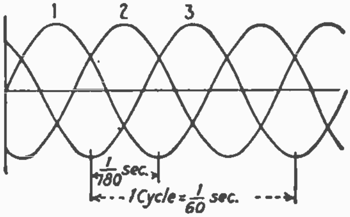


Fig. 28.—Three-phase voltage.

Large sizes of alternating-current generators are called *alternators* or *synchronous generators.*

Voltage Control.—The voltage of an alternating-current generator is controlled by varying the field current by means of the field rheostat. The field rheostat controls also the power factor (page 76) at which a generator is operating, so as to allow shifting of low power-factor load from one generator to another as required, without actually changing the kilowatt loading on the machines.

Regulation.—The voltage drop from no load to full load, stated as a percentage of the full-load voltage, is called the regulation of the generator. If the voltage is approximately constant, the regulation in per cent is small, and, on the other hand, if the voltage drop is considerable, the regulation in per cent is greater.

$$\text{Regulation in per cent} = \left(\frac{E_0 - E_f}{E_f}\right) \times 100$$

where E_0 is the no-load voltage in volts and E_f the full-load voltage in volts.

Part 3

ELECTRIC MOTORS

Operation of Electric Motors.—The *principle* of operation of an electric motor is similar to that of an electric generator. It has already been mentioned that many motors and generators are theoretically interchangeable.

A motor is used to change *electrical* energy to *mechanical* energy, which is opposite to the purpose of a generator.

In the case of a *direct-current motor* there are *field poles* and an armature as in the direct-current generator, both the field and the armature being supplied with electricity from the supply wires connected to the motor. The windings on the field poles consist of many turns of wire wound around *laminated iron pole pieces.* The windings on the field poles produce a very strong magnetic field between poles of opposite polarity. The *armature winding* of a direct-current motor consists of heavy wire wound on the rotating part of the motor, the ends of this winding being connected to a commutator and brushes.

The operation of an electric motor is illustrated in Fig. 29, which shows the imaginary *flux lines* of the magnetic field between the field poles, in the direction from the north to the south pole. This magnetic field is uniform and may be represented by straight lines drawn between the faces of the field poles. The current flowing through the wires of the armature by way of the brushes and commutator also produces a magnetic field which is set up around each of the wires of the armature. These *two magnetic fields interact* upon each other causing the distorted condition shown in the figure. The lines of force of the magnetic field are much denser above than below the wire. The greater number of flux lines on the top of the wire tends to cause a motion of the wire into the less crowded area or downward. Thus a wire carrying a current placed in a magnetic field will tend to move, bringing about a change of electrical into mechanical energy.

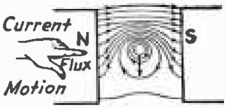


Fig. 29.—Magnetic field distorted by single wire.

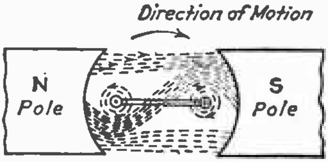


Fig. 30.—Magnetic field distorted by wire loop.

If, instead of a single wire, a loop of wire is considered, as in Fig. 30, the following action will be observed: If the right-hand side of the loop is carrying current away from the reader, the resulting magnetic field is in a *clockwise* direction, as determined from the right-hand rule for generators (page 209). Similarly, the left-hand wire, carrying a current toward the reader, has a magnetic field in the opposite or *counterclockwise* direction. The main magnetic field between the field poles is distorted from its uniform path as shown in the figure. This has the tendency to force the left-hand wire to move upward and the right-hand wire downward, thereby causing a *clockwise rotation of the loop.* This action of the loop may be explained by the statement called the *left-hand rule* for motors. According to this rule, if the forefinger of the left hand is pointed in the direction of the flux lines of the magnetic field and the bent middle finger in the direction of the current in one of the wires of the armature, the thumb will point in the direction of motion. This rule is just the *opposite* of the *right-hand rule* for generators.

After the rotation of the loop of wire from its original position until it reaches the vertical position, that is, after rotation through 90 degrees, its further motion is opposed by the action of the combined magnetic fields, and the loop would be held in the vertical position. In order to cause rotation for one-half revolution more beyond this position, it is necessary to reverse the current through the loop of wire. This reversal of current through the loop is accomplished by the commutator in a similar manner to its use on a generator, the current being reversed just as the loop reaches the *neutral,* in this case, the vertical position. In order to prevent "locking" of the armature in the neutral position, a second loop of wire may be placed at right angles to the first. Then the rotation is due to the combined effects of the two loops and is more uniform than it is with only one loop.

The force which the armature loops exert on the shaft to cause rotation is called *torque.* If the motor has been at rest and is being started, the force which it can exert is called the *starting torque.*

Counter-electromotive Force.—When a motor is rotating and driving a rotary pump, for example, the field poles and the armature must both be supplied with electricity from the power supply wires. If under such a condition the power supply is suddenly cut off, a direct-current motor acts as a generator, supplying its own field and generating electricity until the friction and load cause it to stop. This shows that while a motor is operating and taking electric power from the supply lines, it is also *apparently* furnishing power to the supply lines in a lesser amount. This is shown by Fig. 31 which indicates the values of the applied voltage, the generated voltage or *counter-electromotive force,* and the resultant voltage. The voltage supplied from the line tends to cause a current to flow in one direction through the armature. The generated voltage, in opposition to the supply voltage, tends to cause a current to flow in the opposite direction. The *resultant voltage* acting on the armature is the difference between the voltage of the

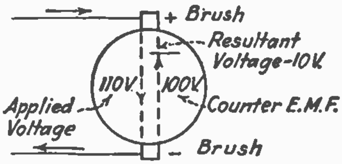


FIG. 31.—Voltages in motor armature.

current which is supplied and the generated voltage (counter-electromotive force). It is the *resultant* voltage which determines the actual current flowing through the armature.

Starting Resistance.—When a motor is operating at full speed, the counter-electromotive force is almost equal to the applied voltage. At standstill or at low speeds, however, the counter-electromotive force, which depends on the speed of rotation, is very small, so that the resultant voltage, acting on the low resistance of the armature, tends to cause a heavy current to flow. In order to limit this current, a *variable starting resistance* or *rheostat* is placed in series with the armature. As the motor comes up to speed, this resistance is gradually cut out of the circuit. Figure 32 shows the method of connecting a simple starting resistance in series with the armature of a motor.

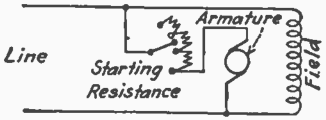


FIG. 32.—Starting resistance of motor.

In order to prevent the starting resistance from being left out of the circuit after a motor has been shut down, due to the failure of the supply line to furnish current or some other reason, the starting handle has usually an attached spring which returns it to the starting position, except when held up by a magnet which is energized only when the motor is running properly. This magnetic device may be operated by loss of field current, as shown in Fig. 33, or by overload, loss of line voltage, overspeed, or some other means.

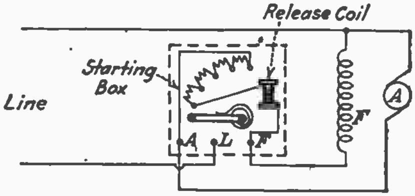


FIG. 33.—Starting-resistance box.

The terminals of motor-starting *rheostats* must be marked to indicate the part of the circuit to which each terminal is to be connected, as, for example, "line," "armature," and "field."

To provide protection to the operator handling a motor-starting rheostat, it is frequently entirely enclosed in a metal box with only the operating handle on the exterior, or it may be operated by an automatic remote-control relay (page 698), arranged to advance the contact arm of the starting rheostat after successive time intervals.

It is easier to obtain satisfactory operation of the commutator on electric motors than on generators, because the reactions which in generators are additive are compensatory in motors. As the running speed of a motor depends on the development of a counter-electromotive force, *speed variations* within wide limits can be obtained by a simple modification of the magnetizing effect of the current supplied to the field magnets. The load on a direct-current motor can be widely varied at any suitable speed of operation, for the reason that the speed is self-regulating within a small per cent, even though the load varies from zero to the full rating or the reverse. Starting the motor under normal or heavy load is accomplished easily and promptly by using a resistance in the armature circuit, this resistance being cut out when the motor reaches its full speed. The efficiency and the reliability in operation of a well-designed, direct-current motor, even of relatively small size, leaves practically nothing to be desired. Change of direction of rotation can, in like manner, be attained by the simple reversal of current in either the armature or the field circuit, practically no other adjustment being required.

Automatic Motor Starter.—The circuit diagram of Fig. 34 shows the automatic motor starter of the R.C.A. two-kilowatt, 500-cycle type (P-8) radio transmitting set. This starter functions also as a main-line circuit breaker by means of an overload relay switch. It has three resistance units in series with the motor armature. The field winding of the motor is connected across the direct-current line through the field-regulating rheostat. An increase in the resistance of this rheostat increases the speed of the motor and increases also the frequency of the alternator. The field winding of the generator is connected across the direct-current line through the voltage-regulating rheostat, through an antenna change-over switch and a control switch which are not shown, to the contact point marked "5" of the starter. When the starting circuit is closed, the plunger of the starter moves toward the contact points, cutting out the resistance gradually in three steps. The field circuit of the generator is open until the bar on the plunger of the starter reaches the contact 5. When the plunger bar reaches the contact 4, the armature of the motor is connected across the direct-current line.

The tripping magnet of the overload relay is connected in series with the armature of the motor on the negative side. If an excessive current flows through the tripping magnet, the lever of the overload relay is lifted, breaking the circuit to the winding on the plunger of the starter. When the lever lifts, it closes the circuit through the holding magnet which holds the lever until the main direct-current line or the motor-starting switch is opened. The switch S which is in a shunt connection with the resistance

R_1 is opened automatically by the plunger of the starter when the motor attains the normal speed. When the circuit to the plunger winding is broken, the plunger drops and, by making contact at the point A, inserts the resistance R_2 into the armature circuit of the motor. The motor then acts as a generator and builds up a heavy current. This current in the motor armature sets up a magnetic field which acts with the field poles to stop the rotation of the motor.

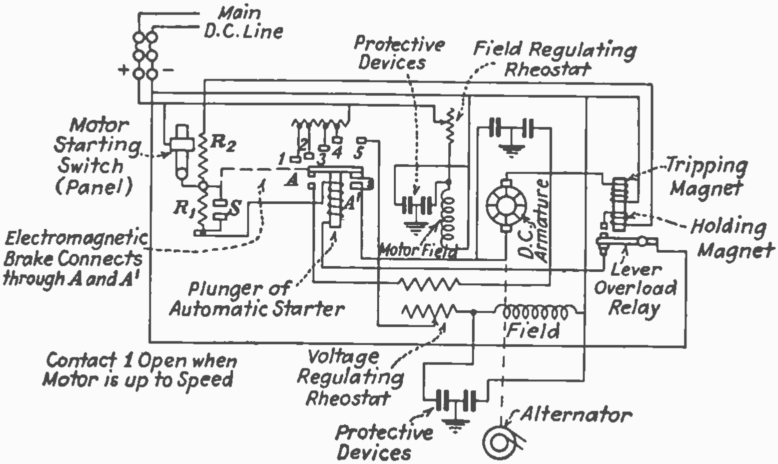


FIG. 34.—Automatic motor starter.

Characteristics of Direct-current Motors.—There are three general classes of direct-current motors: (1) series, (2) shunt, and (3) compound. In the *series motor*, as shown in Fig. 35, the entire armature current passes through the field circuit. The field magnetism increases as the load of the motor is increased, causing a sufficient torque to carry the load. As the load is *decreased*, the motor speeds up; and as it is *increased*, the motor slows down. If the load is suddenly removed entirely, the motor will run away and will probably be broken. Because of this tendency, a series motor is always geared or direct connected to the load. The control of speed and of starting is obtained by a variable series resistance, such as the *controller* for the motors on street cars. This type of motor is best adapted to large variable-speed

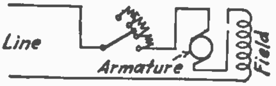


FIG. 35.—Wiring of series motor.

loads such as electric cars, cranes, and hoists but is not used for radio services where a constant-speed motor is needed.

The *shunt motor* has the field winding with its field rheostat connected in parallel with the armature across the line as in Figs. 32 and 33. The field magnetism is thus fairly constant and gives this motor a constant speed, with variations not exceeding 5 per cent. Slight speed adjustments of about 15 per cent above or below the normal value are obtained by varying the resistance of the field rheostat; but, if the field current is reduced too much, there will be trouble from sparking at the commutator. Increasing the field current reduces the motor speed; and decreasing the field current increases the motor speed. If the field circuit is opened, the motor will attain excessive speed; hence a "no-field" release is necessary, as was mentioned before in connection with starting rheostats (page 122). The shunt motor is used chiefly for small lathes, machine tools, etc., which require a relatively constant speed.

In some cases it is desirable to drive ventilating fans, blowers, etc., by a constant-speed motor with several large speed ranges. By inserting a variable resistance in series with the armature, a shunt motor may be made to run constantly at 50 per cent, 75 per cent, or some other percentage of full speed. This variable resistance carries the main armature current and introduces large electrical losses. Such an arrangement is called an *adjustable-speed shunt motor.*

Adjustable-speed motors, if controlled by means of field regulation, must be so equipped and connected that they cannot be started when the magnetic flux in the field poles is weak, unless a device providing the necessary safeguard is incorporated in the design of the motor.

The *compound motor* is a combination of the shunt and series arrangements of winding; that is, each field pole has a shunt winding and a series winding, as shown in Fig. 36. The relative strengths of the two windings determine whether the motor has more nearly the characteristics of the series or the shunt machine. The presence of a shunt winding prevents "running away" in case the motor should have its load suddenly removed, while the series winding provides a large starting torque. The *differential* type of compound

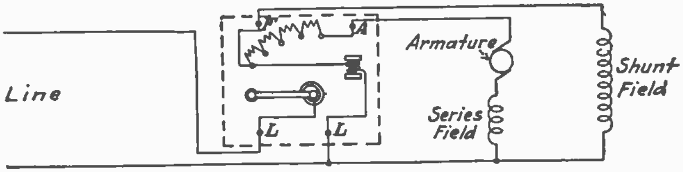


Fig. 36.—Wiring of compound motor.

motor has shunt and series fields which are wound in opposite directions so that they oppose each other, and thus decrease the field strength as the load is increased. The effect is to maintain the speed of the motor practically constant, or even to increase it as the load increases. Compound motors are usually employed for heavy intermittent duty at constant speed, such as in driving punch presses, printing presses, passenger elevators, and alternating-current generators in radio-telegraph sets. When the key of the transmitter is depressed, the load on the motor changes from very light to full load.

When a motor is subjected to severe duty, such as heavy momentary overloads, wide-speed variation, and reversing operation, the brushes frequently spark badly, injuring the commutator and burning the brushes. The sparking is caused by a shift of the neutral position in the armature without a corresponding shift of the brush position. In order to compensate for this shift of the neutral position, additional field poles are often placed between the main field poles and are known as *interpoles* or *commutating poles*. They are connected in series with the armature so as to vary their effect as the load on the motor varies. Such a motor is known as an *interpole motor*.

Reversing Direct-current Motors.—By reversing the direction of *either the field current* or *armature current* on any type of direct-current motor, the *direction of rotation may be reversed.* It is apparent from a study of Fig. 30 that if either the direction of the current in the loop or the direction of the flux lines in the magnetic field between the field poles is reversed, the dense portions of the magnetic field will shift to the opposite side of the wire in the loop.

Uses of Enclosed Types of Motors.—Because of the sparking which may occur on all direct-current motors and some types of alternating-current motors when overloaded or because of motor troubles, it is often necessary to enclose a part of a motor or the entire motor in places where this sparking may cause a fire or explosion. An enclosed motor is one surrounded by a casing which will prevent accidental contact of a person with live parts. A *totally enclosed motor* is one which is so completely enclosed by covers as practically to prevent the circulation of air through the interior. Such a motor is not necessarily air-tight. A *dust-proof motor* is so protected that an accumulation of dust will not interfere with its successful operation, while a *dust-tight motor* is so constructed that no dust can enter the casing. The type of protection which must be used for a motor and its control apparatus depends on the degree of hazard which may be present.

If the sparking of a motor is due to overload or heating from too frequent starting, the motor rating should be investigated. For this reason every motor must be provided with a name plate giving the name of the maker, the ratings in volts and amperes, the normal full-load speed, and the interval during which it can operate, starting cold. The time interval given must be 5, 10, 15, 30, 60, or 120 minutes, or continuous.

Synchronous Alternating-current Motors.—Some types of alternating-current motors are similar to alternating-current generators in principle. The *synchronous motor*, for example, has a field winding which is excited by direct current usually supplied by a small generator on the same shaft with the motor. The armature, however, is supplied with current from an alternating-current line. As the armature rotates, its wire loops pass the north and south field poles, alternately, while the armature current is reversing at the same rate. The reversal of the armature current occurs at the neutral position of the field magnets, just as in the direct-current motor, with its commutator. This type of motor is used on constant-speed drives, such as those for mill work, air compressors, and motor-generator sets (page 235). It has the decided advantage of being capable of operation at variable power factors by varying the strength of the magnetic field between the field poles. By operating synchronous motors at *leading power factors*, correction may be made for low power-factor motors on the same mains, so that the average power factor of all the motors will be nearly unity. This will result in minimum line losses and lower power-factor charges. A synchronous motor when used in this way may be operated at *no load* and is then called a *synchronous condenser*.

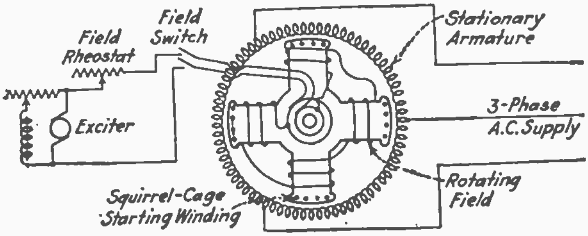


FIG. 37.—Wiring of synchronous motor.

The synchronous motor has the disadvantage that it does not have sufficient *starting torque*, which means that it will not start without some special starting device such as a starting motor on the same shaft, a *starting winding* consisting of short-circuited copper bars built into the field poles, or some other means. If too much load is applied to a synchronous motor, it will "pull out of step" or lose synchronism with the alternations of the applied current, and, unless disconnected immediately, its windings will be burned out. If the synchronous motor is built for three-phase operation, it will have more starting torque than the single-phase motor, but even under this condition special starting devices are commonly used.

Figure 37 shows the typical method of wiring a three-phase, *self-starting synchronous motor* built with a rotating field and a stationary armature similar to the synchronous generator. When such a motor is being started, the field switch is kept open and the field is short-circuited through a field resistance until the motor is at its rated speed. The field switch is then closed on the exciter with the field resistance cut out of the circuit by a special switch, as shown in the figure.

Induction Motors.—The most rugged and common type of alternating-current motor is the *squirrel-cage induction motor*. This type has a stationary armature winding somewhat like that of a synchronous motor. The rotor, however, consists of heavy bars of copper which are short-circuited at the ends by rings. The current flowing in the stationary winding, called the *stator*, induces a current in these loops of copper on the rotor by the principle of transformer action (page 134). The current induced in the rotor sets up a magnetic field which, combined with the magnetic field of the stator, causes the rotor to turn.

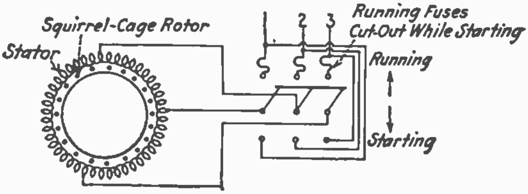


Fig. 38.—Wiring of squirrel-cage motor.

The single-phase, squirrel-cage induction motor (Fig. 38), like the *single-phase*, synchronous motor, has very little starting torque and, therefore, requires some starting device. If *started by hand in either direction, it will continue to run in that direction.* The *three-phase, squirrel-cage induction motor* has a *large starting torque*, however, which makes this motor particularly applicable for driving machines which must be started under heavy loads.

Reversing Rotation.—The direction of rotation of a three-phase, alternating-current motor may be changed by reversing any two of the connections of the supply lines to the stator.

Starting Methods.—Single-phase, squirrel-cage motors when equipped with a starting device, are very commonly used because of their uniform speed, simplicity, and ruggedness.

For small motors a *shaded pole winding* is frequently used, consisting of a single loop of heavy wire around one-half of the face of each field pole. This shaded pole winding distorts the field magnetism enough to start the motor turning in the correct direction. To reverse the direction of rotation the loop must be placed on the other side of each field pole.

For motors rated at one horsepower or less, a *split-phase winding* is common, which may consist of small field poles wound with fine wire between the main poles. This arrangement gives the effect of a moving magnetic field and thus causes rotation. A centrifugal switch is used to cut this split-phase winding out of service when the motor attains the rated speed. On the larger motors of this type, a clutch is sometimes used to pick up the load after the motor has reached full speed. Other methods of starting single-phase induction motors use combinations of resistance, reactance, and condensers to give an effect similar to that of a three-phase power supply while starting.

Autotransformer Starters.—When a large squirrel-cage motor is being started, it is necessary to reduce the voltage applied to the motor and the resultant current it requires by the use of an *autotransformer* (page 144) or a resistance device. Figure 39 shows the connections for an autotransformer starter. The contacts of the throw-over switch are usually operated under oil so that electric arcs may be extinguished rapidly. The autotransformer may be equipped with several tap connections to provide for different starting voltages on the motor, depending on the nature of the load. The oil tank containing the contacts of the throw-over switch must be marked in a suitable manner to indicate the proper oil level. The switch must provide an "off" position, a "running" position, and at least one "starting" position.

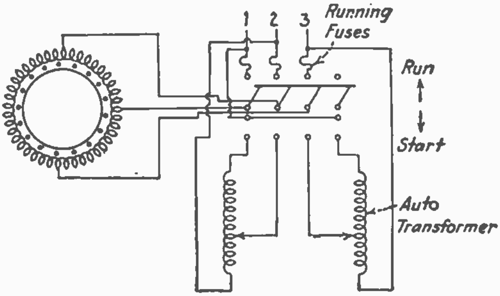


Fig. 39.—Autotransformer starter.

Speed Control.—Both the *synchronous* and *squirrel-cage induction motors* are constant-speed types. The former maintains a constant speed from no load to full load if the frequency of the supply voltage is constant. There is a slight falling off of the speed of the squirrel-cage motor from no load to full load. In order to get widely varying speed ranges such as are obtainable with direct-current motors, other types of alternating-current motors are employed. There are, however, one or two methods by which squirrel-cage induction motors may be operated at varying speeds by the use of *pole-shifting devices*, changing the number of poles, or changing the frequency of the line current.

Slip-ring Induction Motors.—In those cases where a very large load is started from a standstill, the squirrel-cage motor takes an excessively large starting current. For such purposes a *slip-ring alternating-current motor* may be used which has a resistance connected in the armature circuit similar to the way such a resistance is used in direct-current, variable-speed shunt motors. This resistance may be made variable and in this way provides a ready but *inefficient* means of speed control. When used for starting purposes only, such resistances are short-circuited after the motor reaches full speed. Some motors have internal resistances in the rotor with a centrifugal switch, and, therefore, require no slip rings. Figure 40 shows a slip-ring or wound-rotor induction motor of the kind generally used on variable-speed work.

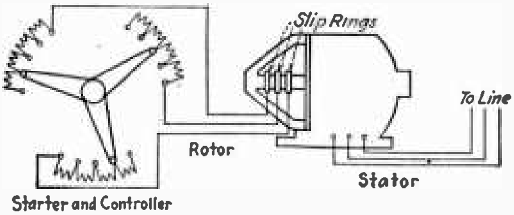


FIG. 40.—Wiring for varying the speed of slip-ring induction motor.

Repulsion Motors.—Because of the inability of single-phase synchronous motors and the simple type of induction motors to start from standstill when heavily loaded, the alternating-current repulsion motor and combinations of it were developed. The repulsion motor has a wound armature with a commutator and has characteristics similar to those of the direct-current series motor, that is, large starting torque with a small current requirement and variable speed. The two brushes running on the commutator are short-circuited in this motor *when it attains its maximum allowable speed.* The starting effect thus produced is sufficient to start a heavy load.

Repulsion-induction Motor.—To raise the power factor of the simple repulsion motor, a *compensating winding* may be added across the brushes. Control of speed may be obtained by placing a variable rheostat across one pair of brushes with the compensating winding across the other pair as shown in Fig. 41. This type of variable-speed motor is frequently used in ratings up to 5 horsepower; and when used for uniform-speed operation the repulsion-induction motor is built in sizes up to about 15 horsepower.

Repulsion-starting, Induction-running Motor.—This type of motor is very commonly used to retain the advantages of the repulsion motor for starting, thus giving a high starting torque. The objection to the ordinary repulsion motor after it gets up to speed is that the main armature current passes through a commutator with attendant commutator difficulties. In this type of motor, a centrifugal device throws the brushes out of contact with the commutator at full speed. At the same time all of the commutator segments are short-circuited by a ring, thereby allowing the motor to run as a simple induction motor. This motor is the most common single-phase motor for small-power work.

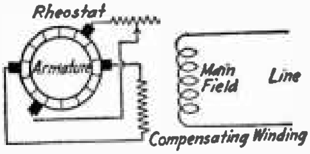


Fig. 41.—Wiring of repulsion-induction motor.

Alternating-current Series Motor.—Fractional horsepower motors of the *universal type*, that is, operating from either an alternating-current or a direct-current source, are of the series type. The field and armature are connected in series, with no control except by the load. No serious commutation difficulties are experienced in motors of this type in ratings less than one horsepower. This type of motor is very commonly used for many household and store appliances.

Comparison of Motors.—In order to understand properly the distinction between the several classes of motors which have been described, comparative tables are given on the following pages. These tables are based on the relative merits of alternating-current and direct-current motors. Comparison is also made of the several types of alternating-current motors.

COMPARISON OF PERFORMANCE OF TYPES OF MOTORS

Load requirements	Alternating-current type	Direct-current type
Very constant speed......	Synchronous motor	Shunt motor
Semiconstant speed......	Induction motor	Compound motor
Speed adjustable but remaining constant	Nothing competitive	Shunt motor with field control
Speed varying with load..	Induction motor with rotor control	Series motor

The choice of a motor often depends on other factors than performance. The following table gives the necessary information:

COMPARISON OF DIRECT-CURRENT AND ALTERNATING-CURRENT MOTORS

Direct-current Type	Alternating-current Type
Voltage limited to 230 volts on ordinary lighting mains	Any voltage available by use of transformers
Simple speed adjustment	Difficult speed adjustment
High efficiency	Lower efficiency
Good intermittent starting service	Heavy current and unsatisfactory intermittent starting service
Low starting currents (generally)	High starting currents
Maintenance high because of commutator troubles	Low maintenance, rugged and reliable

In choosing a motor for a particular use where alternating-current service only is available the following table is useful:

PERFORMANCE OF ALTERNATING-CURRENT MOTORS

Type	Operation	Starting torque	Applications
Three phase, squirrel cage	Constant speed, 5 per cent variation	Low with heavy current	Small machine tools
Slip-ring induction....	Adjustable constant speed at low efficiency	High with small current	Hoists, cranes, fans, air compressors
Synchronous.........	Fixed constant speed	Low with heavy current	Pumps, large compressors with flywheel
Single-phase repulsion.	Constant speed	High with small current	Small machine tools, portable use, below 15 horsepower
Single-phase induction	Constant speed	Low with large current requirement	Household appliances, small sizes
Single-phase, series...	Variable speed with load	High with large current requirement	Portable appliances, fractional horsepower sizes

Protection of Motors.—In order to cut off the power supply of a motor and thus prevent serious damage to the motor in the event of heavy overload, protection is usually provided by fuses or circuit breakers.

The maximum allowable rating or setting of the automatic overload protective devices (fuses and circuit breakers) to be used in each ungrounded wire of any individual motor circuit is given in the usual motor tables (page 22).

Motor Calculations.—To determine the proper size of a motor to be used for known requirements, it is first necessary to determine the horsepower required to operate the machine which is to be driven. In many cases where individual drives are employed with geared motors, the motors are furnished or specified by the manufacturers of the machines. In those cases where belt drives with countershafts are used, or where line shafting is used, the motors are often purchased independently of the machine. The type of motor to use is determined by the kind of work to be performed. The size of the motor is also often determined by the space available. In most cases, the manufacturer of a motor-driven machine specifies the size of the motor necessary to operate it. Where no size is stated, a test may be made to determine the necessary size or rating.

When the horsepower required to operate a machine is known, the kilowatts input required by a direct-current motor to operate the machine may be determined by the following expression:

$$\text{Kilowatts input} = \frac{\text{horsepower output} \times 0.746}{\text{efficiency of motor}}.$$

In the case of an alternating-current motor, the kilowatts input will be the same as for the direct-current motor. The kilovolt-amperes (kv.a.), however, which determine the current, is determined by the following expression:

$$\text{Kilovolt-amperes} = \frac{\text{horsepower output} \times 0.746}{\text{efficiency of motor} \times \text{power factor of motor}}.$$

Example.—A machine requires a 5-horsepower, repulsion-induction motor to be operated from a single-phase, alternating-current supply. The full-load power factor is 85 per cent and the efficiency 80 per cent. What is the kilovolt-amperes input of the motor?

Solution.—Kilovolt-amperes $= \dfrac{5 \times 0.746}{0.80 \times 0.85} = 5.5.$

Grounding of Motors.—In many cases there are no ground connections on a three-phase, three-wire, alternating-current distribution system for motor supply. If, in such a system, one phase of a motor becomes attached to its frame in some way, the frame would become "alive." As there is no circuit breaker or fuse to take care of such a condition, it is a good practice to connect the frame of a motor, or generator as well, to a ground wire, in order to avoid injury to an operator or workman.

In electric distribution systems which are normally grounded on one wire it is also customary to ground the frames of motors to protect workmen, and also to prevent an arcing condition inside the motor which may result if there is no ground connection on the frame. Of course, with a grounded frame, the touching of any wire of the motor circuit to the frame will cause the "blowing" of the fuse or the opening of the circuit by whatever protective device is used. The rules of the National Electrical Code require that the frame, except for portable motors, must be grounded if the motor operates in excess of 150 volts and is accessible to other than qualified persons. When the frame is not grounded, it must be permanently and effectively insulated from the ground.

Ground Connection for Motors.—Because of the large size of the wires or other conductors supplying current to a motor, the ground wire must be correspondingly large. The size is actually determined by the size of the nearest fuse or circuit breaker protecting the wires. The path to the ground provided by a grounding wire must, in general, have current-carrying capacity sufficient to insure the continuity and continued effectiveness of the path under conditions of excess current caused by accidental grounding of any normally ungrounded wire or other conductor of the circuit or the system to which it is electrically connected. The size of a conductor (wire or pipe) used for grounding an interior conduit system, armored cable, metal raceway, and fixed equipment must be not less than that given in table XXIV.

TABLE XXIV.—SIZES OF GROUNDING WIRE AND PIPE

Capacity of automatic overload protective device, amperes	Size of copper wire, American or B. & S. gage	Nominal size of grounding pipe, inches
30	14	½
60	10	½
100	8	½
200	6	½
400	4	¾
600	2	¾
800	0	1
1,000	00	1

Number 18 copper wire may be used for grounding portable equipment if the wires are protected by fuses not larger than the 15-ampere size. For portable equipment requiring fuses of more than 15-ampere rating, the table must be followed. In addition to the ground connection on the frame of the motor, the autotransformer, relays, and other control equipment must be grounded to protect the operator.

Mounting and Foundations for Motors.—Small motors are usually mounted directly on benches or tables or mounted as part of a machine. Silencing of small machines against vibration may be accomplished by rubber or cork layers under the base. Large motors for *industrial use* are generally mounted on a metal base which may be adjusted for belt tension and for alignment by a *take-up arrangement.* Very large motors and generators are set on *concrete foundations* reinforced to prevent vibration. A rigid foundation prevents the machine from getting out of line.

On small motor generators (page 235), the use of flexible couplings will often take care of slight irregularities of alignment and also prevents the machine from getting out of line. Flexible couplings will, in most cases, have a tendency to reduce the shock of one motor-generator unit upon the other when they are started. The proper alignment of motor generators is very important to prevent damage to the bearings or the shafts of the machines.

Machines in constant use which cannot be conveniently shut down for oiling must be provided with special guards to prevent the oiler from coming in contact with live or moving parts of the machine. When the bearings of a machine are of a type which drip oil, care must be taken to prevent such drippings of oil from causing fire or slipping hazards.

Part 4

MOTOR GENERATORS, ROTARY CONVERTERS, AND DYNAMOTORS

A change in the form of an electric current may be made by transformers, rectifiers, motor generators, rotary converters, and dynamotors, according to the requirements. A *transformer* changes the voltage of an alternating current but the frequency remains constant. A *rectifier* changes an alternating current into a pulsating direct current. The other devices are used to change alternating current at one frequency to alternating current at another frequency, or to a steady direct current, or the reverse, and also to change direct current from one voltage to another.

Motor Generator.—The alternating current required for the operation of a spark transmitter (page 40) for radio telegraphy is usually obtained from a motor generator. In marine service such a machine is designed to transform the direct-current output of the ship's generator into alternating current. The high-voltage direct-current supply required for vacuum-tube and arc transmitters may be obtained by means of a motor-generator operating on low-voltage direct current. In land stations a local supply of alternating current is usually available.

A diagram of connections for a 500-cycle motor-generator set operated on direct current at 110 volts is shown in Fig. 42. The field current of the generator is taken from the supply line, and the field rheostat of the motor controls the speed of the machine. An increase in the applied resistance of the rheostat increases the speed, and a decrease in this resistance decreases the speed. The field rheostat of the generator controls the voltage of the alternating-current output. The frequency of the output depends on the speed of the machine. Thus if the speed of the machine is lowered, both the voltage and the frequency of the output are decreased. A motor-generator used with a radio transmitter must take a variable load and maintain a constant frequency or voltage or both. The necessary voltage regulation of the motor generator is obtained by using one of the following types of direct-current motors for driving a simple alternating-current generator: (1) shunt motor, (2) compound motor, (3) differential compound motor (page 225).

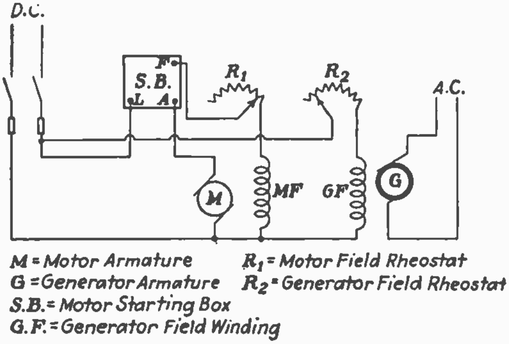


FIG. 42.—Wiring of motor generator.

Motor generators are available also for operation on 110-volt, 60-cycle circuits, with a built-in exciter. An inductor alternator (page 218) may be used instead of a revolving-armature generator. The 500- or 600-volt direct-current supply for arc transmitters (page 459) may be obtained from a motor-generator operated on a 110-volt lighting circuit. The 500- to 900-cycle alternating current for the transformer of an audio-frequency spark transmitter (page 456) may be obtained from a motor-generator operated from a low-voltage storage battery or a 110-volt lighting circuit. A voltage of 300 or more volts for the plates of vacuum tubes used to generate undamped (page 90) radio-frequency currents may be obtained by means of a suitable motor generator.

Rotary Converter.—A direct-current armature with connections to a pair of collector rings on its opposite sides will deliver alternating current from the rings and, at the same time, direct current from the armature. The circuit diagram of such a device, called a rotary converter, is shown in Fig. 43. Each ring must have as many connections to the armature as there are pairs of poles, for a multipolar machine. When the connections to the collector rings are passing under the brushes, the alternating voltage reaches its maximum value, and when they are halfway between the brushes the voltage is at its minimum. A machine of this kind, when connected to a direct-current circuit, operates as a shunt motor and can be used to generate an alternating current; this type is called a *double-current generator*. On the other hand, when the machine is operated as a motor on alternating current, it delivers direct current and is called a rotary converter. When an alternating-current generator operates as a synchronous motor (page 227), it runs at a definite speed (synchronous speed), depending on the frequency of the current supplied and requires for its field a direct current which is taken from the commutator. When a rotary converter is used to change direct current into alternating current, the frequency depends on the speed of the armature and the machine is said to operate as an "inverted rotary." Thus the rotary converter, sometimes called a synchronous *converter*, may be considered as a synchronous motor including a commutator.

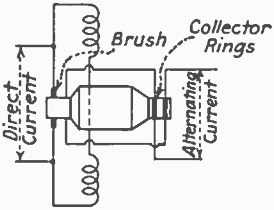


Fig. 43.—Wiring of rotary converter.

Dynamotor.—A machine which is used to change the voltage of a direct-current supply is called a dynamotor. This cannot be accomplished by means of a rotary converter. The dynamotor has two separate armature windings on a single core, one of which serves as a motor and the other as a generator. The two windings are connected to commutators at opposite ends of the shaft, and the output voltage depends on the applied voltage. Only one set of field magnets is used and the field coils together with the motor armature are supplied with current from the same supply. The diagram in Fig. 44 shows a dynamotor having a direct-current output of 300 to 1,000 volts on a low-voltage battery input of 10 or 12 volts. In both the dynamotor and the rotary converter the same armature serves as a generator and as a motor. This construction makes a smaller machine than a motor generator, because only two bearings are required and only one short armature is needed. These machines deliver an alternating-current output on a direct-current input, or the reverse. The dynamotor has one generator winding and one motor winding; the rotary converter has one winding for both direct and alternating current. The rotary converter, as a single machine, takes the place of the two units in a motor-generator outfit. It has the disadvantage that the generator voltage (effective value) depends on the voltage supply to the motor, being about 71 per cent of the supply in single-phase conversion. Because of constructional difficulties it is not practicable to design rotary converters in small sizes to deliver alternating current at frequencies as high as 500 cycles. For use with a radio transmitter, neither the dynamotor nor the rotary converter is so efficient as a motor generator.

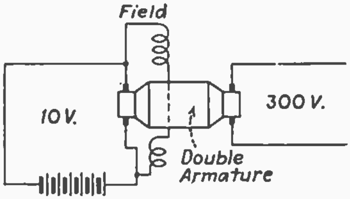


Fig. 44.—Wiring of dynamotor.

Protective Condensers.—The windings of a generator must be protected by some means against high-voltage surges originating in the secondary winding of the power transformer (page 138). The *protective-condenser device* provided for such protection has three connecting terminals, the two outer ones being connected across the machine to be protected and the middle one being grounded. On board ship the ground connection is made to the hull of a steel vessel and to a copper plate beneath the water line on the hull of a wooden vessel. The primary winding of the power transformer is likewise provided with a protective device.

If a high-voltage surge occurs, it is first absorbed in the protective condenser and then discharged across a *safety gap*. Any radio-frequency currents which are induced in the circuit are by-passed to the ground through the low impedance of the condensers. A condenser in which the dielectric has been punctured by a high-voltage discharge must be replaced. Condensers having a capacity of 0.5 to 1.0 microfarad may be used for this purpose. Protective condensers are connected across the motor armature, the motor field terminals, the generator armature, and the generator field terminals. In some cases fuses are placed in series with such condensers to protect the line if the condensers become short-circuited.

Trouble Chart of Motors and Generators.—Almost all unusual happenings on a motor or generator indicate that there is some trouble with the machine. Such happenings may be accompanied by smoke, flame, or pounding, or they may be of apparent minor importance, such as sparking, sudden changes in speed, frequent blowing of fuses, etc. It is advisable, after any such unusual occurrence, to make a careful investigation and test of the machine.

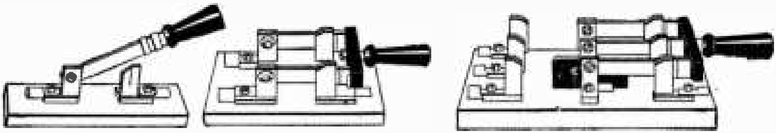
Symptom	Cause
Noise	Loose bolts or screws
	Out of line—vibration
	Rubbing or improper end play—pounding
	Brush trouble—squeaking
	Loose belt—flapping
Brush sparking	Overload or brushes set wrong
	Rough commutator, or sticky or broken brushes
	Armature winding damaged
Heating of coil	Overload or poor ventilation
	Short-circuited or grounded windings
	Moisture
Heating of bearing	Poor alignment or bent shaft or rubbing
	Bearing too tight, scored or dirty
	Poor or insufficient lubrication
	Belt too tight
Hot commutator	Sparking
	Poor brush contact
	Unsatisfactory ventilation
Blowing fuses	Low voltage on mains
	Overload
	Short circuit or ground on coils
High motor speed	Field current too small or field open
	Wrong connections
	Brushes set wrong
	Insufficient load (on series motor)
Low motor speed	Overload or too great friction
	Open armature connections or leads
	Brushes set wrong
	Weak magnetic field
Will not start	Overload
	Load locked or on dead center
	Starting device in trouble
	Open phase
	Short-circuited resistance of wound-rotor type
	Excessive friction
	Short circuit in the field coils or in the armature
Runs backward	Wrong connections

Part 5

CIRCUIT CONTROL APPARATUS

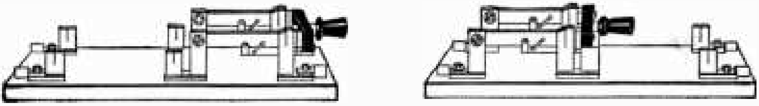
An electric installation must be laid out in such a way that it is at all times under control. This requires the use of certain devices such as switches, fuses, circuit breakers, and associated apparatus including cabinets, panel boards, and switchboards.

Kinds of Switches.—Electric switches are used for connecting and disconnecting electric circuits, for the transfer of an electric current from one circuit to another, and as a means of emergency control. They are made for a variety of uses in many sizes and styles. In a *knife switch* the connecting part consists of a hinged bar or blade. A *single-pole switch* disconnects two wires, a *three-pole switch* disconnects four wires, and so on. A knife switch may be *single throw* or *double throw* and may have fuse terminals



Single-Pole, Single Throw Double-Pole, Single Throw Three-Pole, Double Throw

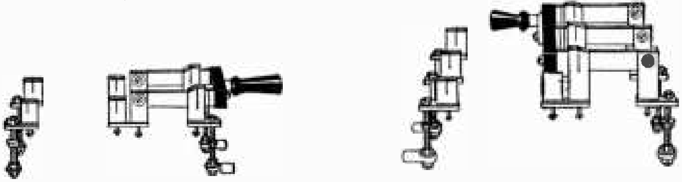
Front Connected



Double-Pole, Single Throw Fuses at Bottom

Double-Pole, Single Throw Fuses at Top

Equipped with Quick Break Attachments, Front Connected



Double-Pole, Single Throw Fuses at Bottom, Low Jaws

Three-Pole, Single Throw Fuses at Top

Back Connected

Fig. 45.—Knife switches.

included on the mounting. The fuses may be mounted either at the top or at the bottom of the switch. Several types of knife switches are shown in Fig. 45.

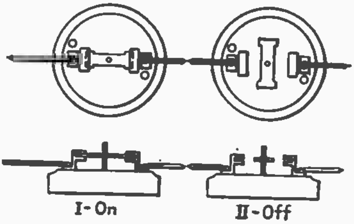
All types of switches must be plainly marked where the marking can be read after the switch is installed, with the current and the voltage for which the switch is designed.

When a knife switch is opened in a circuit which carries a current, an arc is usually formed between the blade and the contact jaw of the switch. Frequent repetition of such an arc will in time destroy the switch. Circuits carrying large currents, therefore, should be provided with either a quick-break switch or a circuit breaker. In a quick-break switch the main blade is first moved out of contact with its jaw, and when it is clear, an auxiliary blade is rapidly pulled out of its jaw by means of a spring, thus reducing the amount of arcing. One form of such a switch is shown in the middle of Fig. 45. Auxiliary contacts of a renewable or quick-break type, or the equivalent, must be provided on all 600-volt switches designed for use in breaking currents from 200 to 1,000 amperes, inclusive. It is recommended that such auxiliary contacts be provided on all direct-current switches rated at more than 250 volts. Knife switches should be used on circuits carrying more than about 30 amperes, and for carrying high-voltage alternating currents, switches immersed in oil are recommended.

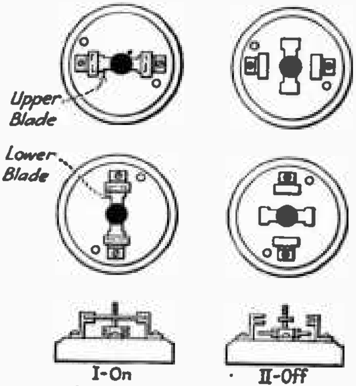
Rotary and Push-button Switches.—A *rotary* or *snap switch* is shown diagrammatically in Fig. 46. This switch is used generally for surface work and may be obtained in either the single-pole or the double-pole type, with a form of indicator which shows whether the switch is off or on. A *three-way rotary switch*, according to the National Electrical Code, is to be considered as a single-pole switch. It has three terminals and a switch blade that can be connected to one or the other of two terminals. A *four-way rotary switch* is constructed in a similar manner. Many other forms of switches are made for special work such as the *two- and three-point surface switches* and the *two- and three-circuit electrolier surface switches*. The action of these switches can be understood readily from a study of the diagrams in Fig. 46.

A *push-button switch* is shown in Fig. 47, and a *tumbler switch* in Fig. 48. These are used mostly for flush and pendant work and can be obtained with either single or double poles. The push-button type is made also in such forms as the three-way, four-way, two- and three-circuit electrolier, pendant, and automatic-door switches.

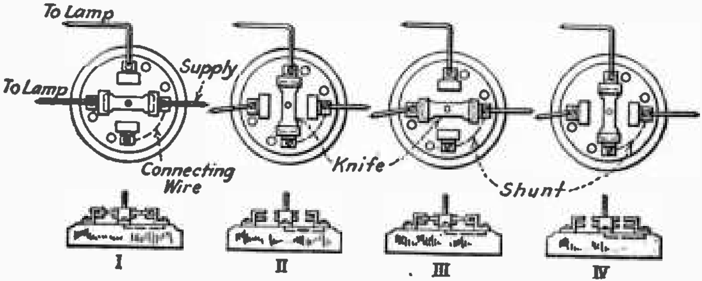
These types of switches are used mostly for small currents, usually not over 10 amperes at 125 volts or 5 amperes at 250 volts. They may be obtained, however, in sizes of greater capacity and higher voltage. The advantage of the snap and the push-button switches is that they afford more protection than the knife switches and can be installed in places which are



Operation of a Single-Pole Surface Switch



Operation of a Double-Pole Surface Switch



Operation of a Three-Way Surface Switch

FIG. 46.—Surface switches.

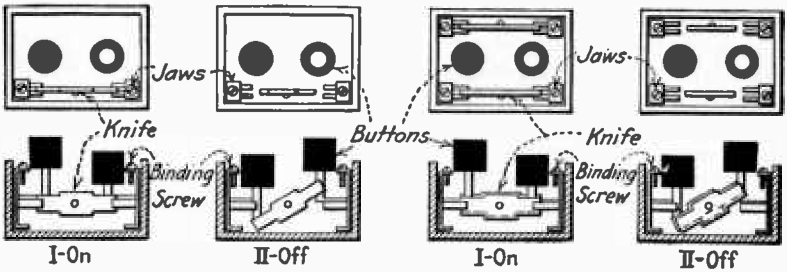


FIG. 47.—Push-button switch.

not suitable for the latter. The *flush construction* is used in concealed work and the *surface construction* in open wiring, molding, and knob-and-tube wiring.

Remote-control Switches.—For control from a distance, switches may be magnetically operated. For example, magnets may be controlled by a knife switch, a momentary-contact push-button switch, or an automatic circuit closer. When the remote-control circuit is closed, the magnets are energized and move a core (provided with copper contact pieces) so as to close the main supply line. This type of switch may be used on small motors, burglar-alarm systems, and for the control of heavy-capacity circuits.

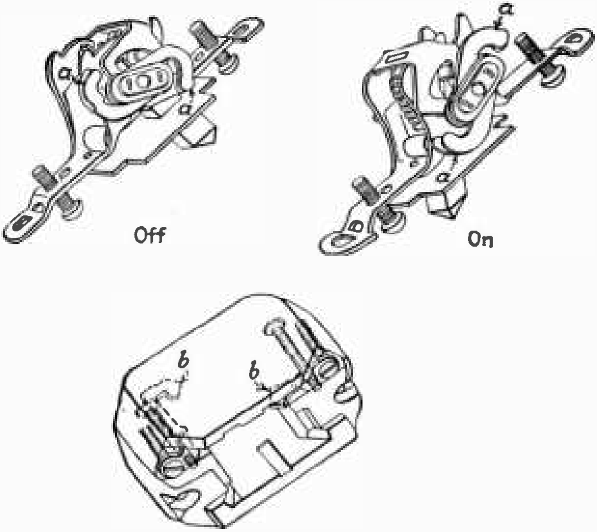
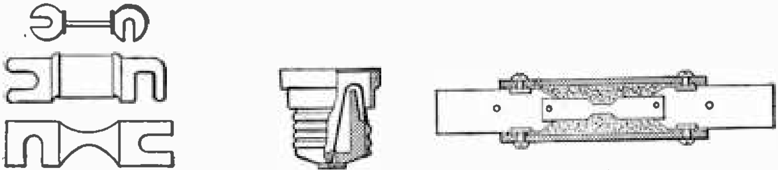


Fig. 48.—Tumbler switch.

Fuses and Circuit Breakers.—A current of electricity generates heat in the wire or other conductor through which it passes. This heat is proportional to the square of the current flowing; that is, if the current is doubled, the amount of heat is increased four times. A dangerous rise in current may be due to a short circuit or to an overload. An overloaded wire becomes overheated, thus causing the insulation to deteriorate or even to ignite. When a short circuit occurs, the weakest part of the system will give way to open the circuit. To reduce the fire hazard and to prevent damage to wires and apparatus from excessive currents, fuses or other protective devices must be installed. The fuse is the principal protective device used in radio, electric-light, and power work. In its simplest form it consists of a piece of wire made of an alloy designed to melt at a comparatively low temperature. It is so connected in the circuit that all the current must pass through it. When the current rises above its allowable strength, the fuse melts and opens the circuit, stopping the flow of current. The melting of the fuse is accompanied by a flash of fire due to the arc which is set up across the break in the fuse wire. This arc may not be very severe with small-capacity fuses on a moderate overload. But with large-capacity fuses, and on short circuits, a very severe flash and explosion may result, throwing molten metal some distance away. The explosion is due to the fact that the outer layers of metal in the fuse remain in a solid state while the metal at the center of the fuse melts and then vaporizes. A momentary overload will not blow a fuse, but when the overload is continued, the fuse has time to heat up.

Fuses may be the open or the enclosed type. The *link fuse* is an example of the open type. Enclosed fuses may be of either the plug or the cartridge form. Illustrations of these fuses are shown in Fig. 49. The cartridge fuses may be refilled by the manufacturer at a considerable saving.



Link Fuses

Edison Plug Fuse

Cartridge Plug

FIG. 49.—Fuses.

Link Fuses.—A link fuse will carry a current about 25 per cent above its rating before it melts. It is for this reason that link fuses must be stamped with 80 per cent of the maximum current which they can carry indefinitely, thus allowing about 25 per cent overload before the fuse melts. Link fuses are used mostly on panel boards and switchboards. They are cheap but damage the mounting when they melt. They may be obtained for low- and high-capacity work on both low- and high-voltage systems. They must not be used for capacities of 300 amperes or less.

Plug Fuses.—Plug fuses are made with a medium-size screw base in various sizes up to 30 amperes for 125-volt circuits, including three-wire 125- to 250-volt systems, and with larger screw bases in sizes from 31 to 60 amperes for 250-volt circuits. Plug fuses of 15-amperes capacity or less must be distinguished from those of larger capacity. Plug fuses are used mostly on branch-circuit panel boards and small-capacity cut-outs. They are cheaper than cartridge fuses.

Cartridge Fuses.—A cartridge fuse consists of a link soldered to copper contact terminals. The link is packed in a porous, non-conducting, non-inflammable filling, in powder or grain form, which is enclosed in a fiber tube. A device of some sort may be provided to indicate when the fuse has melted. Sizes up to 60 amperes are made with a ferrule contact, and those over 60 amperes with a knife-blade contact. There are two general classes of fuse sizes: (1) those for use on circuits carrying current of not over 250 volts; and (2) those for 250- to 600-volt circuits. The construction is such that the 250- and the 600-volt fuses will not fit the same cut-out and, furthermore, that only a small range of sizes will fit a given cut-out.

Enclosed fuses are used extensively in small-capacity as well as in moderate-capacity circuits. In large-capacity circuits, circuit breakers are frequently used. Under certain conditions fuses must be used in addition to circuit breakers.

Cut-outs.—A cut-out is a device provided in a circuit for the easy replacement of fuses. Fuse-plug cut-outs are made for single-, double-, and triple-pole work on both main lines and branch circuits. Cartridge-fuse cut-outs are made for single-, double-, and triple-pole work in sizes up to 100 amperes for voltages up to 250 volts. Cut-outs of larger capacity or for higher voltages are made only for single-pole work.

Circuit Breakers.—A circuit breaker is a device which is used to open a circuit automatically under a variety of conditions. Generally the condition is that of excessive current, but arrangements may be made to open the circuit under the conditions of high voltage, low voltage, or reverse current. Several accessory devices may be added such as the shunt-trip attachment by which the circuit breaker can be tripped electrically from a distance, the inverse-time-limit attachment which causes a circuit breaker to trip almost instantly on heavy overload but much more slowly on light overload, and the trip-free-on-overload or full-automatic overload trip which makes it impossible to hold the circuit breaker closed while a continued overload or short circuit exists on the line. Circuit breakers are usually classified according to their rated voltage, current, frequency, interrupting capacity, and momentary current-carrying capacity. The rated capacity should be at least as great as the maximum allowable one-hour (or more) overload current of the apparatus to be controlled. In general, circuit breakers are used for currents greater than the capacity of the largest approved fuses. They are used also on switchboards of power plants for the protection of light and power lines and for individual motor circuits. The two general types are the *air circuit breaker*, in which the contacts open in air; and the *oil circuit breaker*, in which the contacts open in oil.

Air Circuit Breakers.—In the single-pole, overload-release type of circuit breaker shown in Fig. 50, the current enters at the connection *A*, passes through the brush *B*, the lower contact block *H*, and the coil *D* to the other connection *C*. When the current exceeds the value for which the breaker is adjusted, the armature *E* is pulled up by the effect of the current in the coil *D*, striking the arm *J* and unlatching the toggle. The breaker then opens to the position indicated by the dotted lines. When the breaker begins to open, the brush leaves the contact block and then the circuit is broken by the separation of the carbon contacts *F* to prevent the burning of the main contacts. For small currents the coil is in series with the line circuit, and for larger currents it may be in parallel, or the coil may be a small transformer.

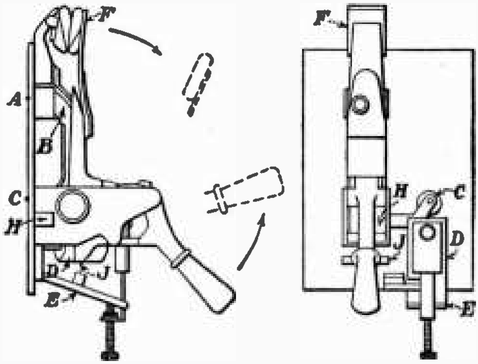


FIG. 50.—Air circuit breaker.

By means of an adjusting screw, the circuit breaker can be set for a considerable range of current varying from 80 to 160 per cent of the rating. This type of circuit breaker is made for both direct- and alternating-current work in sizes from 10 to about 15,000 amperes. The smaller sizes are made with one, two, three, or four poles, and the larger sizes are made with a single pole. The air circuit breaker is not much used for alternating-current work and the oil circuit breaker is in more common use. The advantages of the air circuit breakers compared with fuses are that they will open a circuit more quickly and at less expense. The circuit breaker, however, is high in first cost. The arc of the air circuit breaker is exposed, so that it is not suitable for use where acid fumes or excessive dust and dirt are present. For such places, oil circuit breakers are recommended.

Oil Circuit Breakers.—The type of oil circuit breaker shown in Fig. 51 is made with a tank for holding a supply of heavy mineral oil in which the contact parts are immersed. Since the electric arc is broken in oil, there is but little fire hazard or danger of flash-over. This construction permits the use of circuit breakers for high voltages. The oil circuit breaker is made with single and multiple poles, over a wide range of capacities and for a variety of purposes. The oil circuit breaker compared with the air circuit breaker and fuses has the advantages of protection against shock, better insulation, and no fire hazard from arcs. It is always used for high-voltage and very often for low-voltage work.

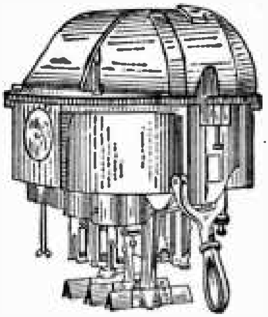


Fig. 51.—Oil circuit breaker.

In general, the capacity of fuses must not be greater than the capacity of the wires which are protected by the fuses. The rating of a fuse provides for an overload before melting or blowing of about 25 per cent for link fuses and 10 per cent for enclosed fuses. But fuses will carry currents much greater than these ratings for short periods because they do not heat up instantly. A circuit breaker responds instantly to the current for which it is set. It may be necessary, therefore, to set the circuit breaker considerably above the capacity of the wire. Circuit breakers of the time-limit and of the instantaneous types must not be set more than 10 and 60 per cent, respectively, above the allowable current-carrying capacity of the wire unless a fuse of a rating which properly protects the wires is also installed on the circuit.

Panel Boards.—Circuit controls are usually grouped together as much as possible for convenience in operation and maintenance. Branch circuits are put on panel boards which are enclosed in metal cabinets, while feeder circuits are put on switchboards which are open.

Switchboards.—The apparatus for the control of light or power feeders is mounted on a switchboard. This consists of individual slate or marble panels mounted on pipe or iron-bar frames. Lighting feeders are generally provided with a knife switch and fuses. Power feeders are controlled by a knife switch and fuses or, better, by a circuit breaker. The meters used are an ammeter for the load, a voltmeter for the voltage (or connected as a ground detector), and a watt-hour meter for the power.

Part 6

RECTIFIERS

Types of Rectifiers.—The several suitable types of rectifiers are crystals, dry-contact rectifiers, electrolytic cells, mechanical rectifiers, the mercury arc, vacuum tubes with filaments, and vacuum tubes without filaments.

The crystal rectifier, which has been described on page 124, consists of two different metals which, when in contact, will allow the flow of current in one direction but will offer high resistance to its flow in the other direction. This type of rectifier is greatly limited as to the amount of current and voltage which it can handle.

Dry-contact Rectifiers.—The most familiar example of this type is the crystal detector, which, however, is capable of rectifying only very small voltages and currents. Recent developments of such devices to handle larger amounts of power are the *copper-cuprous oxide units* ("Kuprox" and "Rectox") and the *magnesium-copper sulphide unit* ("Elkon"). The assembly of a copper-oxide element is shown in Fig. 52. The characteristics of these rectifiers depend upon the state of the surfaces in contact as well as the pressure upon them. The output of a unit often can be improved by tightening so as to increase the pressure on the elements. Like the electrolytic type, these rectifiers have a breakdown voltage and a breakdown temperature which, if exceeded, allow the passage of current in both directions. This condition, however, is temporary because normal operation is resumed as soon as the unit is cooled or the excessive voltage is removed. The copper-oxide type has a breakdown voltage of 11 volts (alternating current) on one disk and a breakdown temperature of about 160°F. The normal current density is 0.2 to 0.5 ampere per square inch. The allowable current density depends considerably on the ventilation provided; and, for this reason, most units are constructed with ventilating fins.

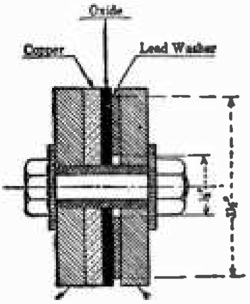


FIG. 52.—Dry-contact rectifier.

Any number of elements may be assembled in series and in parallel into rectifier groups for any desired value of current and voltage. The two standard methods of connecting rectifiers for full-wave rectification are shown in Fig. 53. An assembly of four rectifier elements into a group for full-wave rectification is shown in Fig. 54, the connections being the same as in *B* of Fig. 53.

The rectifier element in a copper-oxide rectifier consists of a disk of copper on which has been formed a layer of copper oxide. Electrical connection with the exposed surface of the oxide is made by means of a terminal member of soft metal, such as lead or metal foil. The elements are made in the form of washers assembled on a bolt to provide a good connection between the contact surfaces of the washers.

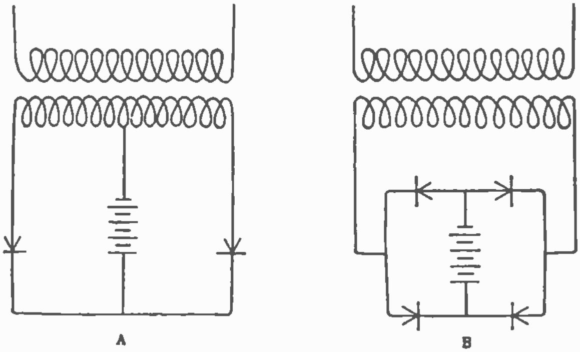


Fig. 53.—Standard methods of connecting rectifiers.

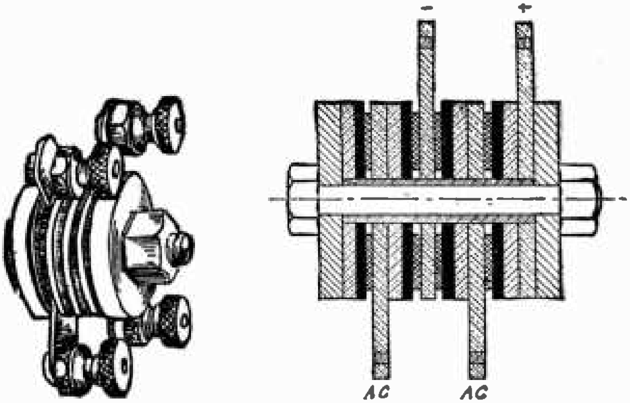


Fig. 54.—Group of rectifiers.

Characteristic Curves.—The relation between current and voltage in the two directions through the copper oxide is shown in Fig. 55. The part of the curve representing the current in the high-resistance direction is drawn to a

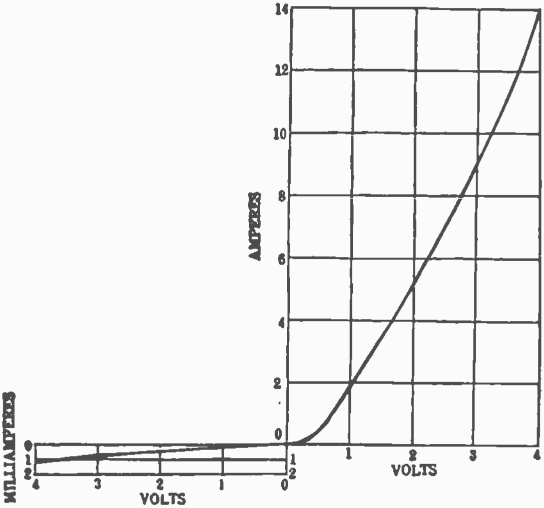


Fig. 55.—Relation between current and voltage through copper oxide. (*Figures 52 to 61 inclusive are from data by Grondahl and Geiger.*)

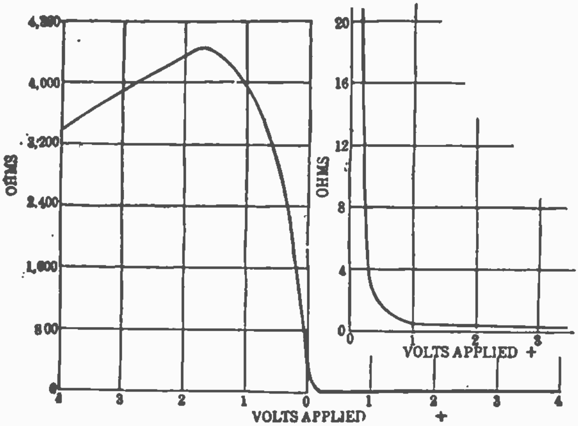


Fig. 56.—Relation between voltage and resistance through copper oxide.

scale one thousand times as great as the remainder of the curve. The scale for current above the horizontal axis is in amperes; that below the axis is in milliamperes.

The relation between voltage and resistance is shown in Fig. 56.

The negative values of electromotive force correspond to the high-resistance direction. The resistances approach a common value as the voltage approaches zero. As the voltage is increased from zero, the high resistance increases and the low resistance decreases, at first very rapidly, and then at a decreasing rate as the voltage increases. The low resistance continues to go down practically along a curve (sometimes called "exponential"), while the high resistance increases to a maximum beyond which it decreases slowly with further increase in voltage. The low resistance is shown in the curve in the upper right-hand corner with the scale magnified 200 times.

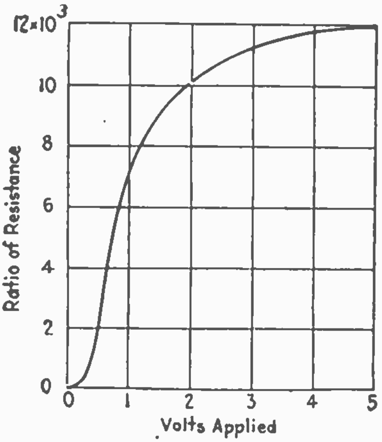


Fig. 57.—Curve of rectification ratio.

The *rectification ratio*, which is obtained by dividing the high resistance at any particular value of electromotive force by the low resistance at the same electromotive force, is shown in the curve of Fig. 57. This ratio bears a definite relation to *efficiency*. The relation between the two is complicated by the fact that in practice the voltage across the elements of the rectifier varies from zero to a maximum, which is different in the two directions. The efficiency curve of a full-wave rectifier constructed with four washers is shown in Fig. 58. This is an average unit. The efficiency here shown is the ratio of direct-current watts output to alternating-current watts input. True power efficiencies of over 80 per cent have been obtained. Since the rectification ratio at very low voltages approaches unity, it follows that the efficiency of the unit as a rectifier at very low voltages approaches zero. At the voltages that are common in the usual applications of a rectifier, the ratio is so high that variations are not often important.

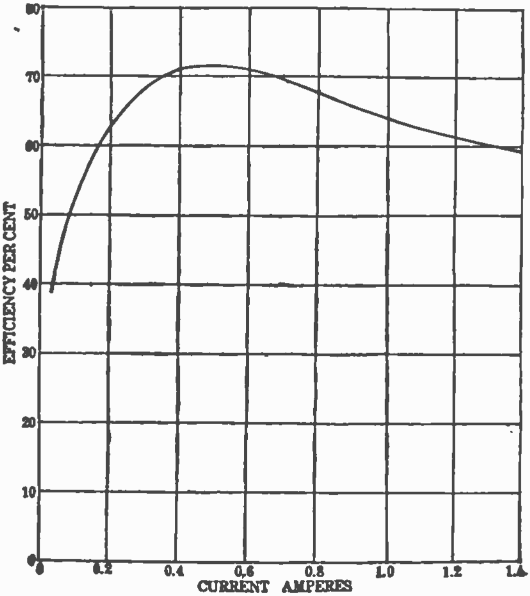


Fig. 58.—Efficiency curve of rectifier.

For most applications, the losses due to reverse current should be taken into account although they are small. In a full-wave rectifier connected as shown in *B* of Fig. 53, the voltage across each element during the part of each cycle when the voltage is applied in the high-resistance direction is considerably greater than the voltage applied in the low-resistance direction. Usually the voltage applied in the high-resistance direction is such that the rectifier is working well beyond the maximum of the high-resistance voltage curve (Fig. 56). For these reasons the ratio of the current in the low-resistance direction to the current in the high-resistance direction is considerably less under actual working conditions than the ratio shown in Fig. 57 of the high to the low resistance measured at the same voltage.

Figure 59 shows the true efficiency curves of a rectifier made up of four 1½-inch elements, as shown in Fig. 54. For obtaining these curves the power output was kept constant for each curve, the designating number on each curve being one-fourth the total power output. Points to the left of the maximum efficiency represent an excess of losses in the low-resistance direction; points to the right, an excess of losses in the high-resistance direction. If a given rectifier is used to supply a practically constant output voltage, as is required for battery charging, the losses in the high-resistance direction remain nearly constant while the losses in the low-resistance direction decrease with a decrease in the charging rate. For this reason, it is sometimes advisable to use a larger number of elements for a rectifier with a small output than is required for one with a larger output.

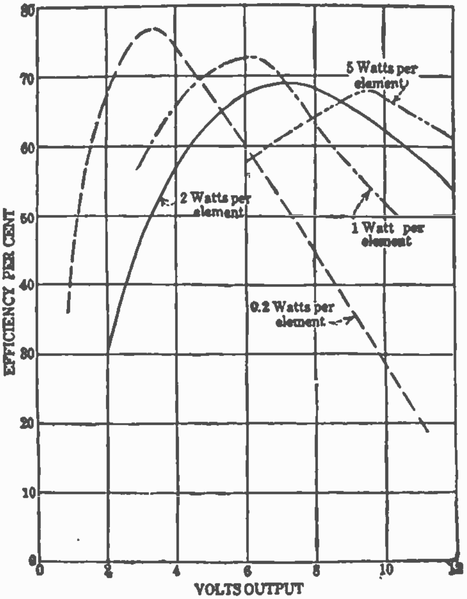


Fig. 59.—Efficiency curves for various values of power.

The number of elements required for a given power output depends also on the method of cooling. The manner in which the elements are to be connected, that is, the number in series and the number in parallel, may be determined from the curves shown in Fig. 59. To obtain maximum efficiency in a complete unit, the number of elements in series between any two terminals of the rectifier is found by dividing the desired voltage output by the voltage giving the maximum efficiency on the corresponding curve. Enough elements are to be connected in parallel to give the desired current output, keeping the output per washer at the value previously determined. If the method of connecting as shown in *A* (Fig. 53) is used, the number of washers in series should be doubled, thereby operating each element on the same portion of the characteristic curve as in the four-element arrangement.

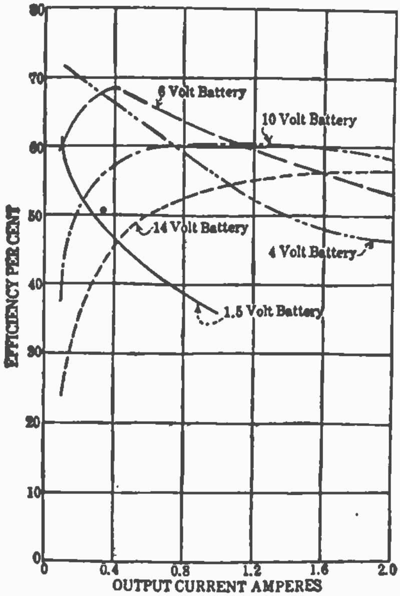


Fig. 60.—Efficiency of rectifier used as charger.

For applications requiring a current of a few tenths of an ampere or less, such as supplying the plate current of vacuum tubes, it is sometimes necessary, in order to obtain the maximum efficiency, to use an element of less than 1½-inch diameter, or a smaller output per washer than would be used in other applications. This can be seen from the curves, for the maximum efficiency (1½-inch washers) occurs at low current values only for the curves of small values of output per element.

Characteristics of Rectifier Groups.—Figure 60 gives the efficiency of a rectifier group used as a battery charger. Since in the charging of a battery the average value of the direct current required is of most importance, efficiency is taken as the ratio of direct-current volt-amperes to the alternating-current watts, which is less than the *power* efficiency.

A rectifier of this kind may be used at any ordinary frequency without any effect on its operation. It has been tried with measuring instruments and found to give good rectification up to a frequency of over 3,000,000 cycles per second. Above 100,000 cycles per second, there is a gradual decrease in the rectification ratio (page 251) which may be due to the effects of capacity.

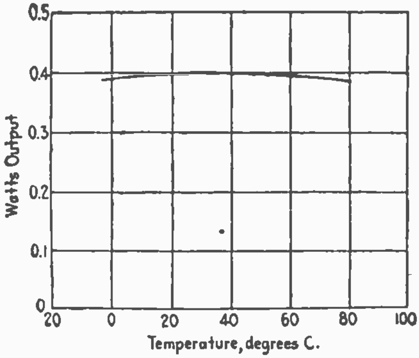


FIG. 61.—Effect of temperature on power output with constant voltage.

The effect of temperature on efficiency may be compensated in various ways and the following is an illustration of what may be done by the proper choice of the size of the unit and by the use of a reactive "ballast." The problem under consideration was to supply a certain constant amount of rectified power at all temperatures from 0 to +80°C. with a constant voltage supply. The results are shown in the curve of Fig. 61.

The voltage regulation of a rectifier depends primarily on the effective resistance of the unit. It may be pointed out that in a battery of storage cells or of primary cells, the current regulation may be controlled by varying the number of cells which are put in parallel, so in the case of this rectifier it is possible to control the regulation by the same method. Within reasonable limits, practically any excellence of regulation can be obtained by building into the rectifier the necessary amount of copper. In a test of a rectifier of small capacity, the regulation between no load and full load may be changed from 16.5 to 8.5 per cent by doubling the amount of copper in the rectifier.

The dry-contact retifier can be made in the proper voltage and current capacities to charge either B and A batteries and to charge them at a normal rate or at a trickle-charging rate as desired. To charge an A battery at a trickle-charging rate, a small transformer and a rectifier consisting of 4 to 16 copper disks may be used. The unit may be assembled in a case together with the A battery itself. Rectifiers have been designed to meet the demand for 2- and 5-ampere chargers.

A B-battery charging unit suitable for a 115-volt B battery may be made by connecting a copper-oxide rectifier with the necessary ballast reactance (page 255) to a 110-volt house-lighting circuit. For a 135-volt battery, it is necessary to use a transformer to step up the alternating-current voltage. The transformer can be built with the necessary reactance so that the size of the unit does not need to be any larger in the second case than in the first. With such a unit, it is necessary only to reverse the switch to disconnect the battery from the radio receiving set and connect it to the rectifier.

The more interesting application of rectifiers in radio is probably in battery eliminators. For this purpose, the rectifiers have to be built with the necessary voltage and current capacity to supply not only the power to operate the vacuum tubes but also the power that is lost in the filters. Units have been made which give satisfactory service as substitutes for both A and B batteries. A dry-contact rectifier in an A-battery eliminator using 1,500-microfarad condensers and 0.2-henry choke coils is shown in Fig. 62.

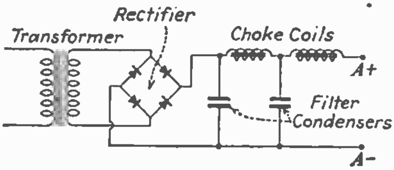


FIG. 62.—Rectifier in A-battery eliminator.

Electrolytic Rectifiers.—Certain metals when immersed in various electrolytes or solutions permit current to pass in one direction only. *Aluminum* and *tantalum* are the only metals which possess this property to a degree satisfactory for commercial purposes. When one of these metals is used for one electrode, the other electrode is usually made of lead. The electrolytes commonly used are ammonium phosphate or borate, diluted sulphuric acid, and ordinary borax. The acid has the disadvantage that it attacks the aluminum when the rectifier cell is not in operation. The maximum voltage which a cell can stand before breaking down varies considerably with the nature of the solution. For aluminum and ammonium phosphate, this critical voltage is about 160 volts. The number of units that are needed in a rectifier of this kind depends on the voltage and the current which are to be handled. The current must be limited so that only a slight glow occurs on the plates during operation.

The electrolytic rectifier does not cause any electrical disturbances in the line, because there are no circuits to be opened and closed, or to oscillate, but the device is not suitable for the rectification of a heavy current. Excessive current causes gassing, destruction of the metal electrodes, and a high temperature of the solution. Such rectifiers for currents over two or three amperes are difficult to maintain and construct, unless used for intermittent service only. The efficiency of the aluminum rectifier improves as the frequency of the power supply decreases. The electrolytic or chemical rectifier is frequently used with radio transmitters in place of the more expensive high-voltage, direct-current generators, batteries, or vacuum-tube rectifiers.

Construction.—The rectifier charging unit shown in Fig. 63 is made with electrodes of aluminum and lead in a saturated solution (in distilled water) of boric acid, sodium bicarbonate, sodium phosphate, or ammonium phosphate. The electrodes are made of metal about 1 inch wide and 1⁄32 inch thick, separated about 1½ inches. It is a safe practice to allow about 50 volts to each cell and to provide an immersed area of aluminum strip sufficient for a current density of about 40 milliamperes per square inch. An electrolytic rectifier and a filter (page 105) as used for plate-supply purposes are shown in Fig. 64.

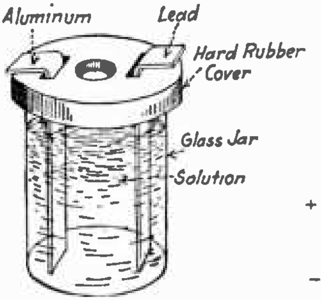


Fig. 63.—Electrolytic rectifier.

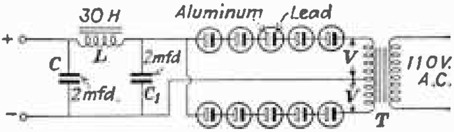


Fig. 64.—Electrolytic rectifier and filter.

Forming.—Before the cell can be used, the aluminum electrode must be seasoned or "formed." This is done by connecting the aluminum electrode to the positive side of a direct-current, 110-volt circuit and the "neutral" metal electrode, usually of lead, through a 25-watt, incandescent test lamp to the negative side of the circuit. The test lamp gradually becomes dim, and finally when it gives no light at all the electrode is ready for use.

Operation in Charging.—If it is desired to use the electrolytic rectifier directly on the current-supply circuit, some form of resistance must be inserted in series with the cell to decrease the voltage. This resistance may consist of an ordinary incandescent lamp or may be in the form of a variable-resistance unit. The lead terminal is connected to one side of the supply circuit, and the aluminum terminal is connected to the positive post of the battery to be charged. The negative post of the battery is connected through the lamp or other resistance to the other side of the current-supply circuit. The charging current may be increased by using (1) a lamp with a higher wattage rating or (2) a lower resistance.

After a period of use, the solution in the jar of the rectifier may discolor. This is a normal condition and does not indicate that the solution is unsuitable. If the unit is left idle for some time, the aluminum plates may become coated. This coating must be removed with fine emery cloth before the aluminum plates can be used again. When the cell is in operation, the temperature of the solution gradually increases.

Full-wave Rectification.—If it is desired to rectify both half waves of the cycle of an alternating current, a transformer with a mid-tap on the secondary winding is necessary, and two aluminum electrodes are used with a single lead electrode in the same jar. The connections are shown in Fig. 65, and the direction of current flow for each half cycle is shown in Fig. 66. It is evident that although the left- and right-hand circuits are used alternately, the current passing through the battery is always in the same direction.

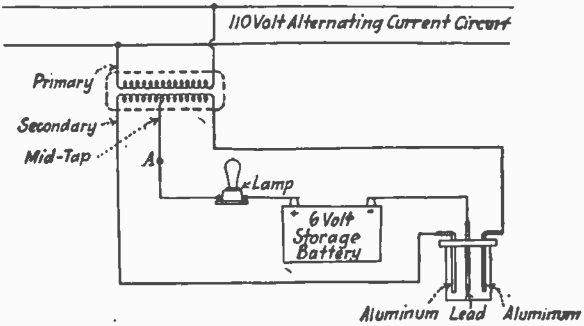


FIG. 65.—Full-wave rectifier.

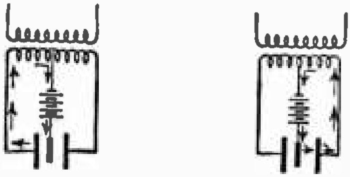


FIG. 66.—Current flow in full-wave rectifier.

Mechanical Rectifiers.—The device called a mechanical rectifier consists of a vibrating reed which alternately makes and breaks contact with the ends of a transformer, as shown in Fig. 67. The reed is a mechanical device which is controlled electrically to make contact at the proper time. The advantages of this device are its low cost, freedom from operating difficulties, and its high efficiency. It is used for charging small batteries and will operate satisfactorily even on small currents, if the make-and-break action can be established.

Mercury-arc Rectifiers.—The current-rectifying device applying a mercury arc is a true rectifier of alternating current which allows current to pass only during one-half of the cycle. If two electrodes are provided, each acts independently to pass one side of the alternating current. The elementary *mercury-arc rectifier* shown in Fig. 68 consists of four electrodes contained in a *glass bulb* which is filled with air and then sealed. The two upper terminals, which are made of graphite, are called the *anodes*. The two lower electrodes are of mercury, one being connected to the battery to be charged and the other being utilized as a "starting" electrode. The device is so mounted that it may be tilted to bring the two lower electrodes into contact for starting. When the tube is in a vertical operating position the lower electrodes are not connected. Before the device is started all the electrodes are covered with a high-resistance film of mercury. The film over the anodes is apparent only when the cathode is positive with respect to one of the anodes. The resistance of the mercury-pool cathode disappears when a current flow is established; but if the current stops, the mercury arc is broken and must be established again. The arc is established by tipping the device to combine the two pools of mercury into a path for the current. When the tube is upright the pools separate, causing a spark which breaks down the resistance. A current will then flow alternately from the two anodes, because the electrodes are at opposite potentials due to the mid-tap connection on the transformer. The choke coil on the supply line is used to

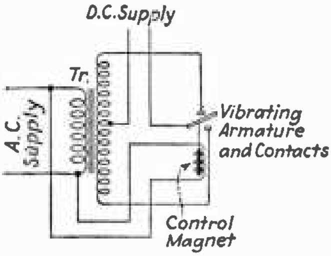


Fig. 67.—Mechanical rectifier.

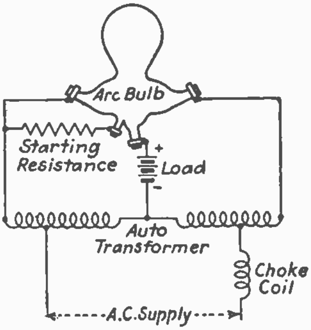


Fig. 68.—Mercury-arc rectifier.

regulate the arc. This is necessary in battery-charging work to increase the direct-current voltage as the charging of the battery nears its completion. The double-electrode rectifier provides a direct current which has a slight ripple but no break as in the current from a bulb with only one electrode.

Two-electrode Tube Rectifiers.—The vacuum-tube rectifier and the gas-filled rectifier are considered as two-electrode tubes and are made in sizes suitable for use ranging from battery charging to plate supply for vacuum tubes. Commercial types of these tubes are listed in table XXVII on page 296.

Battery-charging tube rectifiers are of a gas-filled type, and although they are designed to take loads of from 25 to 1,000 watts, they are not very efficient. The vacuum-tube rectifier for the plate supply of vacuum tubes is a high-vacuum, two-electrode unit made in sizes from 250 to 100,000 watts and for voltages from 1,000 to 25,000 volts.

For radio purposes the current must have a ripple of less than one per cent, as otherwise the carrier wave (page 34) would be affected by interference due to the "side" band frequencies. A half-wave vacuum-tube rectifier delivers an intermittent direct current because the tube passes current only when the plate is positive with respect to the filament. If a continuous current is desired, two vacuum tubes must be used in the rectifier.

Vacuum-tube Rectifiers Using UX-280 or UX-281 Tubes.—The UX-280 tube is a *full-wave* rectifier. It consists of two plates, or anodes, with a filament section for each. The maximum permissible direct current is 125 milliamperes, and the maximum alternating-current voltage is 350 volts (effective value) per anode. This tube may be used to replace the UX-213 tube in devices designed for that tube, and with slightly greater output.

The UX-281 tube is a single-anode type for *half-wave* rectification. The maximum permissible direct current is 85 milliamperes, with a maximum alternating-current voltage of 700 volts (effective value). When two UX-281 tubes are used in a full-wave circuit, the maximum direct current is 170 milliamperes. The tube may be used for replacement in equipment designed for UX-216B tubes. The UX-280 and UX-281 rectifier tubes are of the oxide-coated filament type. The UX-280 tube is rated at 5 volts of filament voltage, with a variation of 10 per cent. This is an adequate variation requirement, since the line voltage commonly varies between 105 and 125 volts and the nominal value is 115 volts.

A battery eliminator must deliver uniform voltage under varying conditions of current requirements. The important factor in obtaining satisfactory current regulation is low internal resistance in the rectifier tube. High internal resistance causes the output voltage to vary rapidly with small changes in the current. Because of the low internal resistance of the UX-280 tube, a transformer supplying a secondary terminal voltage of 220 volts will furnish a direct current of 65 milliamperes at 220 volts at the input of the filter, the voltage at the output of a 1,000-ohm filter being 150 volts. Higher output voltages are available with lower current requirements or higher transformer voltages.

To obtain a smooth direct-current output from a battery eliminator, filter circuits are necessary. The requirements of these circuits are minimized by the use of filament-type rectifiers. There is no arcing or sparking when UX-213 or UX-216B tubes are used, and hence there is no tendency to set up radio-frequency surges or impulses.

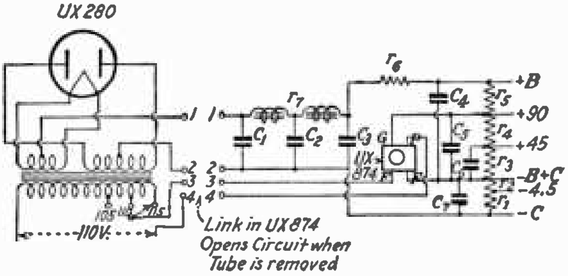


Fig. 69.—Rectifier and filter for UX-280 tube.

Rectifier Circuit Design.—Rectifier circuits for the UX-280 tube are shown in Figs. 69 and 70. The values of the inductances and condensers in the filter circuit, as given in table XXV, vary with several factors. The most important one of these is the amount of ripple voltage which can be allowed. Other factors are the maximum current of the B-current supply and the frequency of the line supplying the alternating current.

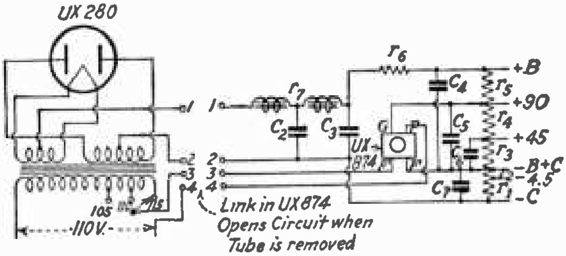


Fig. 70.—Rectifier and filter with input condenser omitted.

TABLE XXV.—CONSTANTS FOR VACUUM-TUBE RECTIFIER CIRCUITS

Select r_1, r_2, and r_3 for the tube of type and voltage desired						Select r_6 and r_7 for the transformer and power-tube type Select r_6 for the choke coils (r_7 is the total choke-coil resistance)							
						Filter circuit in Fig. 69, condenser input				Filter circuit in Fig. 70 choke input			
							Total rectified output[1]				Rectified output[1]		
Power-tube type	$+B$, volts	$-C$, volts	r_1, ohms	r_2, ohms	r_3, ohms	Transformer secondary volts, per anode effective	D.c., volts	D.c., milliamp.	$r_6 + r_7$ ohms	Transformer secondary volts, per anode effective	D.c., volts	D.c., milliamp.	$r_6 + r_7$ ohms
1-UX-112A	160	−11.5	110	71	1,270	220	226	63	865	270	215	63	690
						260	271		1,375	320	250		1,370
						300	327		2,470	370	303		2,090
1-UX-171	133	−27.0	317	63	818	220	217	71	773	270	210	71	777
						260	263		1,420	320	253		1,280
						300	320		2,230	370	297		1,900
1-UX-171	180	−40.3	480	60	1,635	220	214	75	.....	270	208	75	
						260	260		327	320	252		420
						300	317		1,285	370	295		995
2-UX-171	160	−34.5	330	49	1,270	220	200	91	60	270	198	91	38
						260	248		587	320	243		333
						300	302		1,180	370	283		995
1-UX-210	250	18.0	200	67	2,900	220	222	67	.....	270	212	67	
						260	268		0	320	256		
						300	323		820	370	300		477

[1] These values of direct-current (d.c.) voltage and current from the output curves of UX-280 tube shown in Figs. 73 and 74.

r_3 = 10,000 ohms C_1, C_2, C_3 = 4 microfarads.

r_4 = 8,000 ohms C_4 = 2 microfarads.

C_5, C_6, C_7 = 1 microfarad.

NOTE.—The +90 volts remains constant for any current not exceeding 40 milliamperes.

r_6 prevents excessive voltage at the +B tap.

r_7 is the total direct-current resistance of the choke coils.

The circuit diagram of one common type of rectifier and filter is shown in Fig. 69. With this circuit, the load on the tube is heavy, as shown on the oscillograph (page 38) record in Fig. 71, which indicates instantaneous values of the current in the tube. This record shows that a current flows through the tube only when the transformer voltage exceeds the first filter-condenser voltage. The charging of the first condenser in the filter causes a very heavy current to flow through the tube for a short time, reaching a peak of 310 milliamperes. Since the average current (load current) is only 125 milliamperes, the peak current through the tube reaches a value of two and five-tenths times the average current. Thus, the filament must be heavier and longer than would be the case if the rectified current could flow for a longer time, so that the high peak could be avoided.

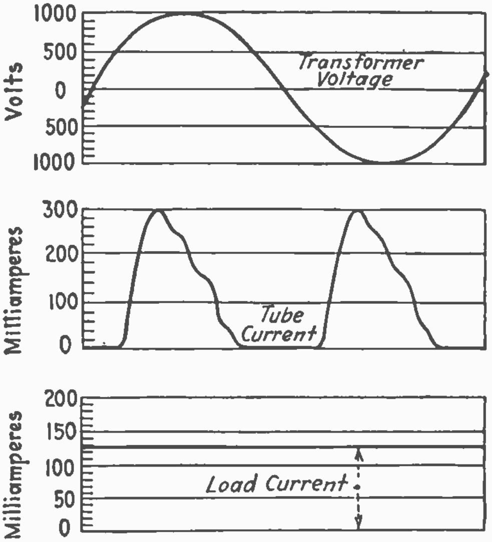


Fig. 71.—Oscillograph records of UX-280 tube.

A reduction in the value of the peak current is obtained by means of the filter circuit in Fig. 70, where the first filter condenser is omitted and the tube feeds directly into the inductance or choke coil. The oscillograph record (Fig. 72) shows the reduction in peak current, which is only 140 milliamperes or one and one-tenth times the "load" current. This reduction is possible because the tube no longer feeds directly into a condenser, and the choke coil keeps the current flowing through one anode or both during the entire cycle. Some voltage is lost in the choke coil, which, however, is a

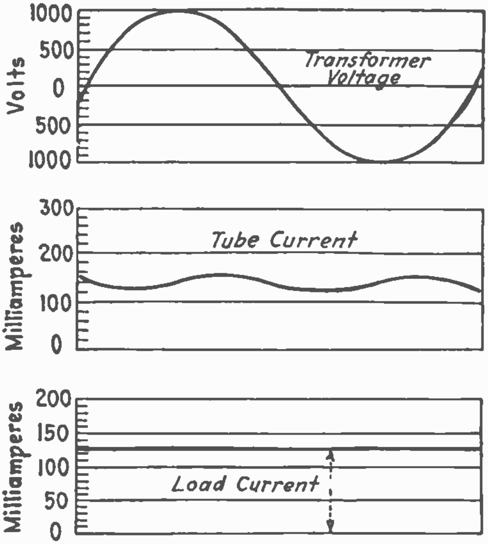


FIG. 72.—Peak-current reduction by omitting filter condenser.

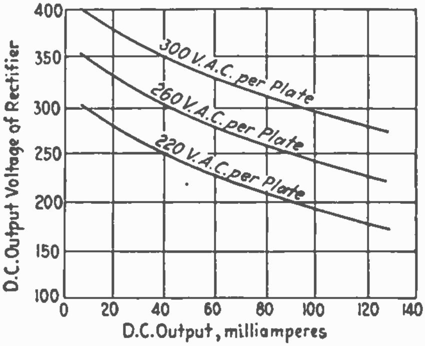


FIG. 73.—Output of UX-280 tube used as rectifier.

reactance load and does not consume power. The efficiency of the two systems is almost the same. The values below bring out the advantages of the latter circuit in tube operation. Operation at this reduced peak current extends the life of the filament of the tube and allows a lower value of emission before the operating efficiency of the tube is affected. A tube having an emission of 200 milliamperes could be used satisfactorily in the circuit of Fig. 72 but not in that of Fig. 71.

The condenser which is used across the input circuit in Fig. 69 should be added across the output of the filter of the circuit in Fig. 70, since the ripple voltage is slightly greater than that from the usual filter.

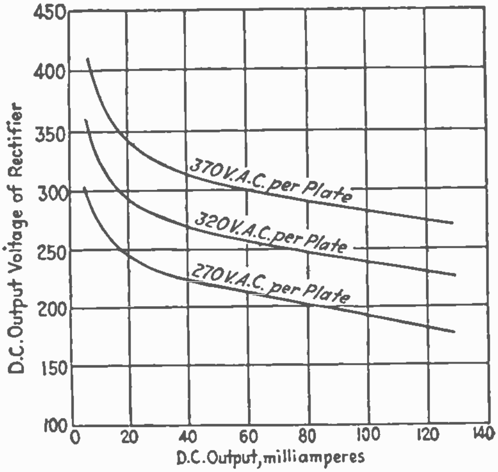


Fig. 74.—Output of UX-280 tube used as rectifier (choke-coil input).

The higher efficiency in the second case is the result of reduced tube losses because of operation at a lower temperature. As shown in Fig. 74, the voltage regulation is better than when a condenser is used, except at very low values of power output.

Operating Conditions

Circuit	Transformer, volts	Power input, watts	Load current, milliamperes	Load, volts	Power output, watts	Efficiency, per cent
Fig. 69	300	62	125	300	37.5	60.5
Fig. 70	360	59.5	125	300	37.5	63

A filter system, in which the input filter condenser is omitted, is not recommended for half-wave rectification, because output current and voltage are reduced considerably and the operation of the filter is impaired. The usual circuit design with a small input condenser of about 1.0-microfarad capacity reduces the peak current of the tube without noticeably reducing the output voltage.

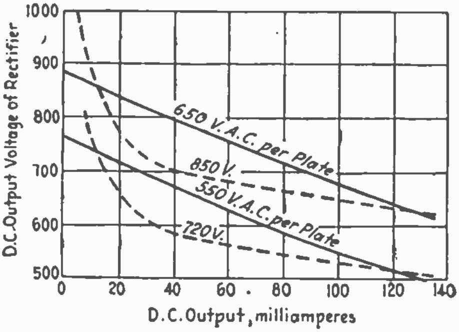


FIG. 75.—Output of UX-281 tube used as full-wave rectifier.

Figure 73 illustrates the regulation curves of the voltage delivered to the filter input by the UX-280 tube at various load currents with the type of filter in Fig. 69. If the filter resistance is known, the output voltage at the filter terminals can be determined. Figure 74 gives regulation curves which show the advantages, at "load" currents greater than 20 milliamperes, that are obtained by using the circuit connections in Fig. 70.

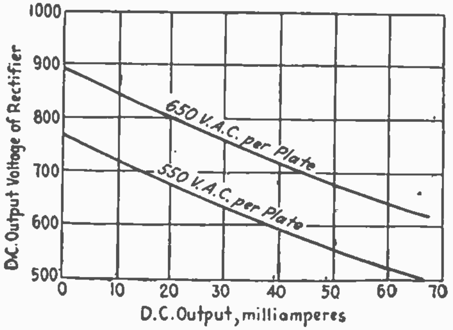


FIG. 76.—Output of UX-281 tube as half-wave rectifier.

The full-line curves in Fig. 75 show the regulation of two UX-281 tubes in a full-wave rectifier with a conventional filter. The dotted lines show the performance obtained in a similar circuit in which the first filter condenser is omitted. The superior regulation of the performance obtained with the use of the choke-input coil is evident. The circuit in which the first filter condenser is omitted is not satisfactory when the tube is used as a half-wave rectifier. The curves in Fig. 76 show the voltage delivered by the tube at the input to the filter with the usual half-wave rectifier circuits.

Output-voltage Regulator or Glow Tube, Type UX-874.—This is for service in *B-battery eliminators* where great flexibility in output current is required or where the alternating-current line voltage varies widely. It is particularly valuable in eliminators with various voltage taps. When a UX-112A or a UX-171A tube is used with a UX-201A tube, the eliminator must supply from 120 to 180 volts with a maximum current drain of 20 milliamperes from this tap, together with a 90-volt tap averaging 20 milliamperes and a detector 45-volt tap with a maximum requirement of about 3 milliamperes. The use of high and variable series-resistance units to obtain these voltages has not been entirely satisfactory. The resistance units may become noisy or burn out and are not effective until current is established in them. When the eliminator is operating without the receiving set, the voltage across the B terminals may rise to very high values with the possibility of damaging the by-pass condensers (page 34).

The *glow tube* (page 701) insures proper voltage regulation of the B-battery eliminator. It also improves the filter action, since it acts as a low-resistance path for the residual ripple voltage from the filter. This is equivalent to extra filter capacity across the output. It is effective in this respect at very low frequencies and thus eliminates the possibility of interstage coupling. For this reason, the tube is useful with amplifiers which are efficient at low frequencies, as the tendency toward instability resulting in distortion and "motor-boating" (buzzing sound like that made by a motor boat) is eliminated.

The UX-874 tube accomplishes voltage regulation from its characteristic that on any current flow from 10 to 50 milliamperes it develops a constant voltage averaging 90 volts. The tube cannot be used without a series resistance to limit the current to a value of 50 milliamperes, which occurs when the receiving set is turned off and the B battery eliminator is left on. The use of this tube in the usual type of eliminator to regulate the voltage at the 90-volt terminal on the receiving set is shown in Figs. 69 and 70.

In operation, the tube shows a glow surrounding the cathode, which in this tube is a large circular plate. If the tube connections are reversed, a bright glow occurs at the small terminal. Proper results are not obtained unless connections are made as in the diagram. The terminals which would normally be "F" are connected together in the base of the tube, and this short-circuited connection may be used as a line switch in the transformer primary winding. Then the B eliminator cannot be operated until the UX-874 tube is inserted in the socket, nor can the tubes be interchanged with the possibility of being damaged. If a rectifier or "power" tube (page 280) is inserted in the UX-874 socket, the transformer primary winding remains open and no current flows to the equipment. Two UX-874 tubes may be placed in series to obtain 180 volts, a central tap between the two tubes then providing 90 volts.

Line-voltage Regulator or Ballast Tube, Type UX-876.—A *ballast tube* like the one known as UX-876 is intended to regulate the input voltage to the primary winding of the transformers used in B-battery eliminators. The tube passes 1.7 amperes at any applied voltage between 40 and 60 volts. The current in the secondary winding of the transformer must be such as to bring the voltage on the tube to 50 volts at normal line voltage. If the line voltage averages 115 volts, the transformer, under load, should be designed to take 1.7 amperes at 65 volts, the remaining 50 volts being required by the ballast tube. If the line voltage drops or rises 10 volts, the voltage across the ballast tube changes accordingly and the primary transformer voltage remains practically constant at 65 volts. The tube requires several minutes to be heated to constant temperature. The voltage drop increases rapidly for the first 3 minutes and then slowly up to about 10 minutes, when the tube reaches its final temperature. During this interval the voltages on the other tubes are slightly high but do not exceed safe values. Thereafter, the ballast tube maintains the voltage practically constant. This tube will regulate the primary transformer voltage at frequencies from 25 to 60 cycles provided the transformer has been designed for the operating frequency. Equipment designed for 60 cycles cannot be used for 25-cycle operation, and *vice versa.* The tube should be protected by a ventilated metal housing for safety reasons in case a defective tube should explode.

Gas-filled Tube Rectifier.—The tungar type of rectifier consists of a bulb, not unlike a bulb of an electric light, which is attached at the bottom to a socket or screw base connected electrically to tungsten wires, separating near the middle of the bulb into a short filament of special tungsten alloy. A short rod of nickel is fused into the top of the bulb and has on its lower end a small graphite plate inside the bulb. A typical rectifying device is shown in Fig. 77, and standard-bulb types in Fig. 78. The bulb "rectifies" the alternating current for the reason that on one-half of the alternating-cycle when the incandescent tungsten filament is negative, the electric current is drawn toward the graphite plate, that is, making the gas inside the bulb conductive for electricity in the direction from the graphite plate toward the tungsten filament. On the other half of the alternating cycle when the tungsten filament is positive, the tendency is for the electric current to be driven back into the filament, because now the gas in the bulb is nonconductive for electricity. The voltage drop in the tube is from 3 to 8 volts.

All bulbs, whatever the material of which they are constructed, are carefully exhausted to the highest possible vacuum and then filled with argon gas in a high state of purity; but as certain impurities, even though present in very small quantities, produce a more or less rapid disintegration of the tungsten filament and also have quite a marked effect on the voltage characteristics of the rectifier, means must be used to insure absolute freedom of the argon gas from these other gases. To accomplish this, certain substances such as magnesium are introduced into the bulb at the time of manufacture, which chemically react with such impurities as may be present in the bulb. This reaction keeps the gas in a pure state practically throughout the life of the bulb. This purifying agent is shown inside the bulbs in Fig. 78 in the form of a wire ring on the graphite. As soon as a current passes through the tube, the purifying agent is volatilized and absorbs any foreign gases and also (unfortunately for the appearance of the bulb) somewhat discolors the interior of the bulb. This is particularly true of the lower-voltage bulbs in which a larger amount of purifying agent is needed.

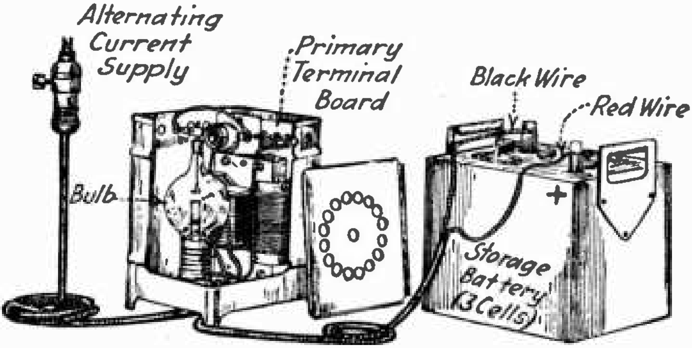


Fig. 77.—Gas-filled tube rectifier.

Figure 79 shows the connections of a half-wave, gas-filled vacuum-tube rectifier in its simplest form. The equipment in this case consists of the bulb *B*, with a tungsten filament *F* and a graphite plate *A*, the transformer *T* for "exciting" the filament, the rheostat *R*, and the "load" which is shown as a storage battery.

Assuming an instant when the side *C* of the alternating-current supply is positive, the current follows the direction of the arrows through the storage battery, rheostat, and bulb, and back to the opposite side of the alternating-current line. A certain amount of the alternating current, of course, goes through the transformer T to excite the filament, the amount depending on the capacity of the bulb. When the alternating-current supply reverses and the side D becomes positive, the current is prevented from flowing for the reason already mentioned. In other words, the current is permitted to flow only from the graphite plate to the tungsten filament. The rectifier must include a transformer which serves to reduce the voltage, usually from about 115 to 30 volts for small outfits and to 75 volts for larger ones. For a storage battery an impressed voltage of 2.5 volts per cell is necessary so that the transformer voltage is reduced from 30 volts or 75 volts, as the case may be, to the number of volts necessary for the number of storage cells being charged. A suitable adjustable resistance serves to reduce the current and voltage, as necessary in order to make the maximum voltage per cell about 2.5. The small sizes of these instruments have an equivalent direct-current rating of 2 amperes for a three-cell battery, 1.5 amperes for a six-cell battery, and for any number of cells up to 12 in the battery, the cells can be charged in series at proportionately reduced current rates. The "tungar" charging device, and especially the half-wave type, delivers a current which though pulsating is suitable for the charging of storage batteries.

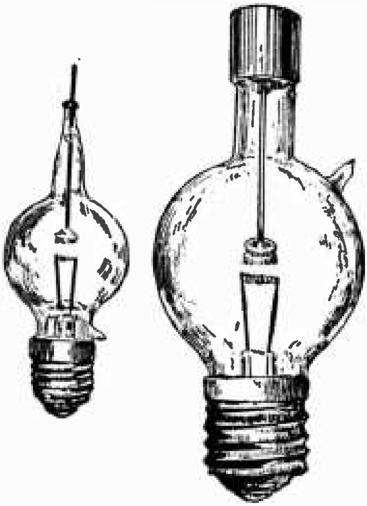


FIG. 78.—Typical bulb rectifiers.

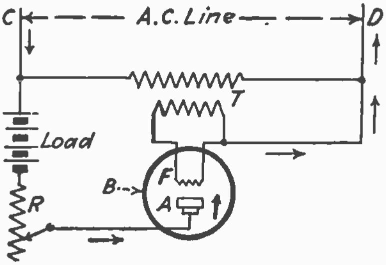


FIG. 79.—Half-wave gas-filled rectifier.

Raytheon Tube Rectifiers.—The use of the filamentless, double-wave Raytheon rectifier tube in the circuit of a B-battery eliminator is shown in Fig. 80. This type of tube really consists of two tubes in one but contains no filaments and operates by *ionization* (page 278). The type BH, Raytheon tube has a rated full-load output of 125 milliamperes at 300 volts (direct current), and type BA, 350 milliamperes at 200 volts (direct current).

In Fig. 80 the diagram of the tube *A* shows two grids and one plate. The tube is so arranged that when used in a standard UX-201A socket, the grids are connected to the filament terminals of the socket and the plate to the plate terminal of the socket with the grid contact left open. The input to this tube is supplied from a step-up transformer *T* that operates on a 110-volt line (alternating current). This transformer has a mid-tapped secondary winding by means of which half the voltage is applied to each side of the tube through its grids. Stable operation of the rectifier is obtained through the use of two condensers of low capacity which are indicated on the circuit diagram (Fig. 80) as C_1 and C_2.

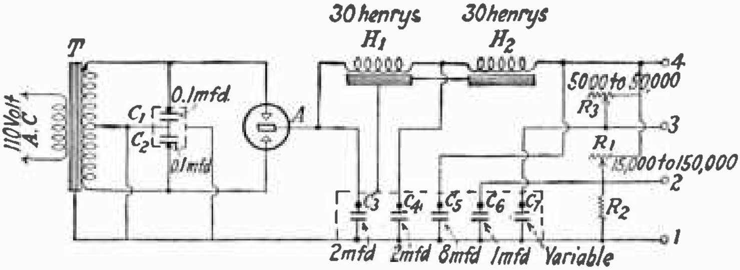


FIG. 80.—Circuit diagram of B-battery eliminator.

The rectified full-wave current is applied across the terminals of the condenser C_3. This voltage is then passed on through a large choke coil H_1 and applied across the terminals of a second filter condenser C_4. The condensers act as voltage "reservoirs," and, since the choke coil resists variations in current, the voltage applied to the condenser C_4 is very constant. The voltage across this condenser is then supplied through a second "filter" choke coil H_2 and is stored up in the large condenser C_5 which acts as the main reservoir for the direct-current energy to be supplied to the tubes.

For use in a B-battery eliminator, for which the amount of current required is small but the voltage is large, the size of a filter is greatly reduced as compared with the filter which would be required for an A-battery eliminator. When notes in the low-frequency range are to be reproduced in a loud-speaker, a larger B-battery current is required than for higher frequencies. If this increase in energy from the B-battery supply is not available, the low notes will not be satisfactorily reproduced or may be lost entirely. This difficulty may be overcome by placing across the output of the B-battery supply a large condenser storing enough energy for a sudden demand.

The full voltage from the filter is applied across the terminals marked "1" and "4," which may be connected directly to the plate terminals of the amplifier tubes of a radio receiving set. The terminal 4 supplies about 80 to 180 volts (positive), depending on the load, the terminal 1 being negative. In order to reduce the voltage for use on the detector tube, a suitable high resistance R_1 is inserted in series with the high-potential line and another fixed resistance R_2 is used across the terminals 1 and 2. The plate circuit of the detector tube should be connected between the terminals 1 (negative) and 2 (positive), these two resistances R_1 and R_2 acting as a potentiometer (page 121). A by-pass condenser C_6 of one-microfarad capacity is used across these two terminals to allow audio- and radio-frequency currents to pass in the plate circuit of the detector tube without being reduced. The resistance of the fixed unit R_2 is rather low, so that the plate-current variation of the detector tube is only a small part of the current flowing through the resistance R_2. This arrangement eliminates any large variations in the loss of voltage across the resistance R_1 which would be detrimental to tone-quality reproduction. The resistance R_3 is connected in such a way that a voltage may be obtained from the terminal 3, which is lower in value than that from the terminal 4. The condenser C_7 acts as a by-pass for this connection.

SECTION VI

VACUUM TUBES

Electron Emission.—When a metal is heated the motion of the electrons increases until some of the electrons are able to break loose from the metal or evaporate. Electron evaporation cannot occur in air because a metal, if heated sufficiently, will oxidize, and even if it could, the electrons would return into the metal, because the heavier air molecules would block the free electrons and cause them to return into the metal. Pure tungsten is not used for electron emission because other substances have been found to emit electrons at lower temperatures.

A tungsten filament impregnated with thorium gives, however, a high electron emission at a bright-red heat. In a *thoriated tungsten filament* a very thin layer of thorium is formed over the tungsten, and the evaporation of electrons takes place from this thorium layer. For a given emission current, the thoriated tungsten filament takes one-fourth the power required by a tungsten filament. If the operating temperature is exceeded because of overvoltage on the filament, the layer of thorium is stripped off or evaporated and the emission drops to zero. A stripped filament may sometimes be restored to its original condition by reactivation (page 291).

An *oxide-coated filament* consists of a thin nickel ribbon coated with a layer of barium and strontium oxides. A plentiful supply of electrons is emitted by this filament even at a dull-red heat. For a given emission current, an oxide-coated filament takes only one-half the power required by a thoriated filament. An oxide filament has a life of several thousand hours; but it cannot be reactivated like a thoriated filament.

Vacuum in Radio Tubes.—The air and gases must be removed from the glass bulb of a vacuum tube to enable the filament to the operated without deteriorating and to avoid the ionization of whatever gas the bulb contained. In the manufacture of a radio vacuum tube, the filament and other parts are first assembled and supported on glass rods. These parts are then sealed into a glass bulb which is connected to a vacuum pump. After a certain amount of the air has been removed, the tube is heated in order to drive the gas out of the various parts and allow the vacuum pump to remove it. The bulb is sealed when the vacuum corresponds to a pressure of about 0.000,004 inch of mercury. By the use of a mercury-vapor pump in series with an ordinary rotating or reciprocating pump, the proper degree of air rarefaction for a vacuum tube can be obtained in a few minutes.

Manufacture of Vacuum Tubes.—A step-by-step description of the assembling of the parts of a vacuum tube will serve to illustrate its construction. Figure 1 shows the glass tube *T* which serves as the main support for the elements of a vacuum tube, and Fig. 2 the kind of construction which is used to hold the supporting posts *R* and the *lead-in wires* *W* in the glass seal *S*. This glass seal is fused to the top of the flanged glass tube *T*, and a long piece of thin glass tubing *E* is fused into the side of the glass tube *T*, as shown in Fig. 3. At the stage in manufacturing shown by these figures, both ends of the glass tube *E* are open because during the fusing process air is blown through the tube. The progress of construction after the supporting posts *R* are bent to the proper position is illustrated in Fig. 4. The type of filament *F* in Fig. 5*a* is welded in the next stage of assembling the parts, to the supporting posts *N* of Fig. 4.

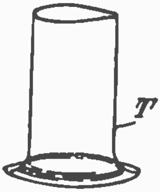


Fig. 1.—Glass support for vacuum tube.

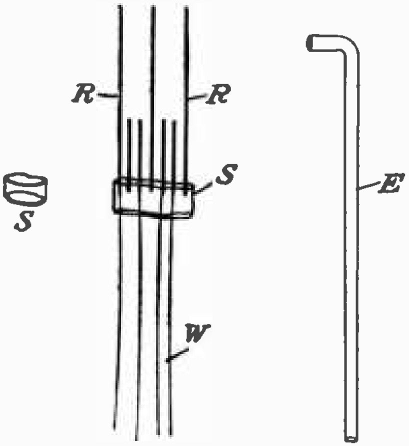


Fig. 2.—Supporting posts and lead-in wires.

One type of grid *G* is shown in Fig. 5*b* where the grid wires are welded to a suitable frame. Another method is to press the grid wires into the soft metal of the frame during the process of winding. A very fine tungsten wire is used for making the grid. This drawing shows, also, one form of *circular grid* (Fig. 5*c*) used in type UX-222 vacuum tube, and in Fig. 5*d* a plate *P* consisting of two pieces which are held together by the small lugs *L*. The tubes *U* thus formed at each side of the *plate P* slide over the supporting posts *R*. In some types of tubes this plate is sand-blasted to give it a better heat-radiating surface.

Various forms of plates are used, from the wire-wound type to heavy sheet metal. The material is usually nickel, molybdenum, or tungsten.

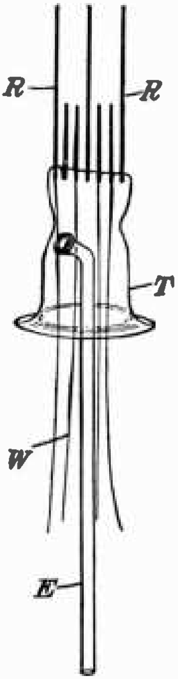


Fig. 3.—Glass tube for removing air.

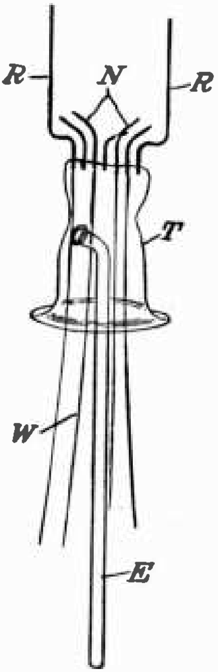


Fig. 4.—Supporting posts for attachment of tube elements.

The *getter*, the action of which is explained on page 278, is contained in the receptacle *C* as in Fig. 5*e* or, in some forms of construction, is fastened directly to the plate *P*.

Figure 6 shows the assembled elements of a standard type of vacuum tube. The ends of the filament *F* are welded to their supporting posts *N*; the frame of the grid *G* and the side tubes *U* of the plate *P* are welded to the posts *L* and *R*, respectively; and the *getter cup C* is welded to the post *S*.

In some types of vacuum tubes the filament may be mounted in such a way that it is held in tension by a spring. Finally, some form of insulating support, in this case a mica strip *M*, is fastened at the top of the assembly to keep the elements in alignment and to provide rigidity. A glass bulb *B* is placed over the unit as indicated in Fig. 7 and is fused to the flange on the large glass tube *T*. The only connection between the inside of the bulb and the atmosphere is through the very small glass tube *E*.

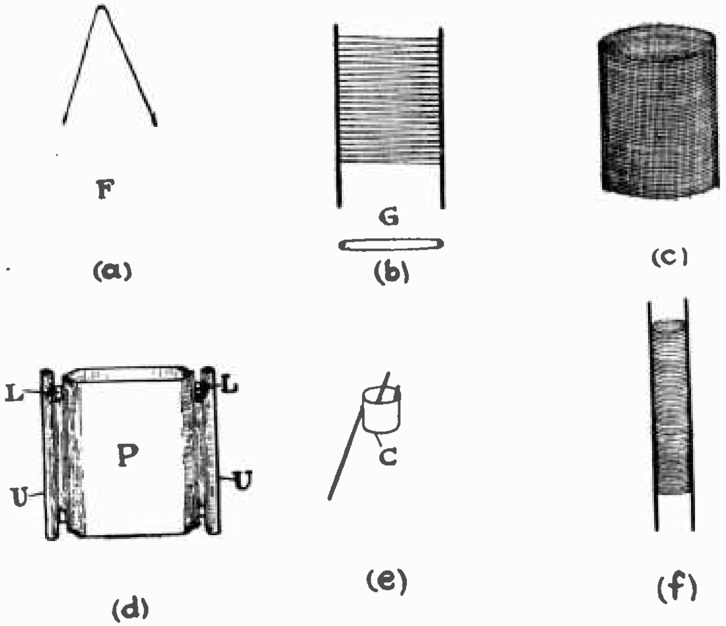


Fig. 5.—Detail of filament, grid, and plate of a vacuum tube

Many of the glass-sealing processes used in the manufacture of vacuum tubes require careful annealing of the glass parts of the tube. This is accomplished by allowing the temperature to drop very slowly. Molten glass which is cooled quickly is subject to internal strains. When the cooling is rapid, the temperature at the surface drops quickly and the outside layer solidifies. The interior, however, tends to contract and exert an inward pressure on the outer layer. This may result in cracks. The air and other gases are exhausted from the glass bulb of the tube through the small glass tube *E*.

Care is required to get rid of all the air and other gases, not only in the space inside the glass bulb but, also, in the walls of the bulb and glass tubes and in the metal of the elements. Even if a bulb is thoroughly exhausted by a vacuum pump, it subsequently would give indications of the gases which gradually come out of the interior parts. At ordinary temperatures, these gases are released so slowly that the period of evacuation would have to be lengthened to a prohibitive extent before the vacuum was satisfactory. In order to drive out quickly these gases from the walls of the bulb and the elements, the tube is kept hot during the process of exhaustion. For a similar purpose, the filament may be heated by electric current and a positive voltage applied to the grid and plate so that they are heated by the

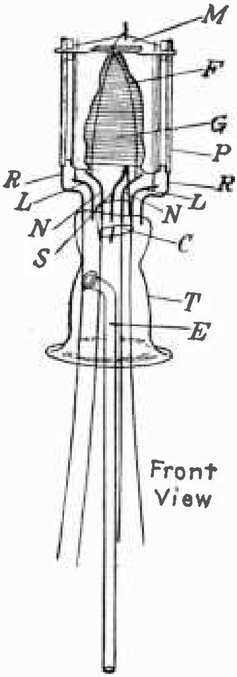


Fig. 6.—Assembled elements of vacuum tube.

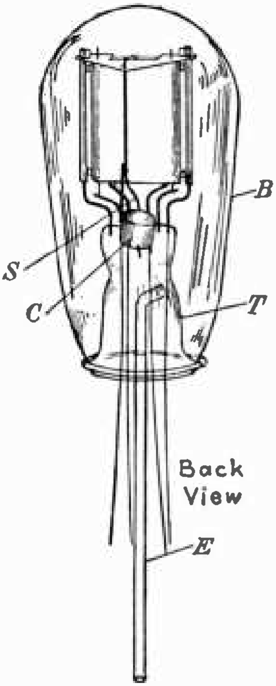


Fig. 7.—Assembled elements covered by glass bulb.

impact of electrons from the filament. The evacuation is continued until the vacuum reaches the required value. When the desired degree of vacuum is obtained, the small glass tube E is melted off and the bulb is thus permanently sealed.

The baking or heating temperature in the tube when air and other gases are being removed is considerably greater than that of normal operation of the tube in service. The tungsten tube can withstand a higher baking temperature than either the thoriated tungsten or the oxide-coated kinds. Hence the degree of vacuum which may be obtained in these vacuum tubes is somewhat limited, particularly in those with oxide-coated filaments, which become impaired quickly when overheated.

FIG. 8.—Vacuum tube showing contact prongs.

During the operation of a vacuum tube in service, a further release of gases takes place. To absorb these gases a small supply of a so-called *getter* is assembled with the tube elements. This consists of a volatile metal such as magnesium, sodium, or caesium or such substances as phosphorus, arsenic, and sulphur, which volatilize readily. After the tube is sealed, this getter is volatilized by heating the tube with a high-frequency coil. The vapor then condenses in a silvery film on the inside of the glass bulb. This film not only attracts the gases as they are released but also tends to seal them in the walls of the bulb. The life of a vacuum tube depends to a considerable extent on the efficiency of the action of the getter.

Finally, the glass bulb is cemented to a suitable insulating base in the bottom of which are four small hollow rods. The lead-in wires pass through these rods and are fastened to them by a drop of solder at the bottom of each rod. These rods form the contact prongs of the vacuum tube which is then made up as shown in Fig. 8. The vacuum tube is next tested as described on pages 280 and 292 and, if satisfactory, is ready for use. The tube fits into a *socket* which is provided with binding posts that connect through spring contacts with the prongs of the tube.

Ionization by Collision.—It is impossible to remove completely all traces of gas from a vacuum tube. In a rarefied gas some of the electrons are parts of atoms and some are free. These free electrons move with such velocity that if one hits an atom another electron may be knocked off. This "stray" electron comes under the influence of the plate voltage and moves in the same direction as the colliding electron, that is, toward the plate in the vacuum tube. The remainder of the atom, which is a positively charged *ion*, moves in an opposite direction toward the filament. Thus, both parts of the atom act to increase the flow of current through the gas. This action of an electron on an atom is called *ionization by collision* and corresponds to the "breakdown" of any electric insulator at excessive voltage. In a vacuum tube which contains residual gas, some ionization will occur when the plate voltage exceeds 30 or 40 volts, although vacuum tubes having a high vacuum may not have their operation appreciably affected by ionization.

Influence of Gas in a Vacuum Tube.—The relation between the plate current and the plate voltage for its operation at the rated filament voltage of a vacuum tube having no gas is shown by the curve A in Fig. 9. Ionization by collision separates the gas atoms into free electrons and positively charged ions which move toward the plate and the filament, respectively. This movement produces an increase of current as shown by the curve B. It may be considered that ionization of the gas tends to neutralize the space charge (page 285) and thus permits a larger current to pass through the tube.

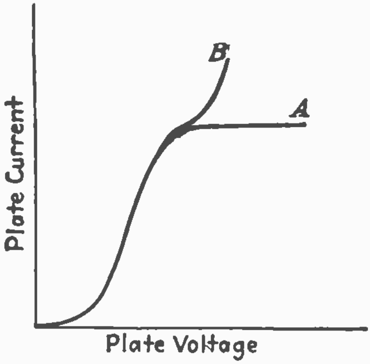


FIG. 9.—Effect of gas on operation of vacuum tube.

There seems to be an apparent advantage in ionization by collision because the plate current is increased; but it happens that under this condition the filament deteriorates rapidly because the positively charged ions are attracted forcibly to the negatively charged filament, and, since they are much heavier than electrons, the impact breaks down the filament surface. Also, if a too high plate voltage is applied, a "blue-glow" discharge may result. In this condition, a tube is erratic in behavior and becomes insensitive because the plate current is so large that it is not affected by variations of the grid voltage. If a tube has a blue-glow discharge, its *characteristic curves do* not repeat themselves and sharp breaks in the curves may appear. Further, such operation heats the tube elements and such heating may injure them.

Ionization in a Detector Tube.—To a certain extent, ionization in a vacuum tube is of value in its use as a *detector*. "Soft" tubes (page 40) are particularly useful as detectors and, if properly selected and operated, may be more satisfactory as detectors than "hard" tubes of similar construction. They are, however, quite critical of adjustment because the plate or grid voltage must be adjusted to a value just under that which produces ionization. The high-vacuum detector tubes used at the present time are less sensitive but much more dependable than the older tubes, which did not have such good vacuums.

Ionization seldom takes place in a tube having a tungsten filament, because the vacuum is high. It is more likely to occur in tubes having oxide-coated filaments, because of the presence of occluded gas.

A *power tube* is a vacuum tube intended for the "last" audio-frequency stage of a receiving set. It takes its name from the fact that its power rating in watts is greater than for the usual types of tubes. A power tube with an oxide-coated filament when once ionized cannot be used again at the usual high plate voltages unless it is reexhausted. It may, however, serve for use at lower than the originally rated plate voltages.

The rectifying property of a two-element tube is ineffective if the plate becomes heated to incandescence. This heating takes place when an excessively high plate voltage is applied. The high voltage increases the velocity of the electrons, which heat the plate by the force with which they impinge on it.

Testing a Vacuum Tube for Presence of Gas.—No considerable number of electrons will be given off from a *cold* element in a tube unless it is subjected to a strong electron bombardment. If, then, there is a current flow in a tube in a direction which shows that electrons are emitted from a cold element, either the grid or the plate, it is proof of the presence of a gas which is conducting the current.

One method of ascertaining the presence of gas in a tube is to apply the so-called *overvoltage test*. This consists of applying a plate voltage, higher than the normal operating value, for a few minutes and then testing the tube for performance. During the application of this excess voltage, some gas is released from the elements of a vacuum tube in which the vacuum is poor. If the tube performance is satisfactory, the amount of gas released is not enough to impair its action.

If a negative voltage is put on the grid of a vacuum tube in which there is no gas, the grid current does not reverse. It is found, however, that even in a tube having a high vacuum there is enough gas left so that the positive ions produce a minute reversed grid current when the grid is negative. The strength of this grid current increases with the strength of the plate current. This action in the flow of grid current can be made to serve as a test of the amount of gas present in a tube.

The presence of a large amount of gas in a tube may be detected during the final stages of manufacture by a simple test utilizing a source of high-frequency voltage which may be impressed across the tube elements. The color and distribution of the arc across the tube elements indicate the condition of the vacuum.

Relation between Tube Constants and Structure.—The two main factors that enter into the design of vacuum tubes are the amplification factor (page 299) and the plate resistance. The *amplification factor* u increases with increasing distance between the plate and the grid and depends, also, upon the spacing and size of the grid wires but not upon the distance between the filament and the grid. In practice it is found that u is not quite constant but decreases slightly at low voltages, although the variation is not appreciable within the operating range.

The *plate resistance* r_p is inversely proportional to the surface areas of the plate and the filament. It depends, also, upon the operating voltages. The value of r_p is further affected by u, which, as shown above, depends almost entirely on the structure of the grid and its position with relation to the plate.

An amplifying tube gives best operation when its *plate resistance* is equal to the *impedance* with which the tube operates. In cases where this is not possible, the total plate resistance may be reduced by operating the vacuum tubes in parallel; or, by the use of an *output transformer*, the plate resistance of a tube may be matched to the impedance of the device with which it operates.

The *mutual conductance* G_m, being equal to u/r_p, depends on the factors which determine these terms. In some types of tubes it is necessary to make this ratio u/r_p as large as possible. Then, for a given value of u, r_p must be as small as possible. To make u large and r_p small, therefore, the grid must be close to the filament.

When a vacuum tube is to be used as a detector, it should have a low internal resistance which changes suddenly within narrow limits when the grid voltage is varied. Since the amplification factor depends on the ratio of the change in the plate voltage to the change in the grid voltage, the maximum action is obtained when, for a given change of the grid voltage, the necessary change of the plate voltage to provide the same current is a maximum. Thus, in a *detector tube* the resistance must drop suddenly from a maximum to a minimum for a small change in grid voltage. In an amplifying tube, on the other hand, a small change in grid voltage should tend to increase the resistance to a maximum. The nearer the grid is to the filament and the farther the grid is from the plate the better are the detecting qualities of a tube. Conversely, the farther the grid is from the filament and the closer the grid is to the plate the better are the amplifying qualities of a tube.

Limiting Operating Conditions.—Since some gas always remains in a vacuum tube, there are in every tube a large number of molecules of gas left even when the vacuum in the tube is as high as possible. Ionization of this gas will occur if the plate voltage applied to the tube is too high, or if both the filament voltage and plate voltage are high. The extent of the effect of ionization on the tube characteristics depends on the amount of gas present. Thus, one limiting condition of the operation of a tube at high voltages is due to ionization of the gases left in the tube. Tubes using oxide-coated filaments cannot be so completely evacuated as those having filaments consisting only of tungsten, hence ionization is more likely to occur in the former.

The other limiting condition is the deterioration of the elements of a vacuum tube from overheating. Thus, the heating of the plate is due to electron bombardment, the amount of power taken by this heating being the product of plate current and plate voltage. The electrons moving from the filament to the plate convert this power first into an increase in their velocity and then into heat which is released when they reach the plate. This heat, since the elements are in a vacuum, can be dissipated only by radiation. It may be mentioned here, again, that a tube may cease to function if its emission is impaired by the impact of positive ions on the surface of the filament.

The factor of *distortion* has a bearing on the possible output of a vacuum tube. Several operating conditions must be assumed if the distortion is to be below the value which is considered to be a minimum. The table on page 383 gives these operating conditions and also the maximum undistorted outputs of a number of tubes.

Water-cooled Tubes.—The plate may get so hot that the glass bulb will give way by sagging. In high-power tubes having a rating of one kilowatt or more this difficulty is avoided by changing the construction so that the outside of the tube comprises the plate. Then cooling water can be circulated around the plate to carry off the heat. By this method the output of the tube can be increased considerably. The plates of high-power air-cooled tubes are sometimes blackened to increase their heat-radiating capacity. Sand-blasting or even oxidizing the plates of low-power tubes produces somewhat the same effect.

Life of a Tube Filament.—The life of a filament is shortened by excessive heating due to impact by positive ions produced by collisions as the result of ionization, which occurs to some extent even in tubes having a high vacuum. The normal life of a filament depends, also, on the rate at which the substance volatilizes. As a metallic filament, for example one of tungsten, volatilizes, its resistance increases. This causes a decrease in the filament current, if operation is at constant voltage, and hence there is a decrease in electron emission. On the other hand, if the operation of the tube is with a constant current, the voltage is increased, and the filament temperature rises. The effect of this is to shorten the life of the filament.

In an oxide-coated filament only the surface volatilizes. The filament current flows mainly through the core, the resistance of which remains constant. With this kind of filament the impact of positive ions produces local heating which is cumulative and tends to burn out the filament at that place.

Emission Current.—When a suitable bulb, from which the air has been removed to obtain a vacuum, contains a filament near the middle and a metallic plate close to it, and the filament is heated, a few *electrons* will leave the filament with sufficient velocity to reach the plate. If this plate in the bulb is *entirely* insulated, the electrons which accumulate on it will soon build up a charge sufficient to prevent a further flow of electrons from the filament. If, however, instead of being insulated, the plate is connected by a conductor to the filament, large numbers of electrons will flow across the space to the plate and back to the filament through the connecting conductor. This current, due to electron emission, is called the *plate current.* The plate current is greatly increased if a battery is connected into the circuit between the plate and the filament so as to create a positive potential or voltage on the plate.

Characteristic Curves.—The performance of vacuum bulbs or tubes in radio communication is studied by the use of curves which show their characteristic properties. The performance of a simple electrical device incorporating an ordinary ohmic resistance can be determined from a knowledge of only one property of the device—its *ohmic resistance.* On the other hand, the performance of vacuum tubes is shown by diagrams from which a determination can be made of all the possible combinations of voltages and currents that may occur in practice. These diagrams, known as *characteristic curves,* are easily obtained by keeping the filament voltage constant, varying the applied voltages, and reading the resulting currents that flow.

Two-element Vacuum Tubes.—A two-element tube consists of a metallic filament and a metallic plate sealed in a glass bulb in which there is a vacuum. The filament may be heated by a current from a battery. The plate is made positive with respect to the filament by connecting a battery into the plate-to-filament circuit. Under these conditions, as explained before, a flow of *electrons* takes place from the filament to the plate. As the *plate voltage* is increased a point is reached at which all the electrons emitted from the filament are drawn to the plate. Hence, any additional increase in plate voltage is not accompanied by any increase in plate current by electron emission. This maximum value of emission is called the *saturation current* and, because it is an indication of the total number of electrons emitted, it is also called the *emission current* or *filament emission.* This condition is shown at point *A* in the curve of Fig. 10. The bend in the curve shows that when the plate voltage has been made large enough there is little further gain in the plate current. Under these conditions the *plate current can be increased*, however, by increasing the filament temperature. The explanation of this is that the number of electrons sent out by the filament increases with the temperature approximately as the square of the excess of the filament temperature above a red heat, and, thus, more electrons are available to be drawn over to the plate. For any temperature of the filament there is a corresponding maximum value of plate current. This maximum is reached when the electrons are drawn over to the plate at the same rate as they are emitted from the filament. The effect of varying the temperature of the filament is shown by the curves *A*, *B*, and *C* in Fig. 10.

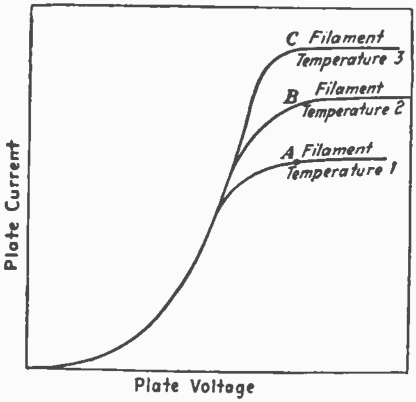


FIG. 10.—Effect of filament temperature on operation of vacuum tube.

On the other hand, if the plate voltage is kept constant, and the filament temperature is raised by increasing the filament current, the emission current or filament emission is increased. The plate current will increase up to a certain temperature, but beyond this temperature it will remain practically constant even though more electrons are being given off. This means that for every value of plate voltage there is a corresponding value of filament temperature beyond which no increase in plate current is obtained. This effect is shown by the curves of Fig. 11.

The explanation of this behavior is that the stream of negative electrons flowing through the vacuum tube acts as a *space charge* of negative electricity which neutralizes the electrostatic field due to the positive plate; that is, the effect of the negative space charge upon the electrons leaving the filament is opposite to that of the positive charge on the plate. In consequence, only a limited number of electrons can flow to the plate per second with a given plate voltage, and the remainder are compelled to return to the filament. It is obvious, therefore, that the condition of either voltage or current under which the filament is to be operated must be specified. The shape of the lower part of the curve indicates that the plate current is proportional to the square of the plate voltage.

For a given plate voltage the maximum possible value of plate current depends on the spacing, size, and shape of the elements of the tube.

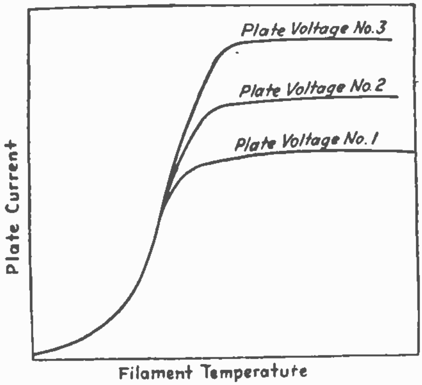


FIG. 11.—Effect of plate voltage on operation of vacuum tube.

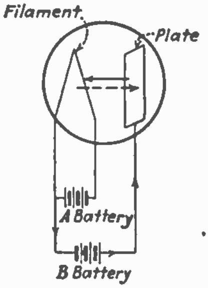


FIG. 12.—Diagram of plate circuit.

Direction of Current Flow.—In a two-electrode tube the direction of current flow is from the positive terminal of the B battery to the plate, then across the space to the filament, and finally back to the negative terminal of the B battery, as shown in Fig. 12. This path is called the *plate circuit.* The flow of electrons is, however, in a direction opposite to that of the current; that is, the electrons inside a vacuum tube flow in the direction from the filament to the plate, as indicated by the dotted arrow.

Commercial Uses of Two-element Vacuum Tubes.—The ordinary commercial applications of two-element vacuum tubes are for the rectification of alternating current and for the production of X-rays. Formerly the two-element vacuum tubes were used in radio reception as a *detector* to rectify high-frequency radio waves from transmitters. Vacuum-tube rectifiers of alternating current are divided into two classes: (1) the tube with a hot filament and a cold plate and (2) the tube with a cold filament and a cold plate (two cold elements). The tubes with a hot filament and a cold plate may again be divided into the type which depends for its action on the ionization of a gas and the type which does not. The various classes of two-element tubes are summarized thus:

- Vacuum tube rectifiers....
  - Hot-filament and cold-plate type
    - Action by ionized gas
      - Tungar
      - Rectigon
    - True thermionic action
      - UX-280
      - UX-281
      - UX-213
      - UX-216B
      - Rectron
  - Two cold-elements type, Raytheon "S" tube

The *Tungar rectifier* functions because of the unilateral (single-direction) conductivity between a hot filament and a cold plate of the tube. The tungsten filament is the source of electrons and is maintained at the necessary temperature by a current from some external source. The tube is filled with *argon* which is an inert gas capable of being ionized by the electrons. In this type of tube the plate current is carried mostly by the ionized gas. The Tungar and *Rectigon* are examples of low-voltage rectifier tubes in which the flow of plate current depends on gaseous conduction. The filament is necessary to give stable operation at the low voltages at which the tubes are operated.

Rectifier tubes such as the UX-280 and UX-281 are of the filament type and depend on true *thermionic action* for their operation, meaning that the electrons can move from the filament to the plate, but, since the plate is not a source of free electrons, when these electrons are once on the plate they are not released and cannot flow back to the filament. Thus, a current flows from the filament to the plate only when the plate is positive, and the current stops flowing when the plate is negative. By use of this device an alternating current may be changed into a *pulsating direct current.*

The rectifier tubes with two cold elements or the gaseous-conductor vacuum tubes are represented by the *Raytheon rectifier* tube and by gas-filled rectifier tubes which do not have filaments. This type depends for its action entirely upon the effects of *ionization* by collision. The tube consists of two elements inside a glass bulb under a reduced pressure of certain gases. The elements of the tube are arranged in such a way that the electrons from one element move a relatively short distance and are absorbed before any ionization by collision with the gas particles can take place. The electrons from the other electrode must move a greater distance and have a path which is long enough so that ionization by collision can take place and new electrons and positive *ions* can be produced. Consequently when a voltage is applied in one direction there will be a very small current due to the flow of free electrons. When the voltage is reversed there is a much larger flow of current due to the effect of ionization by collision. The rectification is not perfect, because some current flows in either direction although the reversed current is nearly negligible in value. This type of tube passes current freely in one direction at about 150 volts but requires about 700 volts to cause a flow of current in the opposite direction.

Three-element Vacuum Tubes.—A factor which will influence the flow of plate current is the effect of an electrostatic charge on a third element in the tube.

The third element, which is placed between the filament and plate, is usually a set of parallel wires or a perforated plate called the *grid*. The spacing between the wires of this third element depends on the service for which the tube is designed. The conventional representation of a three-element tube is shown in Fig. 13. The third element or the grid *G* obtains its electrostatic charge from its connection to the C (*grid-bias*) voltage supply. In tubes in which the filament is operated on direct current the reference point for the grid voltage is taken as the negative terminal of the filament. When alternating current is used to operate the filament the reference point is taken as the midpoint of the filament.

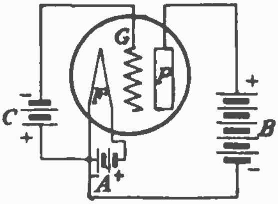


Fig. 13.—Diagram of three-element vacuum-tube circuit.

The filament is nearer to the grid than it is to the plate, so that a voltage applied to the grid exerts a greater attractive or repulsive force than the plate upon the filament electrons. Usually, the grid is charged negatively with respect to the filament. A negative potential may be applied to the grid by connecting the positive terminal of the C (*grid-bias*) voltage supply to the filament and its negative terminal to the grid as shown in Fig. 13.

The negative charge of the grid tends to force the filament electrons back to the filament. This effect, together with that of the *space charge* (page 285), repels the electrons and, consequently, reduces the value of the plate current, because no appreciable number of electrons can reach the plate. If the negative voltage of the grid is reduced, the flow of electrons to the plate is increased. If, on the other hand, the negative voltage of the grid is increased, the flow of electrons to the plate is decreased. In fact, the plate current may be reduced to zero if the negative charge on the grid is large enough.

A positive charge on the grid will neutralize the repelling effect of the space charge on the flow of electrons, thus causing an increase in the plate current. The greater the positive charge on the grid the more the plate current will increase until it reaches as a limit the saturation current (page 284) corresponding to the temperature of the filament.

When the grid is positive some of the filament electrons will be attracted to it and produce an electric current in the grid circuit which flows from the grid to the filament, through the C voltage supply, and then back to the filament. This effect is shown by the curve of grid current in Fig. 14.

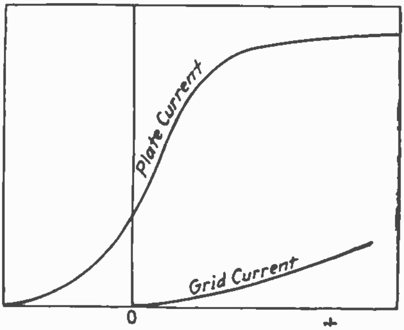


FIG. 14.—Relation between plate current and grid voltage.

The value of the grid current is relatively small, so that it is usually measured in microamperes. The flow of current in the grid circuit may be controlled by using suitable values of the operating voltages. In the action of a vacuum tube as a detector, when a grid leak and grid condenser are used (page 329), the grid current becomes of importance.

The relation between plate current and grid voltage is shown in Fig. 14 for a given value of plate voltage and filament temperature. If the filament temperature is kept constant and a curve of plate current is drawn for each of a series of plate voltages, a group of curves is obtained like Fig. 15. The relation between plate current and plate voltage for various grid voltages may be represented as in Fig. 16.

The electric power consumed in the input circuit of a three-element tube is very small because of the small electrostatic capacity of the grid with respect to the filament. Ordinarily, the grid circuit does not carry any current. A small change in grid voltage produces the same effect on plate current as a much larger change in the plate voltage. Thus, a small input of electric power, largely in the form of voltage on the grid, controls a much larger amount of power in the plate circuit. This characteristic permits amplification of voltage or power to be obtained by the use of a three-element vacuum tube.

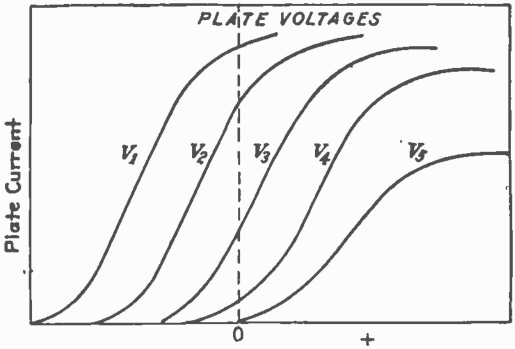


Fig. 15.—Plate current and grid voltage for series of values of plate voltage.

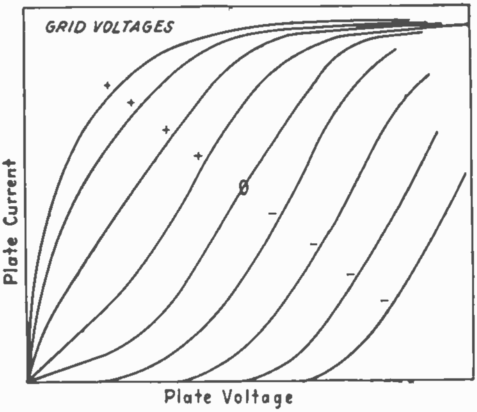


Fig. 16.—Plate current and plate voltage for series of values of grid voltage.

The insertion of the grid element gives the three-element tube the properties of amplification and oscillation which the two-element tube does not have. These properties give this kind of vacuum tube the important place which it has in radio transmission and reception.

Plate Current.—The electron current which flows from the filament to the plate of a three-element vacuum tube depends on the grid and plate voltages, the spacing and size of the grid mesh, the distance between the *elements* (filament, plate, and grid), and the area of the elements supplying current.

The equation for plate current is

$$I_p = K(E_p + uE_g)^x$$

where I_p is the plate current of the tube in amperes, K the constant depending on the type of tube, E_p the plate voltage measured between the plate and the negative terminal of the filament in volts, E_g the grid voltage measured between the grid and the negative terminal of the filament in volts, u the amplification factor of the tube, and x the exponent, usually about 2.0. The term E_p represents the "applied" voltage, being equal to the plate-supply voltage minus the voltage lost in the resistance of the plate circuit. In radio-frequency amplifiers, the resistance in the plate circuit may be neglected, and the applied plate voltage becomes equal to the plate-supply voltage. With resistance coupling, the voltage loss in the plate resistance is at times large enough to consume more than one-half of the plate-supply voltage. The effect of a voltage applied to the grid is given by the term uE_g, so that the grid voltage is u times as effective in causing a plate-current change as the same plate voltage. Since the voltage which is applied to the grid is usually negative, the term uE_g lowers the "effective" plate voltage. Thus, if a UX-201A tube has 90 volts on the plate, and the grid is connected to the negative terminal of the filament, then, at zero grid voltage, the effective plate voltage E is $E_p + uE_g = 90 + 8.5 \times 0 = 90$ volts, and the plate current is 6.0 milliamperes. If now the recommended value of *C-battery* or *grid-bias* voltage to be applied to the grid is -4.5 volts, the effective plate voltage is decreased, although the actual battery voltage remains unchanged. Then $E = E_p + uE_g = 90 + 8.5\ (-4.5) = 90 - 38.2 = 51.8$ volts, and the plate current now decreases to 2.0 milliamperes, since the effective voltage is lower.

Curves showing the variation of plate current with plate voltage are needed only to show the plate current when the grid-bias voltage is zero. The relations for other conditions can be found by determining the effective plate voltage as in the example above and by applying this value to the curve to get the corresponding value of plate current.

On the other hand, if the C voltage supply is connected so that the grid-bias voltage has a positive value, the effective plate voltage is higher than the applied voltage, since the term uE_g becomes positive and adds to the plate voltage E_p. Under such conditions, the grid current is large and the grid absorbs considerable power (watts), so that the efficiency of the tube as an amplifier is reduced.

An inspection of the curves of plate current plotted against applied plate voltage as for the WX-12 tube in Fig. 17 shows that the plate current increases slowly at low plate voltages and more rapidly at higher voltages. This non-linear relation (due to the exponent x in the above equation) permits the use of the tube as a detector. This same relation makes special precautions necessary when a maximum amount of undistorted power output is required, as in power amplifiers.

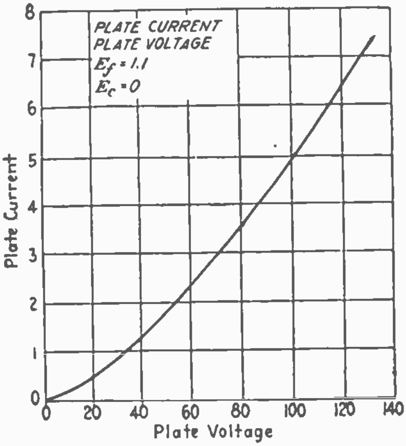


FIG. 17.—Typical characteristic curve of plate current and plate voltage for WX-12 tube.

The normal plate current of tubes differs widely, ranging from 20 milliamperes in the case of the UX-171A tube down to 0.2 milliampere for the UX-240 tube. In general, a vacuum tube having a low plate resistance and low amplification factor will carry a high plate current, and *vice versa*.

Reactivation of Thoriated-tungsten Filaments.—The action of the thorium-oxide layer on the thoriated-tungsten filament of a vacuum tube is such that, when the filament is heated, some of the thorium oxide is reduced to metallic thorium and works out to the surface of the filament. When the vacuum tube is in use, this surface layer of thorium gradually evaporates and is replaced at the same rate by fresh thorium from the interior of the filament. This process continues uniformly throughout the life of the tube provided the normal temperature of the filament is not exceeded. If the temperature is raised a few hundred degrees above the normal temperature, corresponding to a voltage overload of about 10 per cent of the rated value, the balance between surface evaporation of thorium and its supply is disturbed and the active thorium layer is completely evaporated, leaving a plain tungsten surface from which the *filament emission* rapidly decreases. If the operator further increases the filament voltage, the overload on the tube is increased so much that no filament emission is obtained. The filament then is "paralyzed" but can be restored by *reactivation.*

Only tubes with thoriated-tungsten filaments can be reactivated. The oxide-coated filaments cannot be reactivated and would be burned out by the application of the high voltage used in the process. Information as to the type of filament used in a tube is given on the data sheet placed in the tube package or may be obtained from the manufacturer.

Need for Reactivation. Emission Test.—An indication of the condition of a vacuum tube for filament emission is readily obtained by an *emission test.* If the value of emission current indicated on the milliammeter in this test is above the minimum value specified in the following table, the tube filament is in good condition and reactivation is not necessary. Voltages higher than those given in the table must not be used because of the danger of damaging or possibly even burning out the tube.

TABLE XXVI.—EMISSION-TEST CONDITIONS OF VACUUM TUBES

Type of tube	Filament, volts	Plate, volts	Minimum emission, milliamperes
UX-199	3.3	50	6
UX-120	3.3	50	15
UX-201A	5.0	50	25
UX-200A	5.0	50	12
UX-240	5.0	50	25
UX-171	5.0	50	50
UX-210	6.0	100	100
UX-213	4.0	100	50 per filament
UX-216B	6.0	125	100

The value of plate current, when the tube is operated at rated voltages, is not an accurate measure of filament condition. The reason for this is that small variations in the constants of the tube (especially the amplification factor) cause much greater variations in the plate current, even though the performance of the tube is not appreciably affected. If, however, the plate-current reading is low and increases rapidly as the filament voltage is increased slightly above the rated value, it is likely that the filament is becoming inactive. If the plate-current reading of a used tube is less than

80 per cent of the reading when the tube was new (provided the operating voltages in each test are the same), improvement will result from reactivation.

If a test of the emission current after the tube has been reactivated does not show an increase in value, the filament has come to the end of its normal life, the supply of thorium has become exhausted from the effect of overload, or the vacuum in the tube has deteriorated. Tubes with poor vacuum will show a filament-current reading which is greater than the rated value. If the vacuum is very poor, the filament will not light unless the filament voltage is increased considerably above normal—then it will momentarily light up and burn out.

If an operator finds that his tubes need reactivating frequently, say every month, it is likely that they are being overloaded. Overloading or improper operating conditions may be due to the use of (1) filament voltages greater than the rated values for the tubes, (2) high plate voltages without the use of a C battery, (3) reversed A- or C-battery connections, (4) inactive tubes in use together with good ones.

Methods of Reactivating.—The kind and degree of overload which has been put upon a tube determines the method to be used in reactivating the filament. The first method is suitable for tube filaments which have been overloaded only slightly. The filament is burned at the voltage given in the following table, and no voltage is applied to the grid or plate of the tube.

TABLE XXVI*a*.—FLASHING AND BURNING VOLTAGES

Type of tube	Flashing voltage	Burning voltage
	Volts	
UX-199	12	4
UX-120	12	4
UX-222	12	4
UX-201A	16	7
UX-201B	16	7
UX-200A	16	7
UX-240	16	7
UX-171	16	7
UX-210	16	9
UX-213	16	6
UX-216B	16	9

The filament is burned at the voltage specified in the table for 30 minutes and then an emission test is made. If the value of emission current is not above the specified minimum, the filament must be burned again. The length of time necessary for reactivation by this method ranges from 0.5 hour to 1.5 hours. If the emission shows no improvement after the filament has been burned for about an hour, it is evidence that the tube has been overloaded heavily over a long period of time. In such a case, the second method of reactivation should be tried.

According to the second method, the filament is first "flashed" at the flashing voltage for 10 to 20 seconds. During the flashing of the filament no voltage is applied to the grid or plate.

This treatment accelerates the rate at which the thorium works out of the interior of the filament to the surface. Since there is no voltage on the grid or plate, the evaporation of thorium from the filament surface is slow.

The filament is burned for a period of 30 minutes at the burning voltage given in the first method of reactivation as already described. If the emission current shows no improvement at the end of this period, the burning should be continued, making an emission test after each 0.5 hour. If the emission current is unsatisfactory after a burning treatment of 2 hours, the tube cannot be reactivated.

The high temperature developed in flashing is necessary to "strip" or clean the filament surface. After this step, which, in effect, completely paralyzes the filament, the burning voltage is applied in order to form another layer of fresh thorium on the filament surface. It is possible to reactivate a tube filament in as short a period as 10 minutes by using voltages higher than those in the table above. This treatment, however, has a very injurious effect upon the life of the tube and the improvement is only temporary. It must be expected that a small percentage of tube filaments will burn out when the flashing voltage is applied. The number of burn-outs is increased considerably when higher voltages are used in reactivating.

Equipment for Reactivating Tubes.—An arrangement for reactivation in which storage batteries can be used is shown in Fig. 18, the connections being made only to the filament terminals of the socket. The voltmeter is very essential as an aid in securing the correct value of applied voltage. The storage battery intended for flashing must be kept charged, and, to reduce the current drain, only one tube should be flashed at a time.

The following apparatus is needed for direct-current equipment: one A storage battery, 4 volts; one A storage battery, 12 volts; one B storage battery, 24 volts, 6,000 milliampere-hour capacity; one rheostat, 10 ohms; one voltmeter; two tube sockets.

A very convenient arrangement of a similar apparatus which is operated by alternating current from the lighting supply circuit is shown in Fig. 19, If the transformer in this equipment is to be used for both flashing and burning purposes, it must have some provision for adjusting the secondary voltage from about 14 to 18 volts, or else two transformers are required, one with a secondary giving about 14 volts, and another giving about 18 volts.

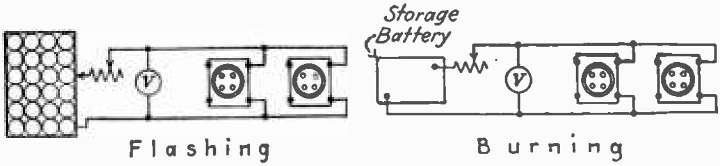


FIG. 18.—Apparatus using direct current for flashing and burning filaments.

A toy or bell-ringing transformer is satisfactory. The General Electric transformer, type 236,093, has a secondary with 2-volt taps from 4 to 22 volts. The alternating-current voltmeter takes an appreciable current and should remain in the circuit, in parallel with the tube, all the time during reactivation.

The following apparatus is needed for alternating-current equipment: one transformer, 110-volt primary, secondary adjustable from 14 to 18 volts; one rheostat, 30 ohms; one voltmeter, for alternating current; two tube sockets.

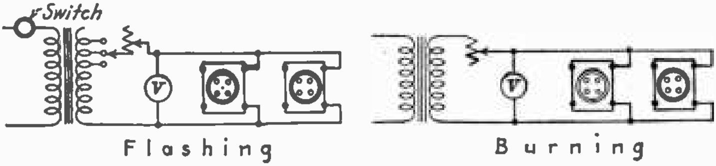


FIG. 19.—Apparatus for using alternating current for flashing and burning filaments.

Some standard types of tube rejuvenators are not provided with voltmeters for indicating the voltage applied to the filament. Many of these are designed to give an excessive voltage, and under such conditions of reactivation the tube filament may be so damaged that the injury is permanent or its life shortened considerably.

Energy Dissipated as Heat.—The electrons which travel from the filament to the plate may be moving at the rate of thousands of miles per second when they hit the plate. When electrons moving at such a high velocity are stopped by the plate, their energy of motion appears in the plate as heat. The rate at which heat is developed in the plate for a non-oscillating tube is equal to the product of the plate voltage and the plate current. For an

TABLE XXVII.—AVERAGE CHARACTERISTICS OF VACUUM TUBES

Tube	Use	A battery supply, volts	Filament terminal, volts	Filament current, amperes	Detector B voltage, volts	Amplifier B voltage, volts	Negative C voltage, volts	Plate current at highest C voltage, milliamperes	Plate resistance, ohms	Mutual conductance, micromhos	Voltage-amplification factor
WD-11 or WX-12.	Detector amplifier	1.5	1.1	0.25	22.5	45	0–1.5	1.1	18,000	340	6.5
						67.5	0–3.0	1.8	17,000	360	
						90	4.5	2.6	16,000	430	
V or UX U199.....	Detector amplifier	3.0 to 4.5	3.3	0.063	22.5 to 45	45	0.5–1.5	1.0	19,500	320	6.25
						67.5	1.5–3.0	1.7	16,500	380	
						90	4.5	2.5	15,000	415	
UX-120...	Power amplifier	4.5	3.3	0.132		90	16.5	3.2	7,700	428	3.3
						135	22.5	7.0	6,600	500	
UX-201A .	Detector amplifier	6.0	5.0	0.25	45	45	0.5–1.5	0.9	18,500	430	8.0
						67.5	1.5–3.0	1.7	14,000	570	
						90	4.5	2.0	10,000	725	
						135	9.0	2.5	10,500	760	
UX-200A .	Special detector	6.0	5.0	0.25	45	.....	....	1.0	30,000	670	20
UX-240...	Detector high-μ amplifier	6.0	5.0	0.25	90	90	1.5	0.2	150,000	200	30
						135	3.0	0.2	150,000	200	
						180	4.5	0.2	150,000	200	
UX-112A .	Power amplifier	6.0	5.0	0.25	45	90	4.5	4.8	5,300	1,500	8.0
						135	9.0	5.8	5,000	1,600	
						157	10.5	7.9	4,700	1,700	
						180	13.5	7.8	4,700	1,700	
UX-171A .	Power amplifier	6.0	5.0	0.25	....	90	16.5	11.0	2,500	1,200	3.0
						135	27.0	16.0	2,200	1,360	
						157	33.0	18.0	2,150	1,400	
						180	40.5	20.0	2,000	1,500	
UX-222...	Amplifier	4.5	3.3	0.132	....	135	1.5[1]	1.5	850,000	350	300.
UY-224...	Amplifier	A.C.	2.5	1.75	....	180	1.5[2]	4.0	400,000	1,050	420.
						180	40.5	20.0	2,000	1,500	
UX-226...	Amplifier	A.C.	1.5	1.05	....	90	6.0	3.7	9,400	870	8.2
						135	12.0	3.0	10,000	820	
						180	16.5	3.8	9,400	870	
UY-227...	Detector amplifier	A.C.	2.5	1.75	45	90	6.0	3.0	11,300	725	8.2
						135	9.0	5.0	10,000	820	
						180	13.5	6.0	9,400	870	
UX-230...	Detector amplifier	...	2.0	0.06	45	90	4.5	2.0	12,500	700	8.8
UX-231...	Power amplifier	...	2.0	0.15	....	135	22.5	8.0	4,000	875	3.5

UX-232...	Amplifier	...	2.0	0.06	....	135	3.0[3]	1.5[4]	800,000	550	440
UX-240...	Amplifier	6.0	5.0	0.25	135	135	1.5	0.2	150,000	200	30
					180	180	3.0	0.2	150,000	200	
UX-210...	Power-amplifier oscillator	8.0 or 7.5 A.C.	7.5	1.25	....	180	12.0	7.0	7,000	1,100	7.7
						250	18.0	12.0	5,600	1,330	
						350	27.0	16.0	5,100	1,500	
						425	35.0	18.5	5,000	1,550	
UX-250...	Power amplifier	8.0	7.5	1.25	....	250	45.0	28	2,100	1,800	3.8
						350	63.0	45	1,900	2,000	
						400	70.0	55	1,800	2,100	
UX-245...	Power amplifier	A.C.	2.5	1.5	....	180 to 250	33 to 50	26 to 32	1,900	1,850	3.5
UX-213...	Full-wave rectifier	A.C.	5.0	2.0	Max. a.-c. voltage plate to filament, 220 per anode			Max. d.-c. load current, milliamperes 65			
UX-280...	Full-wave rectifier	A.C.	5.0	2.0	Max. a.-c. voltage plate to filament, 300 per anode			Max. d.-c. load current, milliamperes 125			
UX-216B .	Half-wave rectifier	A.C.	7.5	1.25	550			65			
UX-281...	Half-wave rectifier	A.C.	7.5	1.25	750			110			
UX-874...	Voltage regulator	...	Rated voltage, 90 volts d.c.			Starting voltage, 125 volts d.c.			Max. d.c. current, 50 milliamperes		
UX-876...	Ballast tube	...	Current, 1.7 amperes			Voltage range, 40 to 60 volts			Standard large screw base		
UY-886...	Ballast tube or current regulator	...	Current 2.05 amperes			Voltage range, 40 to 60 volts			Standard large screw base		

[1] 1.5 volts on inside grid, +45 on outside grid.
[2] 1.5 volts on inside grid, +75 on outside grid.
[3] 67.5 volts maximum on screen grid.
[4] Screen current not over one-third of plate current.

oscillating tube, the rate of heating is equal to about half the product of the plate voltage and the plate current, as indicated by direct-current meters.

Water-cooled Tubes.—A large power tube may develop heat in its plate at a rate of many kilowatts. The plates of even the small tubes may be heated to a dull red color because they cannot radiate the heat rapidly enough, even when operating at their ratings. At higher ratings the heat from the plates may even melt the glass bulb.

A method which has been applied successfully to keep the plate of a vacuum tube cool is water-cooling. In the construction for this method the base of the tube has a copper container surrounding the filament and grid, which is sealed to the glass bulb. This container is then used as the plate of the tube and can be immersed in water for cooling. The cooling water is circulated around the copper container and must be supplied through a rubber hose because most water systems are grounded and the plate of the tube is at a high potential above that of ground.

Plate Resistance.—The internal or *direct-current* resistance R of a vacuum tube permits a current I_p to flow from the plate to the filament when the plate voltage is E_p. An estimate of this direct-current resistance of a vacuum tube may be obtained by observing the plate current corresponding to the plate voltage at which the resistance is desired. The relation between these factors may be expressed as $R = E_p/I_p$.

The vacuum tube as generally used in radio reception operates with pulsating and not constant values of grid voltage, plate voltage, and plate current. Such a *pulsating current*, for example, is considered to be a combination of a direct-current portion and an alternating-current portion, each of which acts independently of the other. The resistance of the tube to alternating current differs from the resistance to direct current.

Unless otherwise stated, the term *plate resistance* in connection with the description of vacuum tubes is the *resistance offered to the flow of alternating current* and is designated as r_p. The *alternating-current* resistance r_p of the plate circuit may be found from the relation

$$r_p = \frac{dE_p}{dI_p},$$

in which dE_p is a small change in plate voltage which produces a corresponding change dI_p in plate current, when the grid voltage is constant. It may be seen from this that r_p is equal to the reciprocal of the slope of the plate current-plate voltage curve at the "point of operation." This slope, and, of course, the plate resistance, is approximately constant over the straight part of the curve but shows an increase at the lower and upper bends.

The expression for the alternating-current resistance may be given also as

$$r_p = \frac{udE_p}{dI_p},$$

in which dE_g is a small change in grid voltage which produces a corresponding change dI_p in plate current. The term udE_g is, of course, equal to the term dE_p from the preceding equation.

It can be shown that the resistance of the tube to alternating current is approximately equal to half the resistance of the tube to direct current. This may be seen from the fundamental relation

$$r_p = \frac{E_p}{2I_p} = \frac{R}{2}.$$

The plate resistance is a measure of the effect of the plate voltage alone upon the plate current. It varies because of the non-linear relationship of plate current to plate voltage shown in Fig. 17. At low values of plate voltage the plate resistance is relatively high. As the plate voltage is raised, the plate resistance decreases rapidly and then more slowly as the normal operating voltage is reached. If the applied voltage is very high, the plate resistance may again increase. This critical value indicates that the saturation point is being reached; that is, practically the full emission current is flowing. This condition is apt to occur when "dry-cell" vacuum tubes are subjected to voltages in excess of rated values or when they are operated without a C or grid-bias (page 36) voltage.

If the filament emission at high plate voltages limits the plate current, the plate resistance will increase. This decreases the efficiency of a vacuum tube as an amplifier (page 355). The available emission of a UX-199 tube is approximately three times the value of the plate current (2.5 milliamperes) when the negative grid voltage is 4.5 volts and the plate voltage is 90 volts. With no grid-bias voltage the plate current becomes 5.75 milliamperes, which is close to the value of the emission current. It is obvious that a grid-bias voltage should be used with such tubes at high plate voltages.

Amplification Factor.—The amplification factor u is the ratio of the change in *plate voltage* dE_p to the small change in *grid voltage* dE_g which produces an equal variation in plate current; that is,

$$u = \frac{dE_p}{dE_g}.$$

The amplification factor depends on the spacing and size of the network of wires in the grid; that is, the closer the spacing the greater the screening effect of the grid on the electrostatic field of the plate. It also varies directly as the distances between the plate and the filament, and between the grid and the filament. The nearer the grid is to the filament the smaller will be the voltage which is needed to produce a field around the filament equal to the field set up about it by the plate. Thus, a tube having a large amplification factor uses a fine grid mounted at a small distance from the filament, as compared to the distance between the plate and the filament.

It is evident from what precedes that the flow of electrons is influenced by an electrostatic field which is the combination of the fields due to the plate and grid charges. The amplification factor is therefore

$$u = \frac{C_g}{C_p}$$

where C_p is the electrostatic capacity of the condenser represented by the plate and filament and C_g is the electrostatic capacity of the condenser represented by the grid and the filament.

This relation shows that the amplification factor is a constant and depends only on the tube structure and not on the operating voltages. It explains also why the curves showing the relation of grid voltage to plate current for various constant values of plate voltage are approximately parallel to each other. The amplification factor is not affected by those factors which influence plate resistance, such as electrode area and filament condition, nor is it altered by changes in the applied voltage, except that at low plate voltages it may decrease slightly.

Actually the amplification factor u is not quite constant but varies with the grid and the plate voltages. The explanation of this effect is that a change in grid and plate voltages causes a change in the shape and location of the space charge (page 285). This, in turn, changes the effect of the grid and plate voltages on the flow of electrons.

Furthermore, the entire filament is not at the same potential, because a voltage drop exists along it. Hence the voltage difference between the grid and various parts of the filament is not constant. For example, if E is the voltage across the filament and if the grid is connected to the negative end of the filament, then the grid is at zero potential with respect to that end but at a potential of $-E$ with respect to the positive end. Electrons can flow from the negative end of the filament without being affected by the grid, because there is no voltage difference between the grid and that end of the filament. But the flow of electrons from the *positive* end of the filament may be stopped entirely by the effect of the grid which, with respect to the positive end of the filament, has a negative voltage of $-E$. The influence of the grid on the flow of electrons, therefore, is not so active as if all of the filament were at the same voltage.

The amplification factor u is, however, practically constant in value over the straight portion of the characteristic curve (page 283). The value of the amplification factor of a vacuum tube expresses the relative effects of grid voltage and plate voltage on the plate current and so determines the plate resistance of the tube. An increased amplification factor corresponds to an increased plate resistance, and *vice versa.* A change in the amplification factor also affects the *mutual conductance* (page 302) to some extent even though the plate area, filament length, and other factors remain constant. A tube with a high amplification factor shows a lower mutual conductance than a tube of similar construction but with a lower amplification factor. This effect is shown in Fig. 20, for a number of tubes with different amplification factors but using the filament and plate construction of a UX-120 tube. It is evident from this drawing that a low value of the amplification factor should be used in order to gain the advantage due to improved mutual conductance, provided that the *impedance load* (page 37) can be adjusted to a suitable value. Such conditions are conducive to maximum power output. For voltage amplification in circuits in which high plate resistance is not important, as in resistance- or impedance-coupled amplification, a high value of the amplification factor u is desirable, because it allows an increase in voltage amplification to be obtained from each stage of the amplifier.

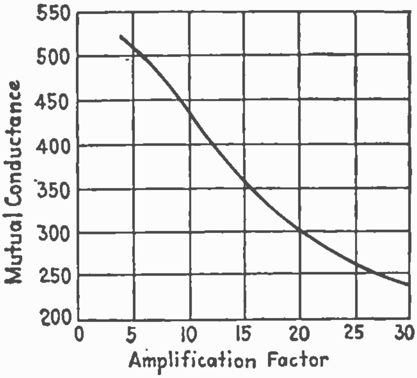


FIG. 20.—Relation of mutual conductance to amplification factor.

The amplification factor u is a measure of the maximum voltage amplification obtainable from the tube alone. The grid-to-filament voltage due to the reception of a radio signal appears in the plate circuit multiplied u times. The voltage developed across a high-impedance load placed in the plate circuit is very nearly equal to the value of uE_g.

Resistance of the Grid Circuit.—In the usual radio receiving set the "grid-to-filament" circuit of the tube is in parallel with the variable condenser (page 401) and its coil. The resistance of this grid-to-filament circuit must be high to avoid broad tuning. As far as tuning is concerned, a circuit consisting of a resistance in parallel with a coil and condenser may be considered as having an *equivalent* resistance in *series* with the condenser. The effect of the grid-to-filament resistance is to increase the resistance of the circuit considerably over that of the coil itself. Consequently, the tuning of the circuit becomes broader and the selectivity less sharp.

The resistance of the input circuit of a vacuum tube is much increased by the use of a negative grid-bias voltage on the grid. The resistance input of the circuit of a tube operated with a negative grid bias of one volt on the grid may be as much as fifty times that of a tube operated at zero grid-bias voltage. At such high values the effect of the resistance of the input circuit on the tuning of a receiver becomes negligible.

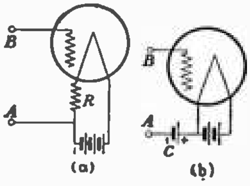


FIG. 21.—Methods of applying negative grid-bias to grid.

Two methods, shown in Fig. 21, may be used to put a negative grid-bias voltage on the grid of the tube. The first of these methods depends on a resistance which is placed in the negative side of the filament circuit. When the "grid return" is connected as shown, the grid is made more negative than the negative end of the filament by an amount equal to the voltage "drop" across the resistance. The disadvantage of this method is that the grid-bias voltage decreases as the voltage of the battery is reduced. The second method utilizes a C or grid-bias battery which is placed in the grid circuit with its negative terminal connected to the grid return and its positive terminal to the negative terminal of the filament. This puts a negative grid-bias voltage on the grid which is equal to the voltage of the battery.

Mutual Conductance.—Both the plate resistance and the amplification factor of a vacuum tube affect its performance as an amplifier. In comparing the merits of tubes it is convenient to use a term, mutual conductance, which takes both of these factors into consideration. *Mutual conductance* is the ratio of the amplification factor to the plate resistance. The usual unit of mutual conductance G_m is the *micromho*. It has been shown that

$$u = \frac{dE_p}{dE_g}, \text{ and } r_p = \frac{dE_p}{dI_p};$$

hence the ratio of the first of these two equations to the second gives the mutual conductance, thus:

$$G_m = \frac{dE_p}{dE_g} \div \frac{dE_p}{dI_p} = \frac{dI_p}{dE_p} \text{ (in mhos).}$$

Or,

$$G_m = \frac{u}{r_p} \text{ (mhos)} = \frac{u}{r_p} \times 10^6 \text{ (in micromhos).}$$

That is, mutual conductance may be expressed as the ratio of a small change in plate current to the change in grid voltage required to produce the same change in plate current. This expression also represents the slope of the curve showing the variation of plate current with grid voltage at the "point of operation." The slope of the curve is greatest, of course, at the point at which the curve is steepest. In other words, at the point of largest value of the slope, a given change of grid voltage produces the maximum change in plate current.

The expressions developed for the values of amplification factor, plate resistance, and mutual conductance show that these three factors are interdependent according to the relations

$$r_p = \frac{u}{G_m},\ u = r_p \times G_m, \text{ and } G_m = \frac{u}{r_p}.$$

Tubes having high values of mutual conductance are more efficient amplifiers than those having lower values, but the comparison must be made between tubes *designed for the same service* and having similar characteristics. Thus the UX-112A tube has an average mutual conductance of 1,600 micromhos with a plate voltage of 135 volts, and the UX-171A tube has an average value of 1,360 micromhos for the same plate voltage. The UX-171A tube can supply a 160 per cent greater undistorted power output than the UX-112A tube, when ample input voltage is available and the load is properly adjusted. In any case, a relatively large change in mutual conductance causes only a small change in the tube performance as judged by the ear in radio reception.

Effects of Interelectrode Capacity.—The elements of a vacuum tube form an electrostatic system, each element acting as one plate of a small condenser. The capacities which exist are the grid-to-filament capacity, the grid-to-plate capacity, and the capacity of the grid-to-plate and grid-to-filament connected together. The *total* capacity of a tube is made up of the capacity of the electrodes of the tube, of the lead-in wires, and of the base. The capacity between the grid and the filament, and between the plate and the filament, is about 5 micromicrofarads. The capacity between the grid and plate is larger, being, for example, approximately 10 micromicrofarads in the UX-210A tube.

It is necessary to remember that the interelectrode capacities of a tube, as measured when the elements are *free*, are not the same as when the elements are *connected*. Thus the "direct" capacity between the grid and plate is increased by the mutual capacity from grid to filament and from filament to plate. The direct capacity between the grid and plate of a UX-201A tube, when the filament has been removed, averages 8 micromicrofarads, while the capacity as measured between these two elements in a complete tube is 10.1 micromicrofarads. The effective value of this capacity is further increased by the capacity of the wiring of the tube socket, the tube base, and also by the amplification action of the tube.

Input and Output Circuits with Electrode Capacities.—When a tube is in use its *input circuit* is considered to be from the grid to the filament, and its *output circuit* from the plate to the filament through a battery and some external load. Thus the capacity of the input circuit may be considered as that of a condenser which has the grid for one plate and the plate and filament connected together for the other. If an alternating voltage is applied to the grid-to-filament circuit of a tube, an alternating current will flow in the grid circuit because of the grid-to-filament capacity. Whether the filament is lighted or not, this grid voltage will set up a current in the plate circuit due to electrostatic induction through the capacity from the grid to the plate.

While the grid-to-filament capacity and the plate-to-filament capacity do not affect the performance of a tube at audio frequencies and have only a small effect at radio frequencies, the grid-to-plate capacity has a very marked effect in a radio-frequency amplifier. As far as the tube itself is concerned, the capacities between the elements of a tube introduce a reactance effect.

When amplification is given in terms of the applied grid voltage, the filament-to-plate capacity has only a small effect, so that the amplification is not affected by frequency for values up to several thousand kilocycles per second. Usually, however, the *amplification is given as the ratio of the output power to the input power*, and the effect of the reactance due to electrode capacities depends on the kind of circuit that is used. If the reactance of the output circuit has the effect of capacity, or if the output circuit consists of a resistance, the input resistance is positive. Under such conditions, power is taken by the tube from the input circuit. The value of this power which is used is so small at ordinary frequencies that it may be neglected. At high frequencies no power is taken by the grid circuit, but the electrode capacities offer a path to the input current and thus reduce the amplification.

The increase in effective interelectrode capacity may become so large under certain load conditions as to affect the performance of the tube at high audio frequencies. Thus, in a resistance-coupled amplifier the effective capacity reaches a value of 250 to 300 micromicrofarads, which is high enough to cause a decrease in amplification at frequencies over 5,000 cycles per second.

In general, then, it may be said that the effect of interelectrode capacity is to produce a coupling between the input and output circuits. Consequently the tube does not have a true unilateral or single-direction characteristic curve. The extent of the coupling depends on the circuit constants. This kind of coupling may cause a *feed-back* of energy to the input circuit or, with certain circuit adjustments, an absorption of energy from the input circuit. The effect of interelectrode capacity is to reduce amplification at high frequencies. Several schemes for decreasing this effect are given in a later section (page 371).

Screen-grid or Four-element Vacuum Tube.—The screen-grid vacuum tube may be represented diagrammatically as in Fig. 22. The conventional method of indicating a vacuum tube of this kind is given in Fig. 23. The filament is shown at *F*, the control grid at *CG*, the screen grid at *SG*, and the plate at *P*. If the plate of the tube is disconnected and the screen grid is used as the plate electrode, the operation of the tube is no different from that of a three-element tube. The screen-grid tube is intended for use as a radio-frequency amplifier and is then connected with a positive voltage on the screen grid by means of a tap from the source of B voltage. The construction is such that the plate gets the necessary number of electrons even though there is a screen grid *SG* in the tube.

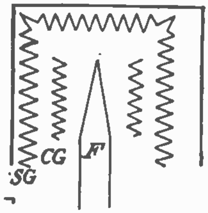


Fig. 22.—Diagram of screen-grid vacuum tube.

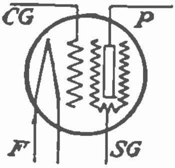


Fig. 23.—Symbolic representation of screen-grid vacuum tube.

It has been explained that the tuning of the input circuit of a tube is dependent to some extent on the adjustments of the plate circuit, because of the effect of the input capacity. Further, the *mutual capacity* between the grid-filament condenser and the plate-filament condenser may produce feed-back. Several circuit arrangements have been devised to be used with ordinary tubes to counteract or neutralize this effect.

The screen-grid tube avoids the necessity of such circuit arrangements because it is constructed in such a way that voltage variations in the plate circuit cannot affect the grid-to-filament circuit. This permits a considerable increase in the possible voltage amplification of the tube. The screen grid, although connected to the source of B voltage which is shunted by a large condenser to a ground wire, is, in effect, at the ground potential with respect to radio-frequency currents. Hence, the control grid is shielded from any plate-voltage variations by the screen grid.

The electrode capacities of the screen-grid vacuum tube may be shown as in Fig. 24 in which the dotted lines indicate the equivalent capacities. Thus C_{F-CG} is the capacity of the condenser action between the filament and the control grid. The capacity between the control grid and the plate, as shown in Fig. 25, is made up of two parts, that is, the capacity between the plate and the ground and the capacity between the screen grid and the control grid. The latter in turn consists of the two capacities indicated in the drawing. Thus the capacity between the control grid and the plate is reduced materially, having a value of a few hundredths of a micromicrofarad, because the resultant capacity of two capacities in series is smaller in value than either of the components.

Although the internal capacity between the control grid and the plate is small, it has been found that neutralization of the radio-frequency amplifying tubes seems necessary when a screen-grid tube is used in the radio-frequency stages of a circuit using regeneration (page 39) applied to the radio-frequency transformer.

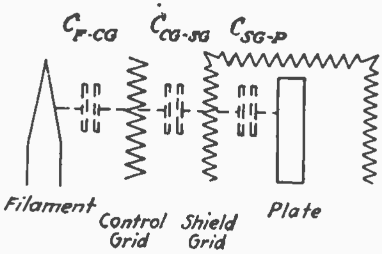


FIG. 24.—Diagram of electrode capacities of screen-grid tube.

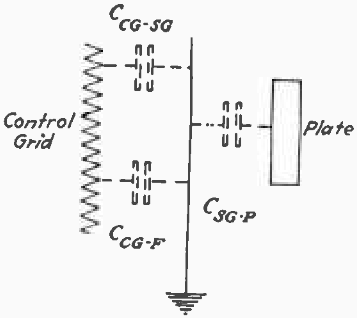


FIG. 25.—Capacity effect in screen-grid tube.

Shielding of Screen-grid Circuits.—The internal shield of a screen-grid tube prevents or greatly minimizes feed-back (page 304) through the inter-electrode capacities of the tube. This, however, is only one form of coupling between the stages. If there is any *magnetic* feed-back from one tuning circuit to the preceding one, there is a tendency for oscillations to take place in the circuit. Hence, it is necessary, also, to shield the input from the output circuit. The amount of shielding depends on the voltage amplification per stage and the design of the circuit. A metallic shield for each tuned stage is usually sufficient. If the voltage amplification is high, it may be necessary to use on the tube a grounded metal covering extending to the base.

Voltage Amplification of Screen-grid Tube.—In the operating range, changes of plate voltage do not cause appreciable variations in plate current because of the screening effect of the second grid. Consequently, the amplitude of changes of plate current produced when the voltage of a radio signal is impressed on the grid is affected very little by an increase in load resistance. For this reason, the use of a very high resistance or impedance in the plate circuit is advantageous in order to obtain high voltage amplification.

The voltage amplification is determined by the mutual conductance of the tube and by the impedance load. The mutual conductance gives the amplitude of changes in plate current due to the application of the voltage of a radio signal to the control grid. The output load voltage is directly proportional to the impedance load, because with an increase in impedance there is practically no change in the amplitude of the signal current. The voltage amplification of a tube which has a mutual conductance of 350 micromhos or 0.00035 mho and which is used with an impedance load of 100,000 ohms is 100,000 × 0.00035 or 35 per stage.

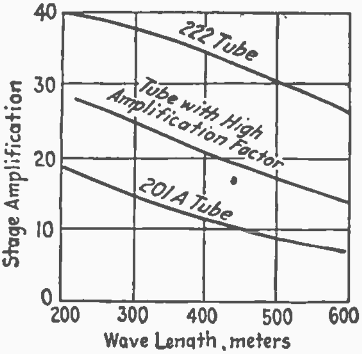


FIG. 26.—Relation of stage amplification to wave length for three types of tubes.

When properly used as a radio-frequency amplifier, the screen-grid tube gives a voltage amplification per stage of 25 to 50 in the broadcast range as compared with 5 to 12 per stage with the three-element tube. At frequencies of 50 to 100 kilocycles per second a voltage amplification of 200 is possible, because a high impedance load can be obtained with the tuned-plate circuit. For the use of the screen-grid tube as a detector and as an amplifier see pages 306 and 341.

Figure 26 shows the stage-amplification curve of a UX-222 tube, which has a tuned circuit connected to its plate. The *stage amplification* is taken as the ratio of $E_2:E_1$ where E_2 is the voltage developed across the plate load and E_1 is the input voltage. The constants of the tube at the "operating point" for this curve are $r_p = 810{,}000$ and $u = 285$. An increase in the plate resistance r_p above 200,000 ohms is not of much advantage so far as amplification is concerned, because it becomes more difficult to couple the circuit to the tube in order to obtain the best voltage transfer.

Figure 26 shows also the stage amplification of a tube with a high-amplification factor u of, say, 50 and a plate resistance of 85,000 ohms, as well as that of a UX-201A tube when operated at $u = 8.6$ and $r_p = 9{,}500$ ohms. In each case the selectivity of the circuit which was used with the tube was adjusted for the same value.

Alternating-current Tubes.—If an alternating current is used to heat the filament of a battery-operated radio receiving set, a loud hum is produced in the loud-speaker, because the alternating voltage on the filament has the same effect on the grid and plate as an alternating radio signal. To avoid this humming effect, a low-voltage filament is used in place of the ordinary 5-volt filament, and the grid return is connected to the filament circuit at a point which is electrically midway between the filament terminals, as shown in Fig. 27. The primary winding of the transformer *T* is connected to a 110-volt, 60-cycle source of power and the secondary winding supplies a voltage of about 2 volts to the filament. A resistance *R* which is connected across the filament circuit is provided with an adjustable contact *A* which is used as the common connection for the filament, the grid circuit, and the plate circuit. The arm of the adjustable contact *A* can be adjusted until the hum in the loud-speaker is reduced to a minimum.

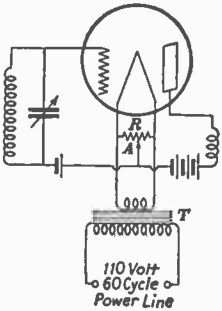


Fig. 27.—Location of grid return with respect to filament terminals for alternating-current tubes.

The alternating-current tubes require a certain grid-bias voltage to reduce the hum to a permissible amount. Both the grid-bias and the "direct" voltage for the plate circuit may be obtained from the circuit supplying alternating current, as explained on page 425.

The screen-grid amplifier and detector tube, type UY-224, is designed for filament operation with alternating current. Its construction is similar to that of the UX-222 tube except that the filament is of the "heater" type. A standard five-prong base like that of a UY-227 tube is used.

The Power Pentode.—A new type of vacuum tube having five elements has found application in European countries. This is the power pentode, its name meaning that it has five elements. This type of tube seems to be ideally adapted for application in radio receiving sets which receive their current supply from batteries. It has, however, no particular advantages for use in alternating-current receiving sets.

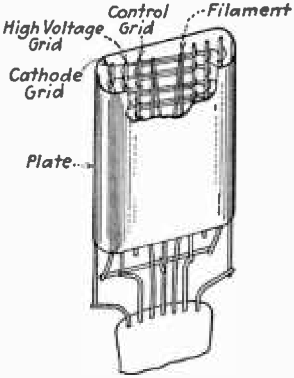


Fig. 28.—Power pentode.

The power pentode is shown in a sectional view in Fig. 28. The five elements of the tube are plainly marked, these being (1) the filament shown at the center, usually constructed in the shape of the letter W; next in order going outward from the center; (2) the control grid serving the same purpose as the ordinary grid in a three-element vacuum tube; (3) the high-voltage grid serving practically the same purpose as the screen grid in a four-element vacuum tube; (4) the cathode grid, usually connected internally to the middle of the filament and serving as a barrier to prevent electrons emitted by the plate due to collision from reaching the high-voltage grid; (5) the plate which serves the same purpose as in the ordinary types in two- or three-element vacuum tubes.

Characteristic Curves of Power Pentode.—The characteristic curves of a power pentode are somewhat different from those of the usual types of three-element vacuum tubes. *Typical* characteristic curves of a power pentode are shown in Fig. 29. The curves in diagram B of this figure show the relation between grid voltage and plate current. Those in diagram A show similarly the relation between grid voltage and the high-voltage grid current. In both groups of curves, it will be noticed that there is a tendency for them to converge as they extend toward the left-hand side of the diagrams. In other words, when the plate voltage E_p is increased from 50 to 250 volts, as represented by the group of curves, these curves are relatively far apart when the grid voltage is zero; but, as the grid voltage is increased to -40 or more volts, the characteristic curves tend to combine into a single line. It will be noted, further, that at low plate voltages the high-voltage grid current is relatively high. The reason for this is that the total emission current from the filament is shared by these two elements—that is, by the high-voltage grid and the plate—and then the electrode having the higher potential at any instant will collect the greater number of electrons and thus produce relatively the greater current.

In a curve showing the relation between plate voltage and plate current, represented as shown in Fig. 30, it will be observed that the curves have a tendency to rise as the plate voltage is increased. The reason for this peculiar behavior of the characteristic curves is that, although the cathode grid prevents a so-called "secondary emission" from the plate, it cannot prevent secondary emission from the high-voltage grid, which has a tendency to increase the plate current. This kind of grid emission can usually be controlled to some extent by varying the mesh of the grid and the spacing of the elements of the pentode.

The spacing of the cathode grid, for example, has an important effect on the operation of the pentode. When properly designed, the cathode grid should be arranged so that it does not directly obstruct the flow of electrons through the meshes of the high-voltage grid. If a power pentode should be constructed so that the cathode grid would obstruct the direct flow of electrons, the high-voltage grid would become red hot in the areas obstructed by the cathode grid. The spacing and also the size of the meshes of the control grid have also an effect on the characteristics of the pentode, as the spacing and mesh will influence the amplification factor and the plate resistance.

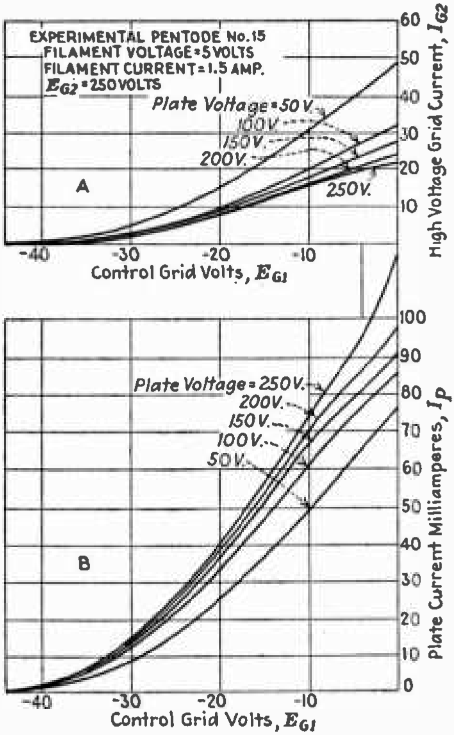


Fig. 29.—Typical characteristic curves of power pentode.

The amount of current required for the high-voltage grid is, of course, a waste of electrical energy, and, fortunately, the characteristics of tubes in which the high-voltage grid current is low are better than those of pentodes requiring a relatively large high-voltage grid current.

The usual fundamental constants of vacuum tubes, that is, (1) amplification factor, (2) plate resistance, (3) mutual conductance, must be used carefully in the design of the power pentode. The reason for this caution is that these fundamental tube constants affect the design of power pentodes in a different way from that in the ordinary types of vacuum tubes. In the vacuum tubes ordinarily used for radio services, the amplification factor, plate resistance, and mutual conductance have nearly constant values throughout the operating range of the tube, while this constancy of value in the operating range does not hold for the power pentode.

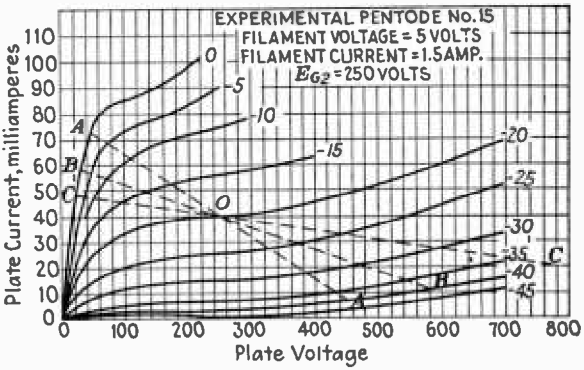


Fig. 30.—Load lines on characteristic curves of power pentode.

Comparison of Output of Power Tubes and Pentodes.—When comparing the power output of a pentode with a typical three-element vacuum tube, it is convenient to make use of the characteristic curves showing the relation between plate voltage and plate current and to plot power-output triangles upon these characteristic curves. Triangles of this kind are illustrated in Fig. 31. Simple circuits for measuring power output as required in such calculations are shown in Fig. 32 (*A*, UX-245 power tube; *B*, typical pentode). In Fig. 31 the line *AOB* is intended to represent the load resistance of 3,900 ohms, which is the value of the resistance for maximum undistorted output from the power tube (UX-245). From the area of the triangle *ACB*, the power output is found to be 1,690 milliwatts. Figure 30 shows a similar set of curves for an experimental pentode. Each curve is drawn for a different value of grid-control voltage. In the latter figure, the line *AA* represents the best load of 6,000 ohms, and the output power is found to be 3,350 milliwatts. This larger amount of power is obtained from the pentode with a grid variation or "swing" of only 20 volts (peak voltage). The UX-245 power tube required a swing of approximately double this voltage to develop a power output about half as large. These data are given to furnish some idea of the comparative power sensitivity when the operating plate voltages and plate current are about the same in the power tube and the pentode. The line *BB* is for a load of 12,000 ohms, and *CC* is for a load of 27,000 ohms, which represents the plate resistance of the tube to alternating currents.

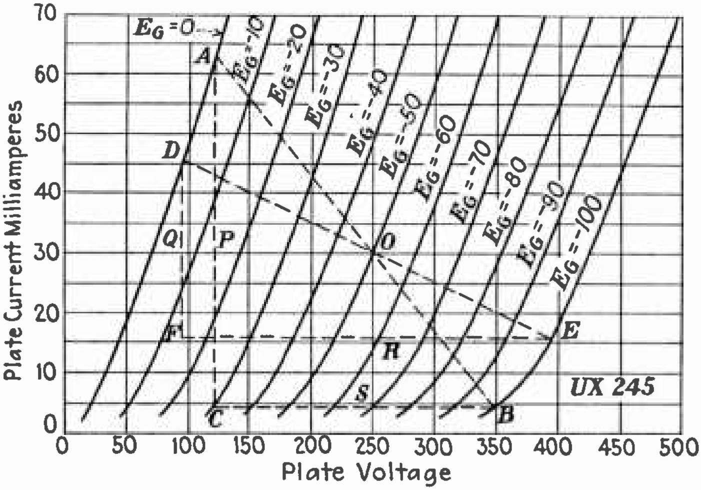


FIG 31.—Power output triangles of power tubes.

A comparison can also be made of the output curves of three-element power tubes and pentodes. Such curves suitable for comparison are shown in Fig. 33. These curves show the shapes of the output waves of an experimental pentode and of a typical three-element power tube. It will be noticed that the wave shape of the three-element power tube does not vary to any great extent from the sinusoidal shape when the load resistance is

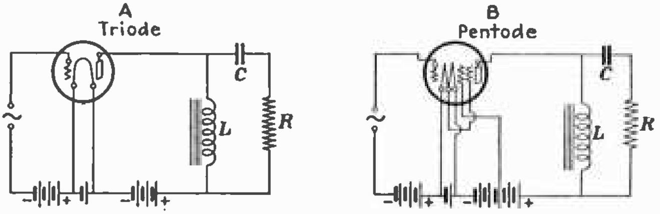


FIG. 32.—Simple circuits for measuring power output of tubes.

varied through comparatively wide limits. On the other hand, the wave shape on the pentode is very much distorted with only slight variations in the load resistance. The dotted curve shown below curve *A* is a sinusoidal wave plotted to the same scale as curve *A*. Many of the recent types of loud-speakers, particularly of the dynamic type, intended to be operated with three-element power tubes, have an impedance characteristic which has increasing values when the frequency is increased. In some loud-speakers of this kind, the impedance of the moving coil at a frequency of 5,000 cycles per second had a value which was three times as great as the impedance at relatively low values of frequency. Sound quality, although fairly good in the dynamic type of loud-speakers when operated with three-element power tubes, would be very much poorer and would, in fact, probably be very disagreeable if the same loud-speaker were operated with a pentode instead of the three-element power tube, for the reason that the shape of the output wave of the pentode at high frequencies would be similar to that shown by curve *B* in Fig. 33. A similar shape of wave would also be obtained when the resistance load is replaced by the magnetic type of loud-speaker. In fact, in the latter case, the variation of impedance with frequency is much greater than in the dynamic type. It is obvious, therefore, that pentodes are not well suited for the operation of any type of loud-speaker as it is now designed.

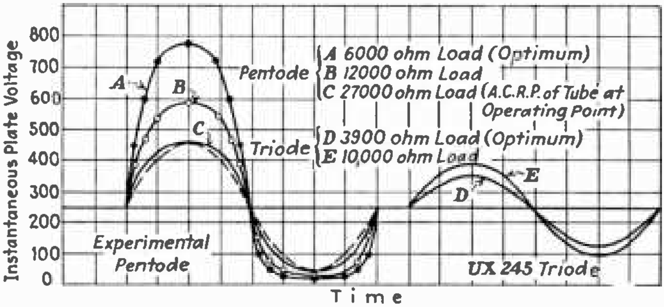


FIG. 33.—Output curves of power tubes and pentodes.

Applications of Power Pentodes.—There seems to be at present no definite demand for power pentodes for use in radio equipment. American designers believe that the present designs of three-electrode power tubes provide adequate current output and have suitable characteristics for practically all present requirements and that, consequently, it is unnecessary to design radio equipment including power pentodes which are relatively complicated because of having five elements. On the other hand, power pentodes have had considerable application in European countries, largely for the reason that the adaptation of radio receiving sets to the complicated power supply system in European countries has caused a good deal of difficulty, and for this reason, considerable effort has been put into the design of improved types of battery-operated receiving sets including power pentodes. The power pentode seems to be particularly useful, therefore, for use in the design of radio equipment which is to be operated by batteries but has no important advantages for radio receiving sets which are designed for alternating-current vacuum tubes.

There is also the possibility of the use of power pentodes for the so-called "rectifying" of high-voltage alternating current for transmission to distances which are now impractical because of the losses involved. Power transmission at high voltages has probably reached its greatest distances because of voltage limitations and consequent electrical losses. Transmission of high-voltage direct current involves, however, much smaller losses, so that if pentodes of sufficient size can be developed to handle the current required for long transmission lines, there would appear to be a possible application in this field.

Still another application of the power pentode is in the low-cost phonograph amplifier. In this device, a single power pentode of suitable characteristics can be made to serve as the amplifier (without other vacuum tubes) for the reproduction of phonograph music by supplying the grid of the pentode with the voltage from a low-impedance pick-up of a phonograph, the pick-up being connected to a high-ratio step-up transformer. An amplifier of this simple type would have very few parts and consequently could be made very cheaply.

The power pentode has also possibilities in application to the radio receiving sets intended for use in automobiles and in rural districts where alternating-current supply is not available for radio equipment. The inclusion of a power pentode into radio receiving sets of this kind would simplify the construction and power requirements considerably. A power pentode for this type of service should have characteristics similar to the UX-112A or the UX-171A three-element vacuum tubes, and the pentodes should be designed to deliver at least 500 milliwatts with a swing of not more than 20 volts at the peak.

Many radio engineers have been working on the problem of designing a detector tube of some type which could be made to operate a loud-speaker directly without the use of audio-frequency amplifying tubes. Some designers believe that the power pentode has possibilities for the realization of this simplified design of radio receiving sets.

Screen-grid Pentode.—The second type of five-element tube might be called a screen-grid pentode because in construction it is similar to the

UY-224 tube (page 308). In the power pentode the additional or cathode grid is located between the high-voltage grid and the plate and is intended to prevent the "secondary" emission of electrons. In the *screen-grid* pentode the additional grid is called a *space-charge grid* and is located between the filament and the control grid. This extra element is intended to neutralize the space charge.

Both types show the presence of the secondary emission of electrons. A comparison of voltage gain indicates that the power pentode is about three times as sensitive as the screen-grid pentode. The plate current of the screen-grid pentode is small, its interelectrode capacity is high, and its power output is low. It is suitable for use in radio-frequency stages, the detector stage, and audio-frequency stages but not in a power-output stage.

The average characteristics of a "Ceco" screen-grid pentode for alternating current are given in the table below for various space-charge voltages. The filament heater has a rating of 1.75 amperes at 2.5 volts.

TABLE XXVIII.—CHARACTERISTICS OF SCREEN-GRID PENTODE FOR VARIOUS SPACE-CHARGE VOLTAGES

Heater, volts	2.5	2.5	2.5	2.5
Heater, amperes	1.75	1.75	1.75	1.75
Control grid, volts	−1.5	−1.5	−1.5	−1.5
Space-charge grid, volts	+10	20	10	20
Screen grid, volts	+180	180	135	135
Plate, volts	250	250	250	250
Amplification factor	575	540	740	750
Plate resistance, ohms	285,000	180,000	380,000	300,000
Mutual conductance, micromhos	2,000	3,000	1,930	2,500
Plate current, milliamperes	4.1	6.0	1.7	2.6
Screen current, milliamperes	0.8	0.9	0.5	0.2
Space-charge current, milliamperes	3.0	10.0	5.0	12.0

Examination of the values given in the table of characteristics shows that the constants of the pentode vary greatly as the operating conditions are changed. In the first column the space-charge grid voltage is 10 volts, while in the second column it is 20 volts. This variation reduces the plate resistance much more than it decreases the amplification factor, a higher mutual conductance resulting. It will be noted that plate current, screen current, and space-charge current have higher values in the second case than in the first. They are so high, in fact, as to have probably a serious effect on the life of the tube. Comparing the first column with the third, it will be noted that the screen-grid voltage is decreased from 180 to 135 volts while the other electrode voltages remain fixed as in column one. The results show a marked increase in amplification factor and in plate resistance, the latter increasing relatively faster than the amplification factor, thus producing a lower mutual conductance. Smaller amounts of plate current and screen current are required in the third case than in the first but the space-charge grid current is increased.

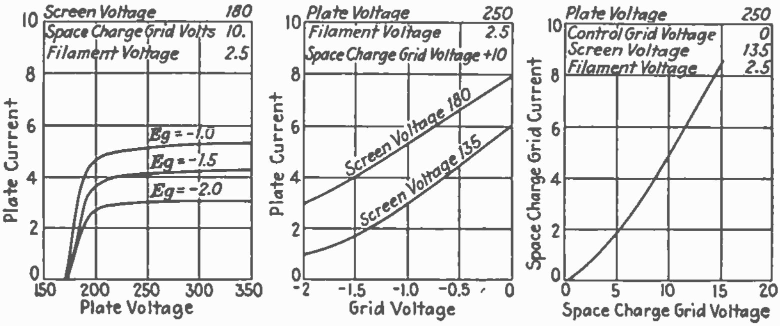


FIG. 34.—Typical characteristics of screen-grid pentodes.]

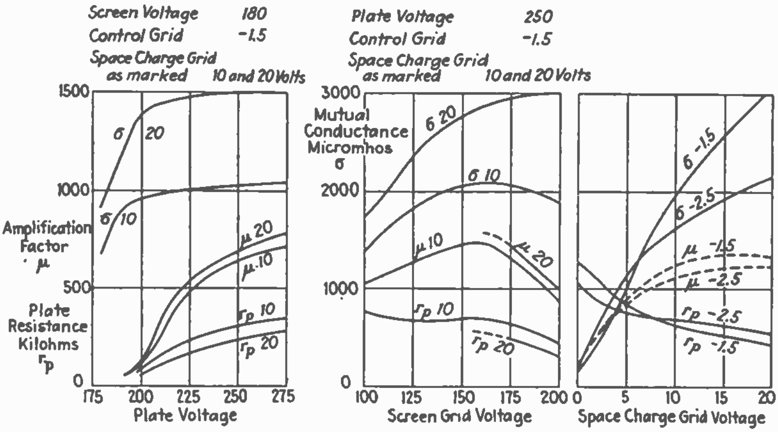


FIG. 35.—Typical curves of mutual conductance, amplification factor, and plate resistance for screen-grid pentodes.

The *interelectrode capacity* between the control grid and the plate is about 90 per cent higher than that of the UY-224 tube. The input capacity between the control grid and the cathode, as well as the space charge between the grid and the screen in parallel, is double the value in the UY-224 tube, as is also the output capacity.

The curves in Fig. 34 show the variation of plate current with grid voltage, the variation of plate current with plate voltage, and the variation of the space-charge grid current with the space-charge grid voltage. Figure 35 shows the effect on mutual conductance, amplification factor, and plate resistance as changes are made in the plate voltage, screen-grid voltage, and the space-charge grid voltage.

Grid-regulated Heavy-current Vacuum Tubes.—The increased use of vacuum tubes for other than radio services has made it necessary to design vacuum tubes which will be suitable for handling much larger currents than are required for radio equipment. The large drop of voltage in the usual high-vacuum tube produces a large internal power loss which makes these tubes of relatively little value for heavy-current work. For this heavy-current service, a new kind of vacuum tube called the *thyratron* has been developed. This new type has been designed so that the internal power loss is very much reduced, and a new type of cathode is used so that it is possible to produce a very high emission of electrons.

For some time, there have been available "hot"-cathode mercury-vapor rectifier tubes which differ mainly from the pool-type mercury rectifiers in that their capacity for passing current through them is considerably larger because of the increased emission of electrons from the hot cathode. In this respect, these hot-cathode rectifiers are similar in operation to the high-vacuum rectifier tubes. There is, however, to be noted this improvement, in that the hot-cathode rectifier contains a small amount of mercury, while the high-vacuum rectifier has none. The vapor produced when this mercury in the hot-cathode rectifier is ionized has the effect of neutralizing the space-charge electrons so that there is a fairly constant voltage drop through the rectifier of only about 15 volts. The mercury-vapor pressure, however, is so low that the plate of the rectifier tube can withstand high voltages when it is negative. A rectifier of this type is, in many respects, almost ideal.

The thyratron is a development of the hot-cathode mercury-vapor rectifier and incorporates, in addition, a control electrode. The method of control of the thyratron is different from that of the usual three-electrode vacuum tube. For any value of plate voltage, there is a definite grid voltage at which ionization will just occur, and at this point, the thyratron just begins to pass some current. This condition of the tube, when the current just begins to flow through it, is called the *trigger point.* The actual grid voltage at the trigger point may be either positive or negative, depending somewhat on the design of the tube. It should be noted, however, in this connection, that if the grid voltage is "more negative" than this trigger point, the discharge of electrons will not occur; but as soon as the grid voltage passes the trigger point the ionization will occur and the tube will begin to pass current. Unlike a vacuum tube, however, when the discharge of electrons once begins. the grid voltage has no appreciable effect on the anode current, control being restored to the grid only when the discharge ceases long enough for the de-ionization of the mercury vapor to occur.

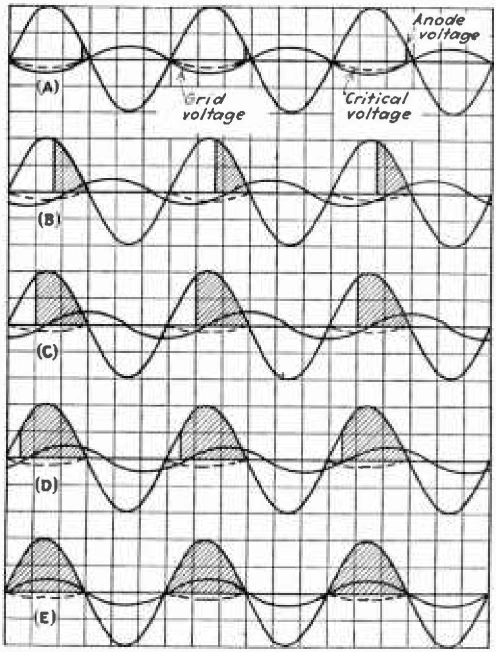


Fig. 36.—Wave shapes produced by shift in phase of grid and plate voltages.

A comparison of the operation of the thyratron with that of a simple rectifying vacuum tube may serve to show the difference in operation of the two. In the simple rectifying tube, the positive ions neutralize the space charge. In the thyratron, the positive ions tend also to neutralize the space charge but, in addition, neutralize the charge on the negative grid. The result is, that, in most cases, a prohibitive current would have to be supplied to the grid before it could regain control by the regulation of the plate current. In order to allow the grid to act, the plate voltage must be practically reduced to zero for a long enough period for the mercury vapor in the thyratron to de-ionize.

If an alternating-current voltage is applied to the plate of a thyratron, its grid may regain control once in each cycle of the alternating current, and it can delay the forming of the arc for as long a period during the cycle, as the grid voltage is more negative. The thyratron is, therefore, a type of control valve which has very little voltage drop and has, consequently, a low internal loss. Figure 36 shows the wave shapes obtained by a shift in phase between the grid and plate voltages. Example *A* shows the wave forms with the tube in an almost non-conductive condition, while example *E* shows rectification throughout the entire half wave. The other diagram shows several intermediate stages of grid control. The phase relation between the grid and the plate voltages determines the amount of current passing through the thyratron.

In addition to the phase-shift method of thyratron control, it is possible to obtain a partial control by a variation in the magnitude of either direct-current or alternating-current grid voltage, and, of course, it is possible to obtain an "on-and-off action" with either direct current or alternating current, provided the anode voltage is alternating. In general, the phase-shift method is the more satisfactory, for the reason that it almost entirely eliminates the effect of variation of vacuum-tube characteristics with temperature and the effect of variation in grid currents. The on-and-off control has no particular difficulties, but it is necessary to supply ample grid voltage at all times from a sufficiently low-impedance source of current.

Recent Designs of Thyratrons.—There are a number of different designs of thyratrons, the tendency of designing being toward the use of a separate non-emitting filament. The efficiencies of thyratrons have been increased to such an extent that it is now possible to obtain a useful electron emission of more than one ampere per watt used for heating. Because of these improved efficiencies, there appears to be no fundamental limitation on the possible size of thyratrons, even up to a size which would pass several thousand amperes.

Cathodes for Thyratrons.—There are several forms in which the cathodes of thyratrons may be made. Those preferred are the following: (1) open-filament type; (2) indirectly heated cathode; (3) shielded-filament type; (4) coiled filament. The type of cathode to be adopted in any particular case depends somewhat upon the service required; for example, if quick heating of the cathode is necessary, the open-filament type should be adopted while the second type, that is, the indirectly heated cathode, should be selected if very high efficiency is expected.

Methods of Thyratron Operation.—There are two general methods of thyratron operation with regard to control characteristics; and the design of the thyratron should be modified as may be necessary in order to be most suitable for the method of operation. One method of operation is known as "negative control," meaning that the applied grid voltage which is just less than the amount required to produce ionization is negative, except for the very lowest voltages. A thyratron with this characteristic is very desirable when it is to be used for operating relays, for the reason that the wattage required for the grid is very small, and therefore the power amplification of the thyratron is very large. A tube of this kind is very useful because it not only rectifies alternating current but also provides a method of control of the amount of current to be rectified; and these results are accomplished with the expenditure of a small amount of power. Another method of operation of thyratrons requires the use of a positive-grid design of thyratron. In the operation of this type, a positive grid voltage is required to start the flow of current through it except for the very highest plate voltages. This type of thyratron is mainly used for control purposes in cases where it is desired to have the tube normally "off," and the thyratron will pass current only when there is an appreciable amount of power applied to the grid. Its proper use is, therefore, for the control of power circuits. As a thyratron of this type is ordinarily designed, considerable time is required for it to de-ionize at the end of a cycle, so that when very rapid operation in a control circuit is required, special design features must be worked out for the thyratron. When these requirements are definitely in mind, it is possible to design a thyratron which will de-ionize in a few microseconds. As already stated, a considerable amount of power must be applied to the grid of this type for its operation.

Comparison of Control Type of Thyratron with High-vacuum Tube.—The advantages of the improved types of thyratrons over high-vacuum tubes for power-control operations may be shown by the fact that if, for the same service, a properly designed control thyratron and a high-vacuum type of vacuum tube are used, the two tubes being of approximately the same size and cost and requiring about the same amount of grid power, the high-vacuum tube will provide for the flow of a current of 0.75 ampere through it while the thyratron will pass 2.5 amperes. It should be noted in this connection that the thyratron has, of course, a higher cathode wattage than the high-vacuum tube, but the larger cathode could not be economically used in the high-vacuum tube because of the excessive voltage drop that would result from the high space charge. In other words, it may be stated that the current-carrying capacity of a suitably designed thyratron is about thirty times as much as that of a high-vacuum tube of the same size and cost.

Typical Circuits for Thyratrons.—A typical circuit for the application of thyratrons for changing single-phase alternating current to direct current is shown in Fig. 37. Only slight modifications in the circuit will be necessary to adapt the thyratrons for the rectification of polyphase alternating current.

Another notable application of thyratrons is in the so-called *inverter* which changes direct current to alternating current and may be either separately excited or self-excited. The circuit for this application is shown in Fig. 38. There are several types of inverters, but the general principle of operation is the same. In every case, direct current is applied to the plate of the thyratrons, and the grid is supplied from a circuit "tuned" to the desired frequency. In this respect, an inverter may be considered as a thyratron amplifier or oscillator. The function of the thyratrons in a circuit of this kind is to commutate or, in other words, perform a switching operation. In all inverters, some form of power storage is necessary in order to supply power during the commutation period. This power supply may be in the form of static condensers, or the power system with a leading power factor, or a suitable type of rotating apparatus.

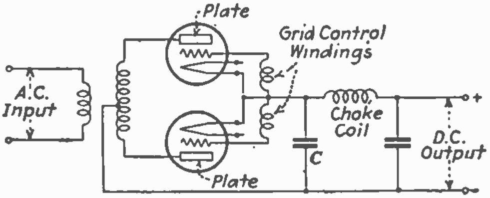


FIG. 37.—Thyratron circuit for rectifier.

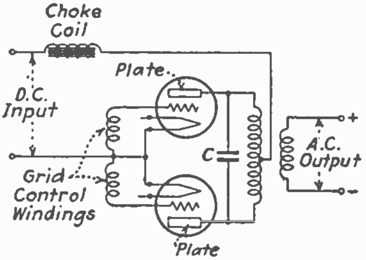


FIG. 38.—Thyratron circuit for inverter.

The action of the inverter may be explained by reference to the diagram in Fig. 38. The anodes of both thyratrons are positive, and it will be assumed that the grid of the upper tube in the figure is positive. Current will then flow from the positive direct-current source through the transformer to the negative direct-current line through the upper thyratron. The grid of the lower thyratron is negative and allows no current to pass. The condenser *C* is charged with the voltage drop across the output transformer due to the flow of current in the upper half of the winding, the upper terminal becoming negative and the lower positive. Toward the end of the cycle, the grids exchange polarity. This change of polarity from positive to negative has no direct effect on the current flow through the upper thyratron but allows current to flow through the lower one, which in effect connects the lower side of the condenser *C* to the negative lead. This places a negative voltage of short duration on the plate of the upper tube and allows the grid of that tube to regain control. As this action continues, voltage is generated in the output winding.

Thyratrons of various power ratings are now being manufactured, and designs intended for considerable amounts of power are being perfected.

SECTION VII

VACUUM-TUBE CIRCUITS

Purpose of Vacuum Tubes in Radio Communication.—A high-frequency radio current which is not audible to the human ear carries the radio signal by low-frequency variations in the amplitude of the high-frequency current. Radio receiving sets, therefore, must contain a device called a *detector* or a *rectifier* which responds to the variations of the high-frequency current. The output current of the detector must be of audible frequency (page 72), so that when this current is passed into a telephone receiver or similar device it is converted into sound. The rectifying qualities of crystals (page 124) may be applied for the purpose of *detection* in simple radio receiving sets. A vacuum tube, however, may be used also as a detector and when so used is more efficient and reliable than a crystal.

A detector tube must be supplied with an input current which is greater than about 0.1 volt in order that it may operate efficiently. Consequently the radio-frequency voltage induced in the antenna (page 169) must be *amplified* or strengthened before it is applied to the detector tube. This is done by "applying" the antenna current to the input circuit of a vacuum tube arranged to operate as a radio-frequency amplifier (page 367). The output current of this tube may be passed through the input circuit of still another amplifying tube; and several such stages of amplification (page 307) may be used in the entire radio-frequency amplifying device. The output current of the radio-frequency amplifier goes to the detector tube, and the output of the detector tube may be passed into an audio-frequency amplifier (page 355) to increase the volume of sound.

The high-frequency currents necessary for radio communication were formerly obtained by the oscillatory discharge (page 89) of a condenser. One disadvantage of this method is that neither very high frequencies nor heavy currents are possible. A vacuum-tube circuit may be arranged in such a way that the tube when supplied with direct current will generate an alternating current of a wide range of frequency. In fact, a suitable design of such a circuit may be made to supply an alternating current ranging in frequency from a fraction of a cycle per second to about 50,000,000 cycles per second. A vacuum tube which is used in a circuit so that it gives an alternating current is called an *oscillator*.

Oscillating tubes of this kind are used at radio transmitting stations to provide the high-frequency current supplied to the transmitting antenna. For radio broadcasting, the amplitude of the antenna current is varied in a manner corresponding to the characteristics of the sound waves which affect the microphone (page 132). This action of varying the amplitude of the antenna current to correspond to the form of the sound waves to be transmitted is accomplished by a vacuum tube arranged to operate as a *modulator* (page 38).

Part 1

USE OF VACUUM TUBES AS DETECTORS

A vacuum tube, in operation in a radio receiver, is actuated by an alternating current due to radio signals. The duty of the vacuum tube, as a detector, is to detect and amplify such alternating currents.

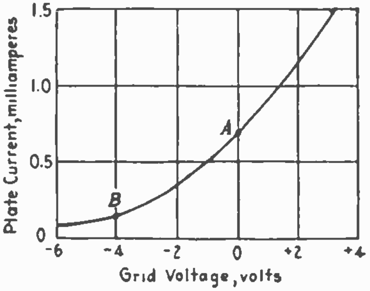


FIG. 1.—Characteristic curve of vacuum tube.

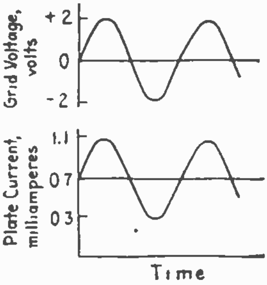


FIG. 2.—Curves of varying grid voltage and plate current for point A in Fig. 1.

An understanding of this action may be gained from a consideration of a vacuum tube of which the curve in Fig. 1 shows the relation between plate current and grid voltage. At the zero value of a steady *voltage* on the grid which corresponds to point *A* on the curve, the plate current is about 0.7 milliampere. Now, if an alternating voltage is applied to the grid of the tube, its voltage will vary above and below the steady value and the plate current will similarly rise and fall. The plate-current variations are the same as the grid-voltage variations because the operation of the tube is on the part of the characteristic curve which is nearly straight. At a grid voltage of +2 volts, the plate current is about 1.1 milliamperes, and at −2 volts it is 0.3 milliampere. These relations are shown in Fig. 2.

The *varying* plate current in Fig. 2 may be considered as consisting of two *components*, one of which is *alternating* and the other of which is *direct* current. (A *component* of an alternating electric current is one of the parts out of which the whole may be obtained by the principle of addition of instantaneous values.) The average value of the *varying* current is the same as the value of the *direct* component. The alternating component, in this case, has an amplitude of 0.4 milliampere and an *effective value* of 0.3 milliampere.

A direct-current ammeter indicates the average value of the current which passes through it and hence would show no change in the value of the plate current, when the alternating grid voltage is applied.

Thus if the grid-bias (page 36) voltage is such that the "point of operation" is on a straight portion of the curve showing the variation of plate current with grid voltage, then the plate-current variations are similar to the grid-voltage variations. This illustrates the use of a vacuum tube as an *amplifier*.

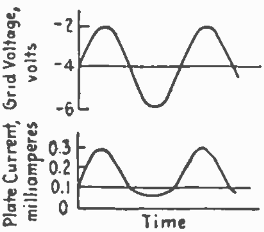


FIG. 3.—Curves of varying grid voltage and plate current for point B in Fig. 1.

If the same alternating voltage is applied to the grid when operation is at point *B* on the curve (Fig. 1) corresponding to a negative grid voltage of 4 volts, then the grid voltage will fluctuate from −2 to −6 volts. In this case, the plate current corresponding to a grid voltage of −4 volts is about 0.1 milliampere; for −2 volts on the grid it is about 0.3 milliampere; and for −6 volts it is only a little less than the value for −4 volts. These relations are shown in Fig. 3. It is obvious that the curve for the plate current is quite distorted in shape when compared with the curve for the grid voltage. This distortion is due to the fact that the point of operation is at the bend of the curve for plate current against grid voltage in Fig. 1. It is evident from this curve (Fig. 3) that the *average* value of the varying current is greater than the *steady* current flowing when no alternating voltage is impressed on the grid. Under these conditions an ammeter would show an increase in the plate current when the alternating grid voltage is applied. This change in the average value of the current is of importance in the operation of a vacuum tube as a detector.

Purpose of a Detector.—The high-frequency alternating currents used in radio transmission and reception will not flow to any considerable extent through the inductive windings of telephones or loud-speakers. Even if the current did flow, the diaphragms of such apparatus could not vibrate at such high rates; and, further, even if the diaphragms could vibrate at this rate, a note of such high frequency would be inaudible. The detector converts radio-frequency currents, which vary in amplitude at an audio-frequency rate, into pulsating direct currents.

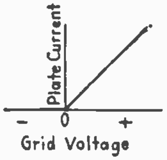


FIG. 4.—Plate current and grid voltage in true detector.

A theoretically *true detector* would operate as shown in Fig. 4. When the grid voltage is positive in value the plate current varies directly with the voltage, and when the grid voltage is negative the plate current is zero. If, now, an alternating voltage is impressed on such a detector and it is operated at zero grid voltage, a plate current will flow only when the grid voltage has a positive value. With a true detector in a radio receiver, the audio-frequency current is directly proportional to the strength of the radio signal. This action, however, is considerably different from that of the ordinary vacuum-tube detector.

Non-oscillating Tube as Detector without Grid Leak and Condenser.—A circuit illustrating the use of a non-oscillating vacuum tube as a detector with no grid leak or condenser is shown in Fig. 5. The reference point for all voltages is taken as the negative terminal of the filament. The grid-return wire is connected to the negative terminal of the A battery or other source of current supply. The filament rheostat is in the negative leg of the filament. Hence the negative terminal of the A battery, and also the grid, is made negative with respect to the reference point at the negative terminal of the filament by an amount equal to the voltage drop across the rheostat. This negative voltage applied to the grid is called the *grid bias* or *biasing voltage* and fixes the point of operation on the curve showing how the plate current varies with the grid voltage. It is obvious that as the voltage of the A battery is reduced the amount of grid-bias voltage also decreases. The con-

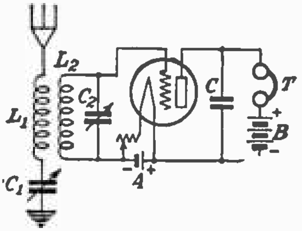


FIG. 5.—Non-oscillating vacuum tube used as detector, without grid leak and condenser.

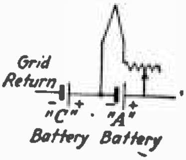


FIG. 6.—Part of circuit in Fig. 5 using rheostat in positive side.

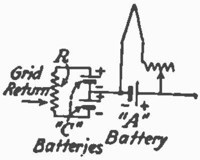


FIG. 7.—Part of circuit in Fig. 5 with variable grid-bias voltage.

nection in Fig. 6 provides a constant grid-bias voltage equal to that of the C battery or the C voltage supply. In this case, the rheostat is put in the positive leg of the filament. The connection in Fig. 7 allows the grid-bias voltage to vary from minus to plus; that is, operation can be made to take place at either the lower or the upper bend of the curve in Fig. 1.

Now, when a radio wave from a broadcasting station passes across the antenna of a receiving set, a radio-frequency current is induced in the antenna circuit, which has been tuned to the wave length of the broadcasting station, by the method of varying the capacity C_1 in Fig. 5 until a condition of resonance is obtained. This current produces a voltage "drop" across the coil L_1 which is transferred by induction to the coil L_2. The secondary circuit consisting of L_2 and C_2 is tuned to resonance in order that the voltage across this circuit may be as large as possible. This voltage, which has the same characteristics as the radio wave, is impressed across the vacuum tube between the grid and the filament. It has already been shown that, when an alternating voltage is applied to the grid under these operating conditions, the wave form of the current in the plate circuit is distorted from that of the grid voltage and that the plate current increases more above the normal value when the grid is positive (relative to the point of operation) than when it is negative.

The average frequency of the waves of sound produced by the human voice in speaking is about 800 cycles per second, but the frequency range varies with the pitch of the tone. A change of inflection in speaking, a change of tone in singing or in the sound of musical instruments, causes changes in the frequency of the air waves which are produced. In a radio-broadcasting transmitter these air waves are made to modulate the "carrier" oscillations; that is, the radio-frequency oscillations of the *carrier wave* which is a radio wave that can be modulated by sound waves, are varied in *amplitude* at the audio frequency or tone rate of the sound in the microphone. Such modulated radio-frequency currents finally produce radio waves which have the same characteristics as the corresponding sound waves. The radio wave is changed by the radio receiver into sound waves having the same characteristics as the sound waves which entered the microphone at the transmitter. The detection of voice-modulated continuous oscillations is illustrated in Fig. 8. The radio-frequency component of the plate current flows through the by-pass condenser C in Fig. 5, and the pulsating audio-frequency component flows through a telephone receiver or a loud-speaker.

In the action which has been described, detection results from the distortion due to operation on the bend of the curve in Fig. 1 showing the variation of the plate current with grid voltage. This method is sometimes called *detection by plate rectification*, or *detection with grid bias*, or *detection without grid leak and grid condenser*.

An *advantage of the plate rectification* method of detection is that no current flows in the grid circuit, because the average value of the grid voltage is maintained negative with respect to the filament in order to operate on the curved portion of the curve. Hence, no power is taken from the tuning circuits and no damping effect is exerted on them. This, however, is offset by the necessity of using a C voltage supply.

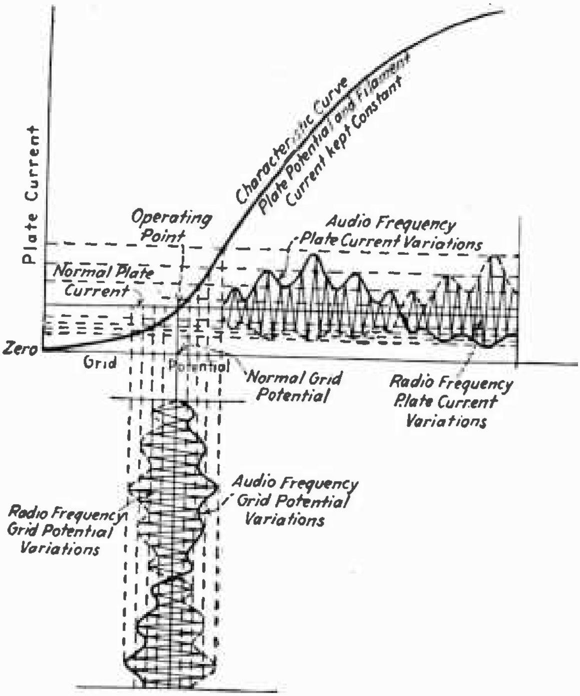


FIG. 8.—Detection of oscillations as modified by the voice.

For radio signals of ordinary intensity, the mean value of the change of plate current is nearly proportional to the square of the amplitude of the oscillations of the grid voltage, although the relation does not hold for strong radio signals.

In this method, operation at the upper bend of the curve is like that at the lower bend. But it should be noted that, for operation at the upper bend, equal variations of the incoming oscillations produce unequal variations of the plate current, so that the plate current is decreased more than it is increased. In operation at the lower bend, the plate current is increased more than it is decreased.

In plate rectification, the result of the action of the tube may be considered equivalent to that of a stage of radio-frequency amplification and a detector. This is because the radio-frequency voltage that is applied to the input is amplified in the plate circuit and changed to audio frequency.

Action of a Vacuum Tube without Grid Leak and Condenser.—It may be shown that the average value of the change in plate current for weak signals is

$$\frac{E^2}{4} \times \frac{d^2I_p}{dE_g^2}$$

where E is the maximum value of the radio signal voltage impressed on the grid and d^2I_p/dE_g^2 is the rate of change of the slope of the curve for the variation of plate current with grid voltage.

The average value of the change in plate current increases most rapidly when the curve in Fig. 1 bends sharply at the point of operation or when the slope of this curve changes rapidly. Operation at the lower bend of this curve is preferable, because at the upper bend the grid is positive and the conductance of the input circuit is high enough to result in considerable damping of the receiving circuit.

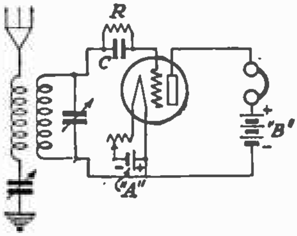


FIG. 9.—Non-oscillating detector with grid leak and condenser.

Non-oscillating Vacuum Tube Used as Detector with Grid Leak and Condenser.—Louder radio signals are obtained with many tubes if the grid is made positive with respect to the negative end of the filament so that a current flows in the grid circuit. Under these conditions the tube, instead of operating on the bend of the curve showing the variations of plate current with grid voltage, operates on the bend of the curve showing how the grid current varies with the grid voltage and on the straight portion of the curve showing variations of plate current with grid voltage. In the operation of this method a fixed condenser C is connected in series with the detector tube in the circuit of Fig. 5, as shown in Fig. 9. It should be noted that the grid-return wire is connected to the positive terminal of the A battery.

When an incoming radio signal as represented in Fig. 10 is received by this circuit, similar voltage variations are communicated to the grid through condenser C. Each time the grid becomes positive, the grid current which flows at the voltage e_0 increases more than it decreases when the grid voltage becomes less then e_0. This means that when the grid voltage becomes positive with respect to the filament, electrons are attracted to the grid, and when the grid voltage becomes negative during the next half cycle, the electrons cannot get away from the grid because they are "blocked" by the condenser C. As this action continues, more electrons are "trapped" on the grid. Hence, the grid continues to gain negative charges and the mean value of grid voltage becomes more and more negative with increasing strength of the incoming oscillations as shown at 3 in Fig. 10. This negative grid charge opposes the flow of electrons to the plate and magnifies the decrease in plate current as shown at 4 in the same figure. This charge can leak off through the condenser C or through the walls of the vacuum tube. If the insulation of the circuit and the condenser were perfect, the plate current would be so reduced that the tube would "block." But in order to make certain that this leakage occurs at the proper rate, a resistance R of a

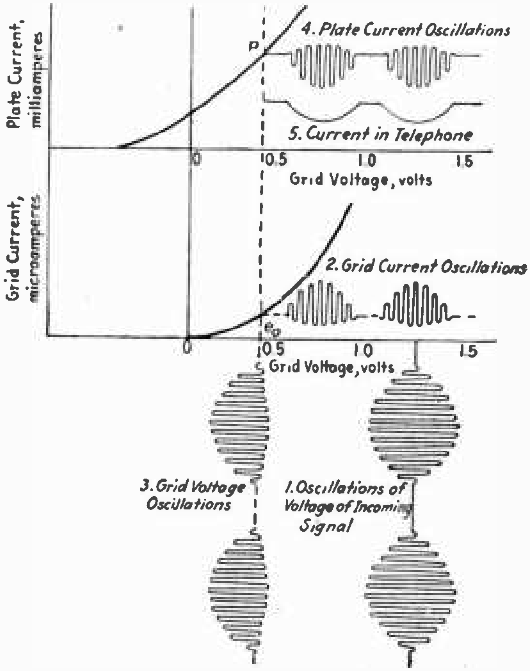


FIG. 10.—Detection of modulated continuous oscillations with grid condenser.

few megohms, called a *grid leak*, is shunted across the condenser C. In a *soft tube* a grid leak is not needed because the charge can leak from the grid to the filament by means of the conducting path through the gas with which the tube is filled.

Values of the capacity C range from 150 to 500 micromicrofarads, and the grid-leak resistance varies from 1 to 8 megohms. The value of R is such that the rate of leakage is proportional to the *period* of the *audio-frequency* variations of the radio-frequency oscillations and not to the *period* of the *radio-frequency oscillations*. The form of the current which flows through a telephone receiver is represented at 5 in Fig. 10.

In this method of detection (grid rectification), the operation is carried out on that portion of the curve showing variations of grid current with grid voltage which has the greatest curvature. At the same time, the plate voltage is so adjusted that the operation of the tube takes place on the steepest portion of the curve showing plate-current variations with those of grid voltage. In order to meet these conditions, the grid must be positive with respect to the negative end of the filament. The average voltage difference between them may be found, approximately, at the point of greatest curvature of the curve of grid current.

When a radio signal is received, the voltage of the grid depends upon the value of the grid-leak resistance, the shape of the curve of the relation of grid current to grid voltage, and the relative voltage of the point to which the grid return is connected. If the capacity of the grid condenser is too small, it will not allow the radio-frequency voltage to be impressed on the grid without acting through the resistance and, thus, decreasing the voltage. The reactance of the condenser should be less than the grid-filament impedance. If the condenser has a too high capacity, it requires more charge and thus may retard changes of grid voltage. This would impair the detecting action of the tube which depends on the fluctuation in average grid voltage.

In grid rectification, the result of the action of the tube may be considered equivalent to that of a detector tube and a stage of audio-frequency amplification. This is because the radio-frequency voltage applied to the input is changed to audio frequency in the grid circuit and the audio-frequency variations are amplified in the plate circuit.

Action of a Vacuum Tube with Grid Condenser.—The average value of the change in plate current for weak signals is

$$\frac{E^2}{4} \times \frac{dI_p}{dE_g} \times \frac{d^2I_g}{dE_g^2} \div \frac{dI_g}{dE_g}$$

where E is the maximum value of the radio signal voltage impressed on the grid diminished by the voltage drop across the grid condenser, d^2I_g/dE_g^2 is the rate of change of the slope of the curve showing values of grid current corresponding to values of grid voltage, dI/dE_g is the slope of the same curve, and dI_p/dE_g is the slope of the curve showing how the plate current varies with changes in grid voltage.

In the action of a detector tube used with a grid condenser, the effect of grid rectification, which tends to cause a decrease in the average plate current, is stronger than the effect of plate rectification, which tends to cause an increase. Detection, therefore, with a grid condenser causes a decrease in the average value of the plate current.

Coefficient of Current Detection.—The varying plate current of a vacuum tube may be considered to consist of one current proportional to the alternating grid voltage and another proportional to the square of that voltage. It is this latter current which produces the effect of detection.

The coefficient of this second term in the expression for plate current can be taken as a measure of the detection current, that is, the audio-frequency component of the output. The current-detection coefficient is obtained from the second derivative of the curve showing the relation between plate current and plate voltage. For the case in which the plate circuit contains only a resistance, Van der Bijl gives the *current-detection coefficient a*, in terms of the structural constants of the tube as

$$a = -\frac{u^2 r_p r_p'}{2(r_p + r_0)^3}$$

where u is the amplification factor, r_p the plate resistance in ohms, r_0 the external output resistance in ohms, and r_p' the variation in plate resistance due to curvature in ohms (derivative of conductance).

Effect of Operating Voltages on Detection Current.—In detection *without* a grid leak and a condenser, if the detection current is measured in terms of the effective voltage $E_p + E_g$, the relation is shown as in Fig. 11. The maximum value occurs when the effective voltage is equal to the voltage drop in the filament E_f. In detection *with* a grid leak and condenser, if the detection current is measured in terms of the effective voltage $\frac{E_p}{u} + E_g$, the relation is shown as in Fig. 12.

Efficiency of Vacuum Tube as a Detector.—The intensity of sounds from telephone receivers in the plate circuit of a detector tube in which the detecting action depends on the bend of the characteristic curve varies as the square of the current flowing through the telephone receivers. The changes in plate current vary as the square of the voltage impressed on the grid for weak radio signals. The sound intensity, therefore, varies as the fourth power of the grid voltage. Further, the voltage at the detector tube is proportional to the voltage or current in the antenna circuit so that the above relations can be given in terms of these quantities. It is evident that all vacuum tubes are inefficient as detectors of weak radio signals. If the antenna current is reduced to one-half its value, the received power is reduced to one-quarter, the plate current is reduced to one-quarter, the output power is reduced to one-sixteenth, and the efficiency to one-quarter. For ordinary tubes, the received voltage impressed on the grid of the detector tube must be several hundredths of a volt to get satisfactory reception.

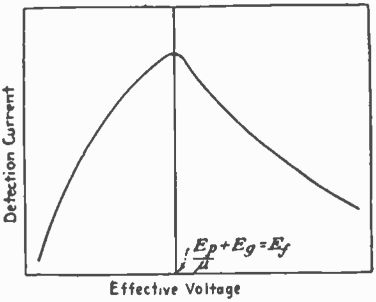


FIG. 11.—Detection curve without grid leak and condenser.

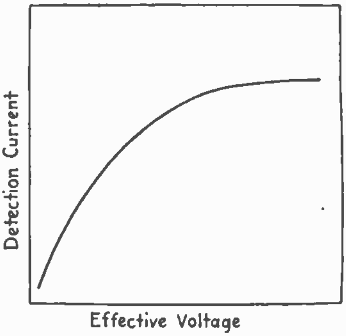


FIG. 12.—Detection curve with grid leak and condenser.

Although the detection coefficient *a* gives an indication of the detecting current, it is affected by the impedance of the load on the tube and consequently is not the best quantity to use for measuring the detecting efficiency of a vacuum tube. A better way of expressing the detecting efficiency is to consider it as the ratio of audio-frequency output power to radio-frequency input power. The former is the product of the square of the detecting current and the external resistance in the output circuit of the detector. The radio-frequency input power is not easily measured, because it is affected by the constants of the output circuit. But there is a definite relation between the audio-frequency power output and the radio-frequency *voltage* input, so it is better to express the detecting efficiency of a vacuum tube in terms of these quantities. The detecting efficiency then is given as a^2r_0, where a is the detection coefficient and r_0 is the external output resistance in ohms.

Effect of Strong Signals.—The effect of a strong radio signal is to increase the efficiency of the detector tube. Under such a condition, the response is proportional to the first power of the impressed grid voltage; that is, the audibility varies directly as the received voltage or current in the antenna.

Comparison of Detection by Grid Rectification and by Plate Rectification. The grid-rectification method of detection is more sensitive than plate rectification and to this extent is better when the input voltages are small. Overloading, however, will occur more readily with the former. When the input voltage is large, plate rectification may be used to take full advantage of the greater output available and of the freedom from distortion which results from overloading. In this circuit arrangement, the impedance of the tube is rather high so that the primary of the first audio-frequency transformer should have a high inductance.

It would seem, then, that more sensitiveness is obtained with grid-leak detection but that best quality of reproduction results from C battery or grid-bias detection. In a regenerative detector, however, one method may be just as sensitive as the other. Furthermore, some authorities claim that for tubes such as UX-201A, UX-199, and UX-112A, grid-bias detection is superior to grid-leak detection with respect to quality and selectivity and need not be less effective with regard to sensitivity.

A recent study (Chaffee and Browning, Theoretical and Experimental Investigation of Detection for Small Signals, *Proc. I. R. E.*, February, 1927) of the detection of weak radio signals brings out a number of interesting conclusions. A rectifying detector depends in its action upon a non-linear relation between the instantaneous output current and the instantaneous applied voltage. If the impressed modulated voltage of a radio signal is small, the output contains the following components: (1) a constant current; (2) a current of modulation frequency; (3) a current of double modulation frequency; and (4) currents of frequencies equal to the sum and difference of the several modulation frequencies. All of these component currents are proportional to the square of the impressed voltage of the radio signal. The component of modulation frequency is proportional to the degree of modulation; all others depend upon the square of the modulation or upon the product of the two modulation factors and, hence, are small in comparison with the current of modulation frequency, if the degree of modulation is small.

The voltage-detection coefficient is a better measure of the detecting action of a rectifying detector tube, because its value is independent of the impedance interposed in the plate circuit during the measurement of the detection coefficient. The term *current-detection coefficient* has already been explained. The expression for current-detection coefficient multiplied by the total resistance of the circuit, for a small change in current, gives an expression called the *voltage-detection coefficient.* This is a name for the equivalent steady voltage produced by rectification acting in the output circuit. The voltage-detection coefficient gives an equivalent voltage which, considered as acting in the plate circuit, gives the audio current which flows through the circuit containing r_p and the plate impedance normally used with the detector. A knowledge of r_p is thus necessary.

A *hard tube* (page 36) *used without* a grid-circuit impedance—that is, a "blocking" condenser and grid leak or the equivalent—and with no radio-frequency impedance in the plate circuit depends for its detecting action entirely upon the bends of the plate-current curve. The resulting detection is usually very small. A gas (soft) tube (page 40) when used in this way gives much greater detection than a similar tube highly exhausted, because ionization increases both the upper and lower bends of the plate-current curve. Ionization also causes kinks in the plate-current curve resulting in a high sensitivity at such points because of the very large values of the ratio of small changes in grid-plate conductance to small changes in grid voltage. A radio-frequency impedance in the plate circuit of a hard tube used without a grid impedance decreases the detection coefficient due to the lower bend of the plate-current curve. A tickler (page 40) usually more than makes up for this decrease in detection coefficient by increasing the strength of the impressed radio signal. All audio-output devices in the plate circuit should be shunted by a condenser having a small reactance for radio-frequency currents.

The sensitivity of a hard tube used *with* a grid impedance depends on the product of grid-plate conductance and the ratio of small changes in grid conductance to small changes in grid voltage and, also, on a factor F which is equal to the equivalent parallel impedance of the grid impedance and the grid-to-filament resistance. For this case, when a hard tube is used, the sensitivity is usually much greater than the maximum sensitivity obtainable without a grid impedance. The grid-plate conductance should be made large by using the proper plate voltage. The value of the product mentioned above is a maximum for grid-biasing voltages of a few tenths of a volt, when positive, but F falls so rapidly for positive grid voltages, due to the increase of grid conductance, that the point of maximum sensitivity is found at a grid voltage more negative than that which gives a maximum value of the product. The *detection-coefficient curves* have very narrow peaks so that it is necessary to adjust the grid-biasing voltage to the proper value, usually 0.1 or 0.2 volt positive. Because of the steady rectified component of current in the grid circuit, a strong radio signal unfortunately alters the grid-biasing voltage.

The ordinary grid leak and blocking condenser is not the best form of grid impedance because of its variation with the frequency, and especially its large value at zero frequency. The ideal impedance is one having negligible resistance to steady currents, a high impedance for frequencies from 100 to 10,000, and low impedance for the radio-frequency current.

A tickler coil (page 40) used with a detector provided with a grid impedance increases the detection coefficient.

Experiments show that a tube having a high amplification factor is usually more sensitive as a detector than one having a low amplification factor.

Effect of Static on Detection.—A strong impulse due to a static pulsation may cause a variation in the plate current a hundred or even a thousand times as great as that caused by the radio signal in a tube having the usual characteristic shown in Fig. 13.

A tube having a low emission and operating at low plate voltages would impose a severe limitation on the effect of static. Thus, consider the characteristic curve of the tube shown in Fig. 14 in which the operating plate current and the plate voltage are, respectively, about one-tenth and one-fourth of those of the tube in Fig. 13. Both the maximum and the operating currents are low in value. A variation of the grid voltage, therefore, in either direction cannot cause a disturbance of the same magnitude as that mentioned above.

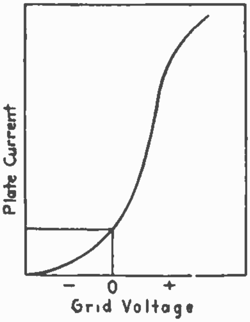


FIG. 13.—Characteristic curve showing low and high bends.

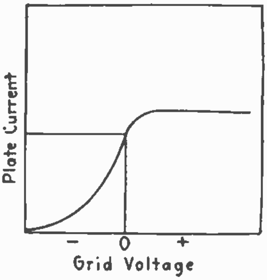


FIG. 14.—Characteristic curve for same conditions as Fig. 13 with less plate current and voltage.

Detection with Alkali-vapor Vacuum Tube.—The alkali-vapor tube UX-200A which is filled with caesium vapor is intended for use as a detector. The filament is the same as that used in a UX-201A, but a finer grid mesh is provided to produce a higher amplification factor, which contributes to greater sensitivity as a detector. The filament must carry enough current to make the tube fairly warm. Stable action does not begin until, after a few minutes of operation, the warming up is completed. As the tube begins to get warm, the plate current increases slowly at first and then more rapidly. Then, finally, it ceases to rise and decreases to a steady value when the tube reaches its final temperature.

When the tube is first lighted, a hiss is produced which continues for a few minutes. While the plate current is increasing, the hissing sound increases to a maximum, then decreases and disappears when the plate current is steady. The occurrence of this hiss with relation to plate-current variation as the vapor pressure increases is clearly shown in Fig. 15 for a tube using a potassium-sodium alloy.

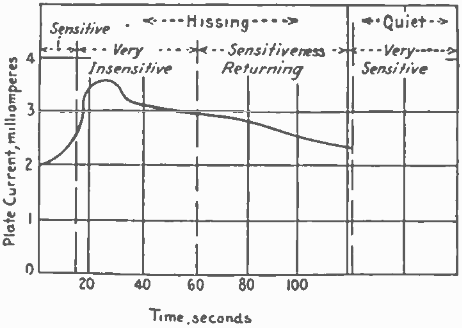


FIG. 15.—Relation of hissing sounds to plate current. (*Data due to Brown and Knipp.*)

The amount of noise produced by the UX-200A tube diminishes as a broadcasting station is tuned in. This behavior may be demonstrated by operating the volume control at a time when a station, tuned in, is "on the air" but is not broadcasting. Any noise which may be present decreases rapidly as the volume control is turned from soft to loud volume. This shows that the noise does disappear and is not "drowned out" by the broadcasting. A tube which does not become quiet when tested in this manner should be checked for leakage.

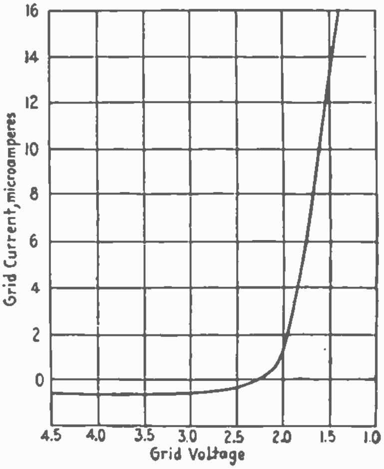


FIG. 16.—Characteristic curve of UX-200A tube.

Detection with a UX-200A tube may be accomplished by either grid-current rectification or plate-current rectification. The usual sizes of grid condenser and grid leak are satisfactory, that is, 0.00025 microfarad and 2 megohms, respectively. The preferred connection for the grid return is to the negative filament. When a grid leak and condenser are used, the tube automatically reaches the correct point of operation, because the flow of grid current through the grid leak builds up the required negative voltage. This is the only function performed by the grid leak in the case of this tube. Best detection is obtained by operating the tube at the point where the curvature is greatest of the curve showing variations of grid current with grid voltage. This occurs at a grid voltage of slightly more than −2.0 volts as shown in Fig. 16 for a plate voltage of 45 volts.

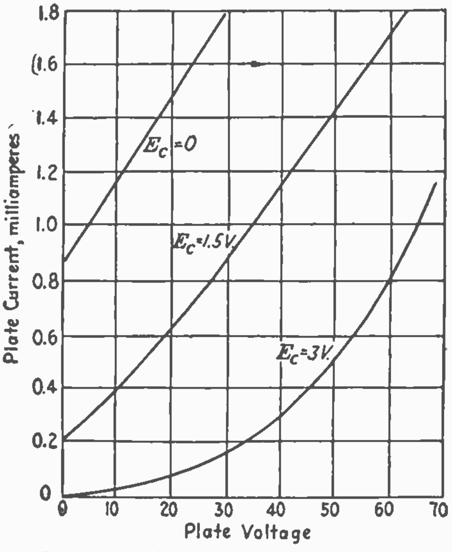


FIG. 17.—Characteristic curves for three grid-bias voltages.

The curves which show the variations of plate current with plate voltage for the UX-200A tube are drawn in Fig. 17 for three values of grid-bias voltage; 0, −1.5, and −3.0 volts. The curves in this figure differ from similar curves for other tubes because a moderately high plate current flows when both the plate and the grid voltages are zero. The plate current, in this case, is not reduced to zero until a negative grid bias of about 3 volts is applied. This flow of plate current is due to the presence of positively charged ions of gas in the space between the electrodes. A plate voltage of

45 volts is recommended, but any voltage above 22.5 volts may be used. The best quality of reproduction and the maximum sensitivity are obtained at 45 volts, because the plate impedance is rather high at low plate voltages. Above 45 volts the detector action decreases rapidly and there is consequent noise.

The audio-frequency voltage in the output circuit of an alkali-vapor vacuum tube is quite critical with respect to the adjustment of the grid-bias voltage. Figure 18 shows the performance of a UX-200A tube of this kind when the audio-frequency output voltage is plotted as a function of the grid-bias voltage with a plate voltage of 45 volts. This curve indicates the necessity for potentiometer (page 121) adjustment when a grid-bias voltage is applied instead of using a grid condenser and a grid leak. A grid-bias voltage of −1.5 volts or less causes a decrease in sensitivity and an increase in damping of the input circuit due to a larger grid current.

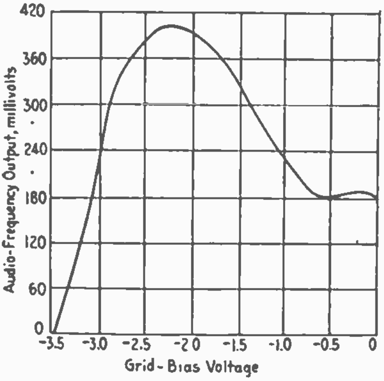


FIG. 18.—Variation of output with grid-bias voltage for UX-200A tube.

It is generally assumed that the properties of tube detectors have a "square-law" relation; that is, that the change in plate current dI_p is equal to $K(E_g)^2$ where E_g is the radio-signal voltage impressed on the grid. For alkali-vapor detector tubes, $dI_p = K(E_g)^x$ where x is nearly unity. This approximates more closely the desired condition of ideal *linear rectification.*

Detection with Tubes Having Filaments for Alternating Current.—Vacuum tubes in which the filament is heated by alternating current operate under such conditions that it is necessary to reduce to a minimum the voltage ripple due to this kind of current.

The UY-227 tube which is intended for use as a detector with alternating current supplied for heating has an oxide-coated metallic cylinder instead of the usual type of filament. This cylinder is heated by an internal single-turn tungsten filament which is insulated from the cylinder. The fluctuations in temperature which occur at the rate of 120 cycles per second when the internal filament is heated with 60-cycle alternating current are prevented from affecting the performance of the tube, because of the thermal inertia of the cylinder and the insulating material. The surface-temperature variations of the electron-emitting cylinder, therefore, are so slight that no appreciable ripple voltage is produced. The grid and plate of the UY-227 are of the cylindrical form similar to that used in UX-199 tubes.

The UY-227 tube may be used with either grid-circuit or plate-circuit rectification. The method of detection has little effect on the amount of ripple voltage, which is kept at a minimum by connecting the "center" tap of the transformer winding in the circuit of the filament of the detector tube, to the positive "detector" tap, thus putting 22.5 to 45 volts between the single-turn filament for heating and the "emitting" cylinder. A potentiometer return (page 121) may be used instead of the transformer tap; but the slight effect produced on ripple voltage by changes in the potentiometer setting makes this construction usually unnecessary. There is no electrical connection between the circuit of the single-turn filament (which acts merely as a heater) and the grid and plate circuits. The return wires from the grid and plate circuits, being connected to the cathode terminal (emitting cylinder), are not affected by the reversals of the current in the filament. The base of this tube has five terminals, two for the filament and one each for the cathode, the grid, and the plate. The UX-226 tube which is intended for use as an amplifier has characteristics similar to the UX-201A tube and is provided with a low voltage, heavy-current, oxide-coated filament in the form of an inverted V. The filament current and the voltage ratings are selected to obtain a close balance between the electromagnetic and the elec-

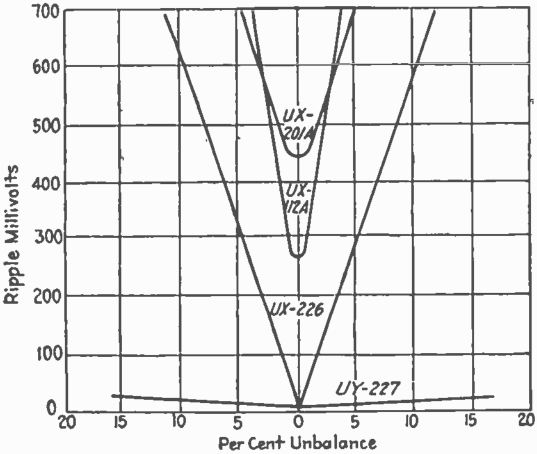


Fig. 19.—Ripple voltage diagram.

trostatic fields due to the alternating current, and this balance is made to occur at the point of most satisfactory operation as an amplifier.

The difference between the amplifying UX-226 tube and the detecting UY-227 tube, when compared as detectors, is readily seen from the ripple voltage produced by each of the tubes as the degree of unbalance from the exact neutral point of the supply system is varied. A comparison of four types of tubes is shown in Fig. 19. These curves show the lower minimum value of ripple voltage of the UX-226 tube as compared with the UX-112A and the UX-201A tubes, and they show also that the grid return is less critical. The grid return of the UY-227 tube is not at all critical, as might be expected from the type of construction. The grid return of a tube operated with alternating current must be connected to the exact neutral point, because any other connection impresses a 60-cycle voltage on the grid and consequently produces a rapid increase in the ripple voltage.

Detection with Four-element Tubes.—When a UX-222 tube is used as a detector, it gives an audio-frequency amplification (page 355) of 40 to 75

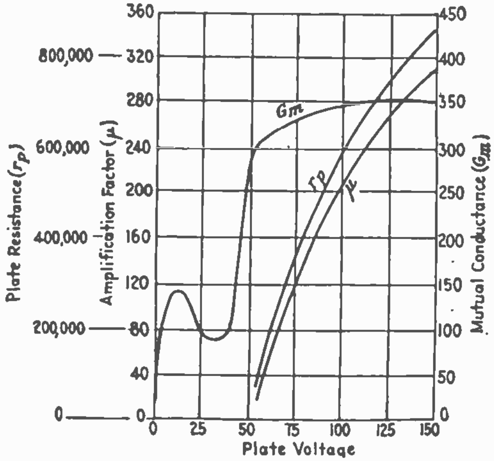


FIG. 20.—Constants of screen-grid tube at various plate voltages.

per stage. The utilization of such high audio-frequency amplification is troublesome because of the increased difficulty from frequency distortion which is due to the coupling between the tubes which are in a common battery or power supply circuit, and also because microphonic disturbances in the detector cause more disturbance.

The amplification of a UX-222 tube can be utilized by using the tube as a detector and eliminating the first stage of audio-frequency amplification. Under these conditions the detector tube must be able to take a radio-frequency input voltage of several volts and must be able to supply 20 to 30 volts to the grid of the power tube (page 280).

The high radio-frequency amplification, which is necessary to give to the detector tube a radio signal of several volts, may be obtained by using a *screen-grid tube* (page 305) as a radio-frequency amplifier.

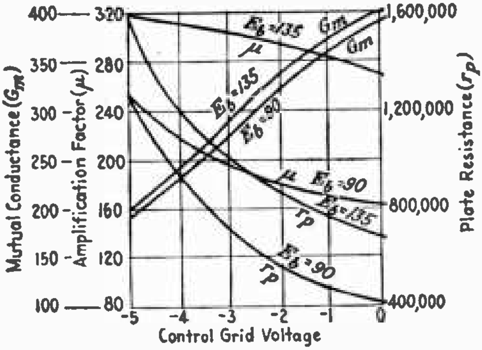


FIG. 21.—Constants of screen-grid tube at various grid voltages.

The method of grid-leak detection is not possible, because it cannot operate on a heavy radio-frequency input voltage without overloading, and it reduces the selectivity of the tuned circuit because of damping. Plate rectification with the UX-222 tube does not have these limitations.

In the theoretical screen-grid tube the only factor affecting the output of a vacuum tube under usual operating conditions is the *mutual conductance* (page 302), because the plate current is independent of the plate voltage, and because there is but little capacity between the control grid and the plate. Voltage amplification is equal to the product of the mutual conductance and the external impedance. The amplification factor varies with the plate, control-grid, and screen-grid voltages but has a definite value as soon as all the voltages are specified. The relations between the various constants of this tube such as plate resistance r_p, mutual conductance G_m, amplification factor u, and the plate voltage are shown in Fig. 20
when

$$E_{c1} = 1.5 \text{ volts}$$

and

$$E_{c2} = +45 \text{ volts}.$$

The relations between these constants and the control-grid voltage are shown in Fig. 21

when

$$E_{c2} = +45 \text{ volts.}$$

A consideration of Fig. 22 which indicates the elements of a circuit using the UX-222 tube shows a number of interesting conditions. This circuit has no input impedance because there is no mutual capacity between the control grid and the plate. The interelectrode capacity of the control grid to the filament is considered a part of the tuning capacity *C*. There can be no grid rectification in this case because there is no low-frequency grid impedance, and there is no control-grid current because of the negative bias on the control grid. Thus, the internal impedance from the control grid to the filament is extremely large. A fixed positive grid bias from a direct-current source is applied to the screen grid. The effect of this screen grid, however, is constant. Since there is no impedance in the screen-grid circuit, it has a zero potential for alternating current. The plate current, then, is a function of only two variables, the voltage on the plate and that on the control grid.

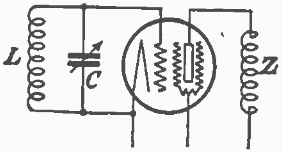


Fig. 22.—Circuit for UX-222 tube.

The steady value of the plate current I_p is given in this case in amperes by the following relation:

$$\frac{r_p}{r_p + R} \times \frac{dG_m}{dE_g}\left(1 + \frac{B^2}{2}\right)\frac{A^2}{4}.$$

In this equation, which applies to the use of the tube as in Fig. 22, r_p is the plate resistance of the tube, *R* is the direct-current resistance of the coil *Z*, dG_m/dE_g is the first derivative of mutual conductance G_m with respect to the voltage of the control grid E_g, *B* is the degree of modulation expressed as a decimal, and *A* is the peak value of the radio-frequency voltage impressed on the grid. The relation between plate current and plate voltage varies according to the "square" law because dG_m/dE_g decreases with input voltage and because r_p decreases as the input voltage decreases.

The curves of Figs. 23 and 24 give the relation between dG_m/dE_g and control-grid voltages with respect to plate voltage and screen-grid voltage under different conditions of operation. In Fig. 23 the conditions for the curves *A*, *B*, and *C* are as follows:

A—static value, E_p = 135 volts, E_{c2} = 67½ volts,
B—dynamic value, E_p = 225 volts, E_{c2} = 67½ volts,
C—dynamic value, E_p = 135 volts, E_{c2} = 67½ volts,

where E_g is the plate voltage and E_{c2} is the screen-grid voltage.

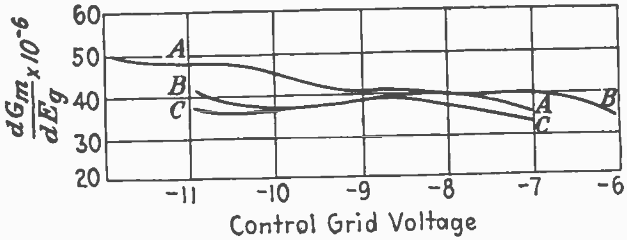


FIG. 23.—First derivative of mutual conductance when screen-grid voltage is 67½ volts.

In Fig. 24 the conditions for the curves *A* and *B* are as follows:

A—static value, E_p = 135 volts, E_{c2} = 45 volts,
B—dynamic value, E_p = 135 volts, E_{c2} = 45 volts.

It is obvious that although the value of dG_m/dE_g, is practically constant, it decreases as the control-grid voltage is made less negative. Another

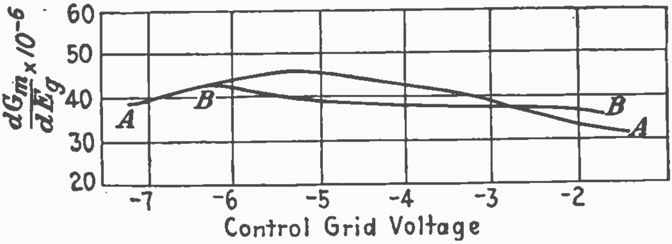


FIG. 24.—First derivative of mutual conductance when screen-grid voltage is 45 volts.

relation is shown in Fig. 25 where the value of dG_m/dE_g is approximately constant for input voltages nearly as great as the control-grid bias value but decreases somewhat as the input voltage is increased. For these curves the grid-bias voltage E_{c1} is -7.5 volts and E_{c2} is $+45$ volts.

If R is constant, the value of $\frac{r_p}{r_p + R}$ decreases with an increase of r_p. The variation of plate resistance with plate current when the plate voltage and screen-grid voltage are constant is illustrated in Fig. 26. If $R = 400{,}000$ ohms and r_p varies from 4 megohms to 1 megohm, the value of the term $\frac{r_p}{r_p + R}$ changes from 0.91 to 0.71.

The drawing in Fig. 27 shows the variation of the current with the plate voltage of a UX-222 tube for various plate input voltages at 1,000 kilocycles per second. Different load lines are drawn from the point corresponding to 270 volts. The voltage applied to the screen grid is $E_{c2} = +67.5$, and the grid-bias voltage is $E_{c1} = -12.3$ volts. This tube is used as a detector in the circuit of Fig. 28. Here, $R = 5 \times 10^5$ ohms, $r = 2 \times 10^6$ ohms, and $C = 0.2 \times 10^{-6}$ farads. The alternating-current impedance of the combination is approximately 4×10^5 ohms.

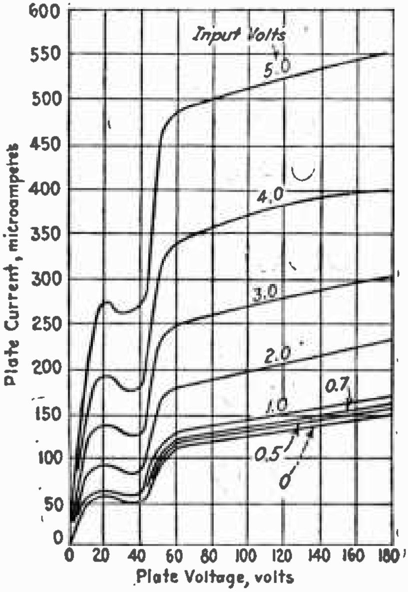


FIG. 25.—Variation of plate current with plate voltage for various input voltages.

The output voltage for a given input voltage and load may be obtained from the curves that have just been mentioned. Thus, with a load of 400,000 ohms and an input voltage of 2 volts (root-mean-square value page 10), modulated 50 per cent, the point A is taken as a reference. The alternating voltage across the resistance R will vary in value between B and C. This

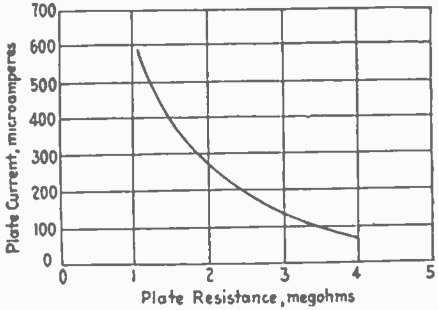


FIG. 26.—Variation of plate resistance with plate current.

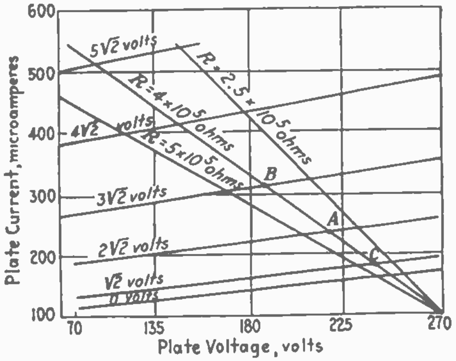


FIG. 27.—Variation of plate current with plate voltage.

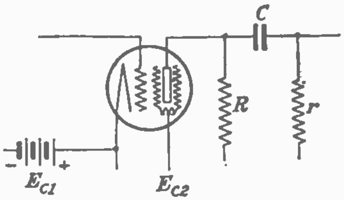


FIG. 28.—Typical circuit using UX-222 tube as detector.

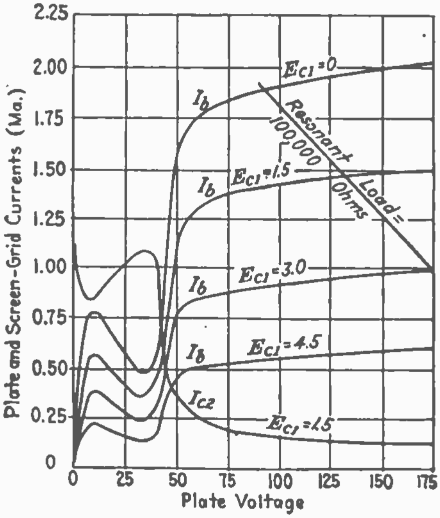


FIG. 29.—Variation of plate and screen-grid currents with plate voltage (screen-grid voltage 45 volts).

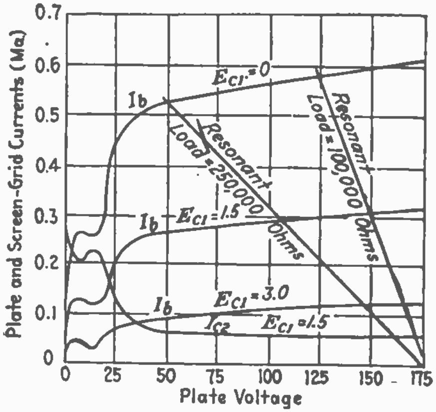


FIG. 30.—Variation of plate and screen-grid currents with plate voltage (screen-grid voltage 22½ volts).

corresponds to an output voltage variation of approximately 52 volts, so that the peak value is one-half of this value or 26 volts. For 40 per cent modulation, the peak value would be 80 per cent of this or 20.8 volts. For any given input voltage, it is only necessary to draw two other curves; that is, for example, with an input of $2\sqrt{2}$ volts, curves may be drawn for values of input of $\sqrt{2}$ and $3\sqrt{2}$ volts. Then, the variation of voltage at 50 per cent modulation is found, and, since the output voltage is proportional to modulation, its value for other degrees of modulation may be determined. Two other forms of curves showing how the plate current varies with the plate voltage are given in Figs. 29 and 30. The data shown in Fig. 29 were obtained with a value of +45 volts for E_{c2}, while those in Fig. 30 were obtained with $E_{c2} = +22.5$ volts.

Non-oscillating Tube as Detector with Regeneration.—It has been shown that the radio-frequency portion of the plate current of a detector tube does not enter into any action on the telephone receiver or other apparatus in the plate circuit. This radio-frequency current may be used however, to increase the radio-frequency voltage in the input circuit. To accomplish this, a feed-back coil (page 304) is coupled to the secondary coil in the grid circuit. For a given radio-signal strength, the radio-frequency voltages and currents are increased by the effect of regeneration, and, consequently, the volume of sound is also increased. This action is cumulative up to a certain point, but beyond this value the tube begins to *oscillate.* A more complete description of regeneration is given on page 403), but this elementary description serves to introduce the conception of an oscillating tube.

Oscillating Tube in Reception.—The frequency of an incoming radio-frequency current may be changed by another method which depends on the interaction of two currents of slightly different frequencies. Some method of this kind must be employed in order to receive undamped oscillations. Thus, if the input circuit must carry a locally generated current having a frequency either greater or less than that of the incoming current, there is an interaction between the two frequencies which produces a current of a third frequency equal to the numerical difference between the other two. This general method is called *heterodyne action* and the current of the third (and lower) frequency is called the *beat current.* In the *homodyne* method of reception, which can be used for modulated waves, the frequency of the local current is made the same as the frequency of the radio signal so that there can be no interaction. This condition is called *zero beat.* When the same tube generates the local oscillations and acts also as a detector, the action is known as *autodyne* or sometimes as *self-heterodyne.* When an additional tube is used to generate the local oscillations, the action is called *separate heterodyne.* This circuit has the advantage over the self-heterodyne circuit in that the beat frequency does not depend on the tuning adjustment. The so-called *superheterodyne* or *multiple-heterodyne* method of reception is based on the use of several separate heterodyning and detecting stages. These various methods will be considered again, more in detail, on page 408.

One important advantage of the *heterodyne method* of reception is the increase in selectivity and signal strength. In the detection of modulated signals (page 38) or spark signals (page 40) the response varies as the square of the signal strength, with the result that strong signals are amplified more than weak signals; in *beat reception*, however, the amplitude of the beat current and consequently the response varies directly as the amplitude of the signal strength, so that continuous-wave (C.W.), signals (page 35) are amplified by the same amount whether they are weak or strong. By means of the beat method of reception a weak radio signal may sometimes be distinguished more easily through interference such as static.

Part 2

USE OF VACUUM TUBES AS AMPLIFIERS

The action of a vacuum tube in amplification may be determined by obtaining the relations between the instantaneous currents and voltages in both its input and output circuits. The current in one of these circuits depends on the voltages in both. Further, the relations between currents and voltages in a vacuum tube which were considered in a study of "static" characteristics in Section VI were taken with steady applied voltages and no external load. In order to get a clear understanding of the effect of these conditions upon amplification, it is necessary to examine the action of the vacuum tube with respect to the input and output circuits.

Input Circuit.—The resistance r_g of the input circuit (grid-filament circuit) to direct current when the grid is negative is practically infinite. When, however, the grid is positive, the grid current varies as the square of the grid voltage. If the value of the positive voltage on the grid is the same as that on the plate, the grid and plate currents are approximately equal.

The resistance r_g of the input circuit increases as the voltage E_p is increased, in other words, the conductance G_g decreases. The conductance increases with increasing filament current and decreases as the grid-bias voltage is made more negative. The latter relation is the basis of one method for the control of regeneration in tuned radio-frequency amplifiers. The conductance increases with increasing amplitude of input signal voltage. Thus, it is obvious that the grid must be negative with respect to the filament if the input resistance of the vacuum tube is to be kept high.

It may be shown that the capacity of the input circuit varies with the voltage amplification factor of the tube and with the kind of circuit (page 304). The mutual capacity of the internal grid-filament circuit of the tube and the internal grid-plate circuit of the tube may produce a voltage in the former which is in phase with the impressed grid voltage. The effect of this is to make the conductance of the input circuit negative and to allow the plate circuit to react on the input circuit so as to augment the impressed grid voltage. The capacity of the input circuit increases as the plate-circuit resistance is increased or as the plate-circuit resistance is increased or as the plate-circuit reactance is increased. Changes in frequency affect the plate reactance. Since the phase relations between the input voltage and the plate voltage depend on the plate reactance, it is obvious that the input-circuit characteristics will also be affected by frequency because they depend upon the voltage phase relations. Thus, the input capacity is decreased and the input conductance is increased by an increase in input frequency with resistance in the plate circuit. When the plate circuit is reactive, a change in input frequency either increases or decreases the characteristics of the input circuit of the tube depending on the value of the reactance.

The capacity of the input circuit may be reduced by using some form of neutralizing circuit (page 371) or a screen-grid vacuum tube.

Impedance of the Input Circuit.—When a *steady* voltage is impressed on the grid circuit of a vacuum tube, no grid current flows if the grid is negative with respect to the filament. But, when an alternating voltage is thus impressed, an alternating current will flow in the grid circuit because of the path offered by the internal grid-filament capacity (page 303) of the tube, and there will be, also, an alternating current in the plate circuit because of the internal grid-plate capacity of the tube. This action will take place whether or not the filament is emitting electrons. The power thus supplied is dissipated as heat in the resistance of the circuit. In order to maintain a high efficiency of amplification, it is necessary to reduce the former as much as possible. In multistage amplifiers the phase difference between these alternating currents from the input source and the input voltage becomes an important factor.

The magnitude of the current due to the internal grid-plate capacity of the tube depends on the alternating portions of the grid and plate voltages and on the internal grid-plate capacity of the tube. It is equal to the voltage difference between grid and plate divided by the reactance of the grid-plate capacity, thus:

$$I_{g-p} = \frac{E_g - E_p}{1/2\pi f C_{g-p}} = 2\pi f C_{g-p} \times (E_g - E_p).$$

As shown on page 352,

$$E_p = uE_g\left(\frac{R_0}{r_p + R_0}\right).$$

Hence, by substitution,

$$I_{g-p} = 2\pi f C_{g-p} E_g\left(1 - \frac{R_0}{r_p + R_0}\right).$$

Likewise, the magnitude of the current due to the grid-filament capacity is

$$I_{g-f} = 2\pi f C_{g-f} E_g.$$

In these expressions, E_g is the alternating portion of grid voltage in volts, E_p the alternating portion of plate voltage in volts, f the frequency in cycles per second, R_0 the external resistance in plate circuit in ohms, r_p the plate resistance of tube in ohms, C_{g-p} the internal grid-plate capacity of tube in farads, C_{g-f} the internal grid-filament capacity of tube in farads, π is 3.1416, and u is the amplification factor.

It is readily seen that the input impedance depends on two circuits in parallel, one of which contains the reactance of the grid-filament capacity, and the other, the impedance of the grid-plate capacity in series with the external impedance in the plate circuit.

Effect of Load on Plate Current.—The output circuit of a vacuum tube contains the apparatus for using the detected and amplified variations of current and voltage. The voltage acting on the plate of a vacuum tube which has no load in the plate circuit is equal to the plate-battery voltage. But a tube in actual use as an amplifier may have one or more of the following in the plate circuit: a resistance, a primary of a transformer, an inductance, a loud-speaker. When a varying plate current flows through such apparatus, the voltage acting on the plate is not constant because of the varying voltage drop across the load; that is,

$$E_p = E_b - I_pR_0$$

where E_p is the plate voltage in volts, E_b the battery voltage in volts, R_0 the external resistance in ohms, and I_p the plate current in amperes.

The effect of an alternating grid voltage E_g is to produce an alternating plate current uE_g/r_p, and the effect of an alternating plate voltage E_p is to produce an alternating plate current E_p/r_p (page 51). The total plate current produced by grid and plate voltages in combination is, therefore,

$$I_p = \frac{uE_g}{r_p} + \frac{E_p}{r_p}.$$

This expression is true only if the plate-current variations are small enough to extend only over the straight-line portion of the plate current-grid voltage curve (page 288).

In the case of a resistance load R_0, the alternating current I_p flowing through R_0 produces an alternating voltage drop of $E_p = I_pR_0$. The effect of this voltage drop is opposite to the action of the grid voltage; that is, if the grid is made more positive, the plate current and also the voltage drop across R_0 increase, and consequently the plate voltage decreases. Or, if the grid is made more negative, the plate current and also the voltage drop across R_0 decrease, and the plate voltage increases. Hence, when I_pR_0 is substituted for E_p it is given a negative sign. When this substitution is made in the equation above, the plate current becomes

$$I_p = \frac{uE_g}{r_p} - \frac{R_0I_p}{r_p}, \text{ from which } I_p = \frac{uE_g}{r_p + R_0};$$

that is, the alternating current I_p in the plate circuit for an impressed grid voltage E_g is the same as that which would be caused to flow in a circuit having a resistance of $r_p + R_0$ by an alternating voltage uE_g.

It is advantageous to consider the action of a vacuum tube as similar to that of an electric generator. The steady values of plate and grid voltages and plate current are considered only in so far as they affect quantities such as the plate resistance. The grid is omitted from the discussion except when the matter of grid current must be taken into consideration. The tube may then be regarded in effect as a device in which there is connected between the plate and filament an alternating-current generator having a resistance r_p and generating a voltage uE_g. The resistance r_p is determined by the steady or non-varying grid and plate voltages. Actually, of course, r_p does vary with the alternating plate current. The alternating or, more correctly, fluctuating plate current is produced by the voltage uE_g.

In a circuit containing only resistance, the impressed voltage is in phase with the current; that is, the variations of the impressed voltage occur in step with the variations of the current. The countervoltage is opposite in phase to the impressed voltage and to the resulting current; that is, in the tube circuit the plate current is in phase with the grid voltage, the phase difference between the plate voltage and plate current is 180 degrees, and the phase difference between the plate voltage and the grid voltage is 180 degrees.

Since the plate voltage E_p acting on the tube is equal to $E_B - I_BR_0$, where I_B is the battery current, it is evident that when an external resistance is inserted in the plate circuit, additional B-battery voltage must be supplied to maintain the plate voltage at its proper value. If this is not done, the plate voltage E_p decreases, r_p increases, and the voltage amplification is reduced. When $R_0 = r_p$ the battery voltage E_B must be about 50 per cent larger than the rated plate voltage of the tube. Under these conditions, a voltage amplification of $u/2$ is obtained.

Impedance Load.—The derivation of the expression for the value of plate current can readily be extended for the case of an impedance load. Thus consider that the plate circuit contains a loud-speaker having a resistance R_0 and an inductance L. The impedance Z of the plate circuit is $Z = \sqrt{(r_p + R_0)^2 + (2\pi fL)^2}$. The voltage divided by the impedance gives the current as $I_p = \frac{uE_g}{\sqrt{(r_p + R_0)^2 + (2\pi fL)^2}}$. Since the frequency term f appears in the impedance, it is clear that impedance varies with frequency as well as with resistance and inductance. The current lags behind the voltage by an angle ϕ which has a value such that $\tan \phi = \frac{2\pi fL}{r_p + R_0}$.

If the plate circuit contains a load having a resistance R_0, an inductance L, and a capacity C, the current is

$$I_p = \frac{uE_g}{\sqrt{(r_p + R_0)^2 + \left(2\pi fL - \frac{1}{2\pi fC}\right)^2}}$$

and the phase angle ϕ is given by

$$\tan \phi = \frac{1}{r_p + R_0}\left(2\pi fL - \frac{1}{2\pi fC}\right).$$

These equations state that, for a given value of impressed grid voltage, the alternating plate current may be considered to have the same value and phase relations as a current flowing in a circuit having a resistance r_p, an impedance Z, and an applied voltage of μE_g.

When the plate circuit contains reactance as well as resistance the phase difference between the plate and grid voltages may not be 180 degrees. Thus, consider a load having an impedance Z made up of a resistance R_0 and a reactance X_0. If the plate current is represented by I_p, as in Fig. 31, then the voltage drop I_pr_p in the tube is located as OY, the drop I_pR_0 in the external resistance is YS, and the drop I_pX_0 in the external reactance is ST, located at right angles to the axis. Then, the drop I_pZ in the external

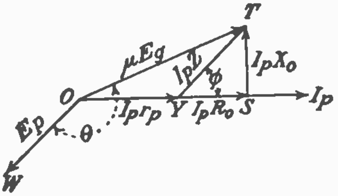


FIG. 31.—Typical vector diagram showing voltage drops in external resistance and inductive reactance.

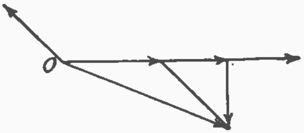


FIG. 32.—Typical vector diagram showing voltage drops in external resistance and capacity reactance.

impedance is YT, the resultant of the resistance drop I_pR_0, and the reactance drop I_pX_0. The impressed voltage uE_g in the plate circuit is given by OT and is the resultant of the voltage drop I_pr_p in the tube and the external impedance drop I_pZ. When the external impedance is equal to the plate resistance, that is, when OY equals YT in Fig. 31, the angle has a value of 45 degrees. Also, E_p is equal to $-I_pZ$ and is represented in the diagram by OW which is parallel to I_pZ or YT. The angle θ, which represents the phase difference between E_p and uE_g or E_g, has a value of 157 degrees.

The phase difference between E_p and I_p is given by the angle whose value is such that its tangent is X_0/R_0, while that between uE_g and I_p is $\frac{X_0}{r_p + R_0}$.

Now, if the reactance X_0 were a capacity, the voltage drop I_pX_0 would be drawn in a direction vertical to I_p but downward, instead of upward as in Fig. 31 in which I_pX_0 is taken as an inductive reactance. The resulting relations would then be represented as in Fig. 32.

Voltage Amplification.—In the simple case in which the external load consists of a resistance R_0, the alternating voltage drop across R_0 is $I_pR_0 = \frac{uE_gR_0}{r_p + R_0}$. The ratio of this alternating voltage which operates in the plate circuit to the alternating grid voltage is the *voltage amplification*, usually expressed as $A = \frac{uR_0}{r_p + R_0}$. When a tube is in use as a voltage amplifier, maximum amplification is obtained by making the load resistance as high as is practical. This becomes evident from a consideration of the above equation for A; that is, with very high load resistances the term r_p becomes negligible and the voltage amplification approaches the amplification factor u of the tube.

When the external load consists of an inductance and if the resistance R_0 of the reactance coil is small compared to r_p and wL, then the voltage across the output circuit is $V = I_pwL = uE_g\frac{wL}{\sqrt{r_p^2 + (wL)^2}}$. The voltage amplification $V/E_g = uwL/\sqrt{r_p^2 + (wL)^2}$ may be made nearly equal to u if wL is large. The B-battery voltage need not be greater than the rated plate voltage of the tube, because the resistance of the coil is assumed to be negligible.

Maximum Power Output.—The voltage amplification may be considered as the load-voltage drop per volt input, since

$$\frac{uR_0}{r_p + R_0} = \frac{uE_g}{r_p + R_0} \times \frac{R_0}{E_g} = \frac{I_pR_0}{E_g}.$$

The current output per volt input is $\frac{I_p}{E_g} = \frac{u}{r_p + R_0}$. The product of these two expressions gives the power output per volt squared of the input as

$\frac{I_pR_0}{R_g} \times \frac{I_p}{E_g} = \frac{I_p{}^2R_0}{E_g{}^2} = \frac{u^2R_0}{(r_p + R_0)^2}$. It can be shown by differentiating this equation that the condition for *maximum* power output occurs when $R_0 = r_p$, that is, when the load resistance is equal to the plate resistance of the tube. It is important to remember that this result is obtained by considering the tube as a generator and *neglecting the effect of distortion*, which modifies the relations considerably. On this basis the output of an amplifier tube should be rated at not more than 5 per cent of the theoretical maximum.

Effect of Phase Relations on Maximum Power Output.—The power output of a tube is a maximum when the current and voltage are in phase and is equal to one-half the product of the normal plate voltage and the normal plate current. In order to obtain a phase relation of this kind, the load of the plate circuit must consist of resistance only of a value equal to the tube plate resistance.

Types of Amplifiers.—An amplifier is usually made up of a number of tubes and associated apparatus. Each tube and its related devices is considered as one stage. The apparatus is arranged in such a way that the fluctuating plate current of the tube in the first stage produces a fluctuating voltage which acts on the grid circuit of the tube in the second stage. The fluctuating plate current of the tube in the second stage, in like manner, is passed on to that in the third, and so on. The plate circuit of the tube in the last stage contains the sound-producing device such as a loud-speaker. The method of coupling one stage to the next determines the different types of amplifiers, for either radio-frequency or audio-frequency use. These types are the resistance-coupled amplifier; the inductance-coupled amplifier, the transformer-coupled amplifier, and various combinations.

The vacuum tube with its associated apparatus may be used as an amplifier in *radio-frequency amplification* in which the incoming high-frequency currents and voltages are amplified before detection, or it may be used in *audio-frequency amplification* in which the *detected* currents and voltages are amplified. Although the methods of constructing such amplifiers are similar, the values of the constants differ so that the apparatus is not interchangeable.

Part 3

AUDIO-FREQUENCY AMPLIFICATION

In audio-frequency amplification a tuned circuit is not required, because all of the frequencies must be magnified equally. For radio broadcasting the circuit must give flat amplification over a range of frequencies from 50 to 6,000 cycles per second. An audio-frequency amplifier for telegraph code reception does not need a frequency-characteristic range of more than 60 to 1,000 cycles per second.

Resistance Coupling.—A circuit diagram of a resistance-coupled audio-frequency amplifier is shown in Fig. 33. The resistances of the coupling and the grid-leak resistances are stated in megohms. An incoming signal voltage produces a current through the resistance R_1 in the plate circuit of the detector tube. Voltage variations across R_1, diminished by any drop caused by the blocking condenser, are impressed on the input circuit of the first audio-frequency tube. Grid-voltage variations of the first audio-frequency tube cause corresponding variations of plate voltage across the resistance R_2 which are impressed on the input circuit of the second audio-frequency tube. The voltage variations are relayed in a similar manner by the second and third audio-frequency tubes and are finally impressed on the loud-speaker circuit.

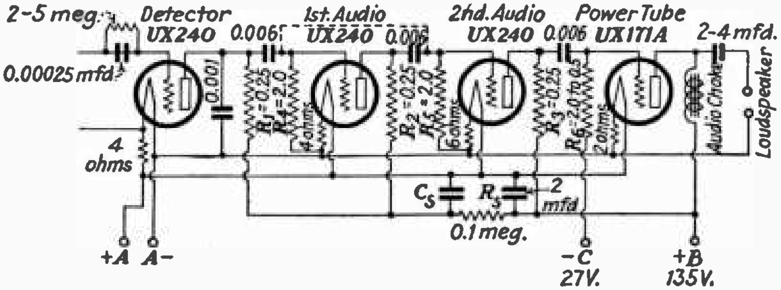


FIG. 33.—Circuit diagram of resistance-coupled audio-frequency amplifier.

The blocking condensers are necessary to insulate the grids of the audio-frequency tubes from the high positive voltage of the B battery. Because the grids are thus isolated they would tend to accumulate negative charges. To prevent this accumulation, a high-resistance leakage path is provided through the grid leaks R_4, R_5, R_6, which ordinarily have a resistance about ten times that of the coupling resistance.

Size of Coupling Resistance.—A consideration of the relation for voltage amplification $\frac{E_{g2}}{E_{g1}} = \frac{uR_0}{r_p + R_0}$ shows that the voltage amplification increases as R_0 increases. When R_0 is so large that r_p may be neglected, the value of voltage amplification reaches its maximum value, $Eg_2/Eg_1 = u$.

The theoretical relation between voltage amplification and load resistance for a UX-201A tube with an amplification factor of 8 and a plate resistance of 10,000 ohms is shown in Fig. 34. The gain in amplification for resistances greater than 50,000 ohms is small. It is necessary to remember that when the plate circuit is loaded with a resistance, the battery voltage must be increased to compensate for the drop in the resistance. From Fig. 35 it is seen that the increase in amplification of a UX-240 tube with an amplification factor of 30 and a plate resistance of 150,000 ohms is small for resistances greater than 500,000 ohms. Ordinarily the coupling resistance has a value equal to twice the plate resistance of the tube.

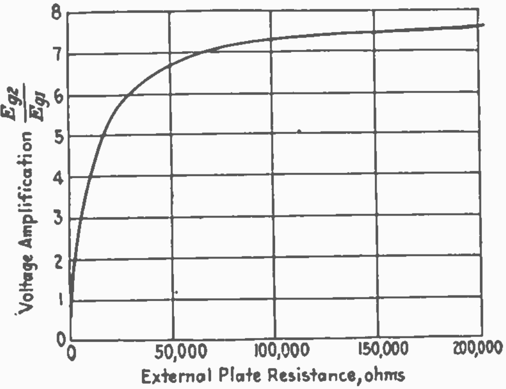


FIG. 34.—Theoretical relation of voltage amplification to load resistance for UX-201A tube.

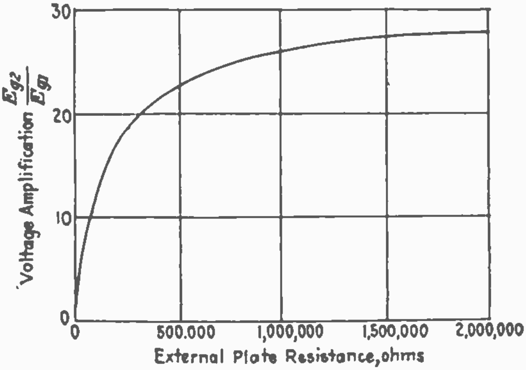


FIG. 35.—Theoretical relation of voltage amplification to load resistance for UX-240 tube.

Size of Grid-leak Resistance.—If the grid-leak resistance is too high, the tubes may become temporarily inactive. A low grid-leak resistance, on the other hand, reduces the amplification; that is, when the grid-leak resistance is low, the total impedance of the input circuit of the stage is decreased, the voltage drop across the coupling resistance is reduced, and the amplification is cut down. Hence the value of grid-leak resistance should be less than the value which will permit the tubes to block.

Size of Blocking Condenser.—Several factors are involved in the determination of the size of a blocking condenser, and the final choice is a compromise among them. The rapidity with which the condenser responds to voice-amplitude variations requires that the *time constant* $R \times C$ be small, where C is the capacity of the blocking condenser and R the grid-leak resistance. In order to make $R \times C$ small, C must be as small as possible for the reason that if R is decreased it causes such a reduction in the impedance of the grid-filament circuit that the voltage drop across the coupling resistance is diminished and the amplification is reduced.

The reactance of the grid condenser acts to reduce the voltage across the coupling resistance and thus diminishes the voltage available in the grid-to-filament circuit. The reactance of the grid condenser must be small compared with that of the circuit from grid to filament. This circuit is made up of the capacity and resistance of the grid-to-filament and the grid-leak resistance. At audio frequencies, the impedance of the path from grid to filament consists mostly of the grid-leak resistance in parallel with the grid-to-filament resistance of the tube and has a resistance of several hundred thousand ohms. This impedance is affected only a little by the reactance of the capacity of the grid-to-filament circuit which may be equal to about a million ohms. Various values ranging from 0.05 to 1.0 microfarad have been used for the coupling condenser, depending on the stage in which it is located.

Use of Tubes Having High Amplification.—With resistance coupling, the amplification is practically dependent on the tube alone and the resistances decrease that slightly. Flat frequency characteristics (page 366) may be obtained with ordinary tubes, but the stage amplification is so low that three stages are necessary. It is, therefore, desirable to use tubes having as high an amplification factor as is practical for this service. When UX-240 tubes are used, two stages afford ample amplification. The UX-240 tube has an amplification factor of 30, and about 60 per cent of this, or 20, may be realized in voltage amplification per stage. This value is approximately equal to the usual transformer stage in this respect. The UX-200A tube is recommended as a detector for use with two stages of resistance coupling and the UX-240 tube for three stages of resistance coupling. When a UX-240 tube is used as a detector, no separate detector B-voltage tap is required if the resistance shown in the detector-plate circuit of Fig. 33 is used.

Effect of Frequency on Amplification.—One of the advantages of resistance coupling is the good response obtained at very low audio frequencies. The frequency range over which uniform response is obtained may be brought to as low a frequency as may be desired in practice by using the proper size of blocking condenser. When a blocking condenser with a capacity of 0.006 microfarad is used, the range of response is extended so that it is as low as 30 cycles per second, but the response of the ordinary loud-speaker below 50 cycles is not satisfactory. The frequency characteristic begins to drop at about 5,000 cycles because of the high effective input capacity caused by the reaction of the plate load upon the input circuit of the vacuum tube in the amplifier. But even at 10,000 cycles the decrease in amplification is only moderate. This method of coupling is well adapted for use in television reception and transmission in which amplification is required over a range of 16 to 20,000 cycles per second.

The good response obtained at very low audio frequencies, however, increases the possibility of trouble from a common plate-voltage supply. The by-pass condensers ordinarily used are not very effective at very low audio frequencies, and therefore the common voltage supply acts as a coupling between the stages. This coupling, due to common voltage supply, gives rise to oscillations in the amplifier called "motor-boating." Such action may be avoided by using a low-resistance grid leak across the input circuit of each stage or by using a smaller blocking condenser. These changes, however, reduce amplification on low frequencies.

If the capacity of the blocking condenser is such that its reactance at low frequencies is of a magnitude which approaches that of the grid leak, the amplification is diminished.

Impedance Coupling.—The impedance-coupled audio-frequency amplifier uses coils, or a combination of coils and condensers in parallel, in place of the coupling resistances as shown in Fig. 33. A diagram of an impedance-coupled amplifier is shown in Fig. 36. Its action is similar to that of the resistance-coupled amplifier. The coupling must have a high reactance at the frequency for which the amplifier is intended and a low resistance to a direct current. The advantage of impedance coupling over resistance coupling is that the battery voltage does not have to be increased to compensate for the voltage drop in the coupling unit.

Size of Impedance.—If the resistance of the coupling unit is assumed to be negligible, the expression for voltage amplification is given as

$$\frac{E_{g2}}{E_{g1}} = \frac{uX_0}{\sqrt{r_p^2 + X_0^2}}$$

where X_0 is the reactance of the unit at a stated frequency. The curves in Figs. 37 and 38 show the theoretical relation between voltage amplification and the reactance of the coupling unit. With the UX-201A tube there is not much gain in amplification at reactances greater than about

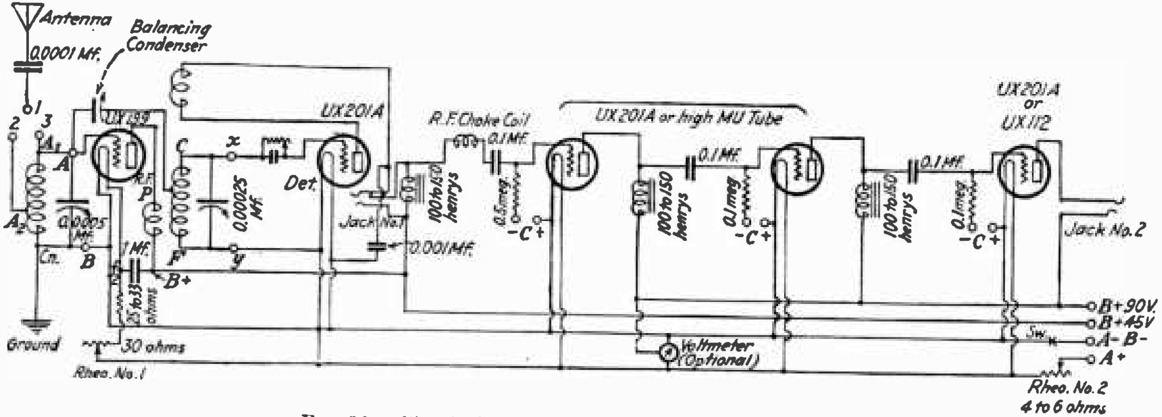


FIG. 36.—Circuit diagram of impedance-coupled amplifier.

30,000 ohms. At a frequency of 50 cycles per second, the inductance of a 30,000-ohm reactance is nearly 100 henrys. Likewise, with the UX-240 tube there is not much amplification beyond a 400,000-ohm reactance which has an inductance of almost 1,250 henrys at 50 cycles. An inductance unit for audio-frequency work is made with an iron core and must have low iron losses and small internal capacity.

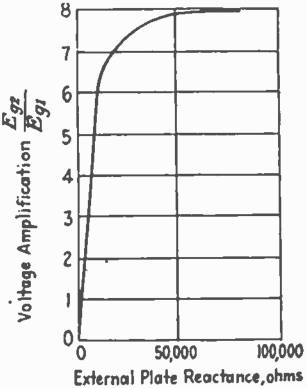


FIG. 37.—Curve showing variation of voltage amplification with external plate reactance for UX-201A tube.

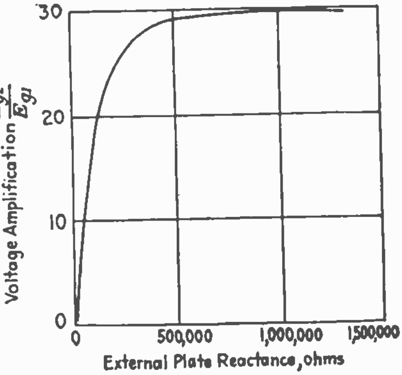


FIG. 38.—Curve showing variation of voltage amplification with external plate reactance for UX-240 tube.

Size of Blocking Condenser and Grid Leak.—The precautions mentioned with regard to the size of blocking condensers (page 358) and grid leaks for a resistance-coupled amplifier (page 357) apply also to an impedance-coupled amplifier. It may be stated here that the resistance type of grid leak may in general be replaced to advantage by the inductance type of grid leak in which case the coupling is termed "double impedance." An inductance grid leak is made with a high impedance for audio frequencies, but a comparatively low direct-current resistance, and, therefore, the accumulated charge can leak off the grid in a shorter time than if a resistance type of grid leak is used. This coil of an inductance type of grid leak and the coupling condenser may be designed for resonance at the low end of the frequency range with consequent improvement in the frequency amplification characteristic of the amplifier tube.

Effect of Frequency on Amplification.—The frequency characteristic obtained with impedance coupling is a curve which is almost as flat as a similar curve for resistance coupling. Here, also, as in the case of resistance

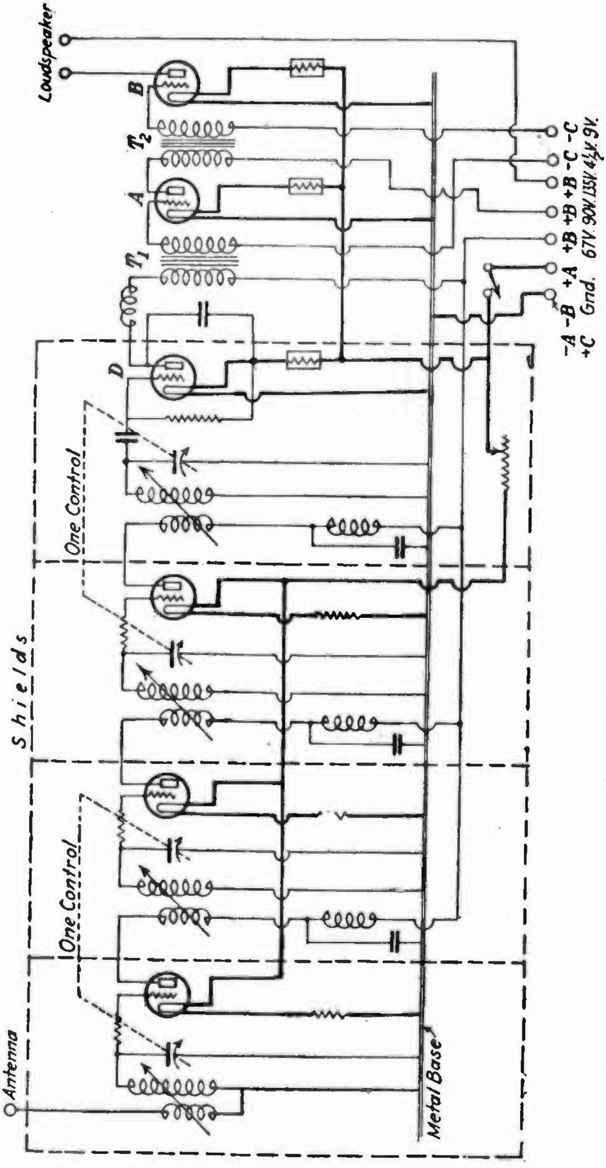


FIG. 39.—Hammerlund-Roberts radio receiver.

coupling, the only voltage amplification obtained from the circuit is due to the amplifying action of the tube. Three stages of amplification are necessary with tubes such as UX-201A and two stages with UX-240 tubes.

When UX-240 tubes are used, the choke coils must be carefully designed to avoid certain difficulties. The low impedance of the choke coil compared with the high resistance of the tube, which is about 75,000 ohms in this case, may result in reduced amplification at low frequencies. The high effective capacity of the input circuit of the tube together with the inductive reactance of the coil may result in resonance, in extreme amplification, or even in oscillations at frequencies from 100 to 300 cycles per second. The high effective capacity of the input circuit of the tube may cause a marked decrease in amplification at high frequencies.

Transformer Coupling.—The use of transformer coupling in audio-frequency amplification is illustrated in Fig. 39. The alternating voltage of the radio signal which reaches the grid circuit of the detector tube *D* produces in the plate circuit of that tube a pulsating current. This current flowing through the primary winding of the transformer T_1 induces a stepped-up voltage in the secondary winding which is applied to the grid circuit of the first amplifier tube *A*. The variations of this stepped-up voltage are amplified reproductions of the grid-voltage variations which were impressed on the detector tube. The second amplifier tube *B* further amplifies the alternating voltage, which has been stepped up, through the action of the second transformer T_2. For audio-frequency work it is customary to use iron-core transformers which may be obtained with various step-up ratios from 1:2 to 1:6.

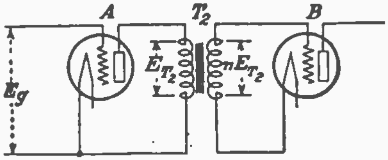


Fig. 40.—Circuit of amplifier in radio receiver in Fig. 39.

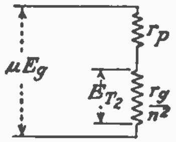


Fig. 41.—Equivalent of plate circuit of tube A in radio receiver in Fig. 39.

Voltage Amplification.—An elementary study of the transformer action between the tube *A* and the tube *B* in Fig. 39 can be made when certain assumptions are made. The tube capacity between the grid and the filament, and between the plate and the filament, which is very small except at high audio frequencies, is neglected. The transformer is assumed to be perfect; that is, it has no leakage or magnetizing current. Also it is assumed that the load on the secondary winding of the transformer consists of a non-inductive resistance equal to the grid-filament resistance r_g of the tube B. The portion of the amplifier under consideration is shown in Fig. 40. For a study of the action of such a circuit with alternating current, the transformer may be considered as an equivalent resistance in the primary circuit and equal to the resistance r_g of the secondary circuit divided by n^2 where n is the transformer voltage ratio. If the secondary current $I_s = nE_{t2}/r_g$ and the primary current $I_p = nI_s$, then $I_p = n^2E_{t2}/r_g$. The voltage acting on the plate circuit of tube A is taken as uE_g. It is then possible to represent the plate circuit of tube A as in Fig. 41. The relation of the voltage E_{t2} in Fig. 41 to uE_g is the same as that of the equivalent resistance $\frac{r_g}{n^2}$ to the total resistance $r_p + \frac{r_g}{n^2}$; that is, $E_{t2} = E_g \frac{ur_g}{r_g + n^2r_p}$. Since nE_{t2} is the voltage acting on the grid of the tube B, the voltage amplification is equal to $\frac{nE_{t2}}{E_g}$ or $\frac{unr_g}{r_g + n^2r_p}$. From this expression it is seen that the voltage amplification depends directly on the voltage amplification u and that as r_g increases the voltage amplification increases, approaching un as a limit. Therefore, r_g should be made as large as possible by keeping a negative "bias" voltage on the grid. In practical applications r_g is equal to about a million ohms, but under certain conditions of operation the value may be only a few hundred thousand ohms. Further, the expression for voltage amplification has a maximum value when $n = \sqrt{r_g/r_p}$, which indicates the best value for the transformer ratio. The voltage amplification, in terms of this value of n, is $un/2$. Both the voltage amplification and the transformer ratio, however, are decreased by imperfections in an actual transformer.

Transformer Construction.—The greater the impedance of the primary winding relative to the plate impedance the larger will be the voltage impressed on the primary coil of a transformer and, consequently, also the amplification. A primary inductance of 100 henrys has an impedance of 628,000 ohms at 1,000 cycles and 62,800 ohms at 100 cycles, which is about six times the plate resistance of the tube. The reduction of impedance with frequency decreases the amplification at low frequencies. The inductance of the primary winding depends on the number of turns in the primary winding, the cross-section of the core, the length of the iron core path, and the amount of direct current flowing in the primary winding. High core losses diminish the amplification at all frequencies. The voltage amplification increases rapidly with an increase of the primary no-load reactance at low values but more slowly at higher values. Beyond a certain point, then, there is little to be gained by increasing the reactance. The factors of size and cost must be considered, also, for an increase in the core increases the size of the unit, and if more turns of the primary winding are used, more turns in the secondary winding are necessary for a given value of n.

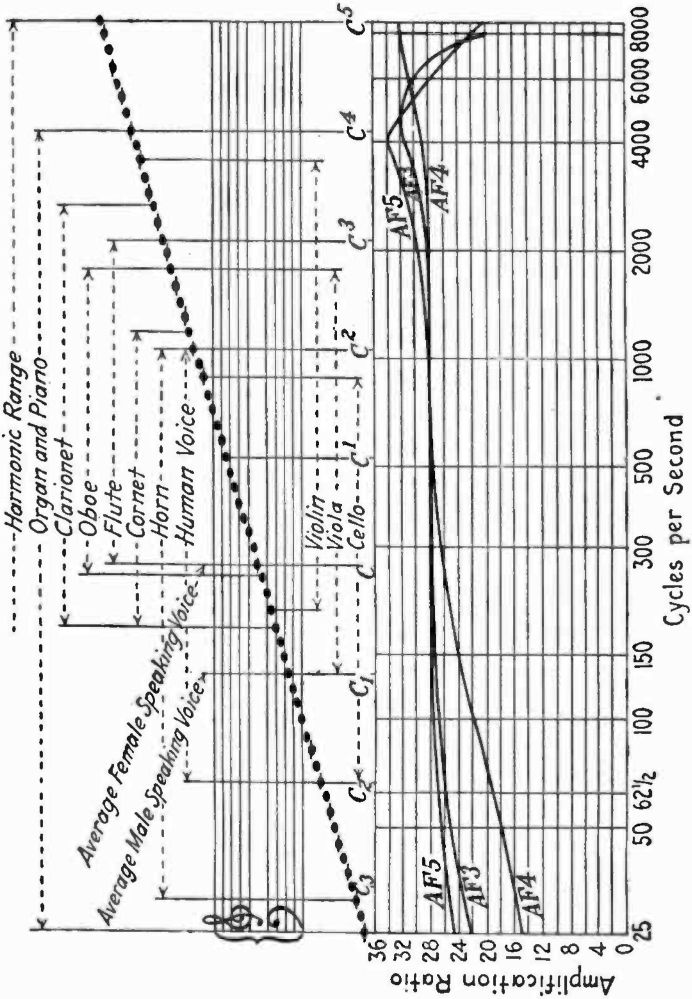


FIG. 42.—Frequency characteristic curves of audio-frequency transformers.

Since the primary and secondary coils cannot occupy the same space, there is a certain amount of magnetic flux called *leakage flux* which does not link both coils. This produces the leakage inductance which decreases the amplification at all frequencies.

The capacity effect between turns and between layers is small and affects amplification only at the higher frequencies. The capacity effect between the primary coil and the secondary coil also acts as a short circuit at the higher frequencies and tends to decrease amplification.

If the transformer ratio n is made high, and there are many turns on the primary winding, a large number of turns are needed on the secondary winding. This results in an increased internal capacity effect which, with the input capacity of the next tube, brings the natural frequency of the secondary circuit within the range of audio frequencies and causes a resonance peak. Amplification beyond this natural or "cut-off" frequency is very poor.

The amplification of low frequencies requires a large number of turns of the primary winding, and a large number of secondary turns diminishes the amplification of high frequencies. Consequently the transformer is made with a rather low ratio, a core having a large cross-section, low internal capacity, and a low leakage inductance.

Amplification Curves.—The performance of a group of modern transformers is shown by so-called "frequency characteristic" curves as in Fig. 42. A UX-112A tube was used and was operated with a plate voltage of 68 and a grid-bias voltage of −3 volts. The specifications for the several types of transformers although given before are repeated in Table XXIX.

TABLE XXIX.—SPECIFICATIONS FOR TRANSFORMERS

Type	Ratio n	Maximum primary current, milliamperes	Resistance, ohms		Inductance, no direct current, henrys		Primary inductance with 3 milliamperes direct
			Primary	Secondary	Primary	Secondary	
AF5	1:3.5	10	2,400	34,000	190	2,330	110
AF3	1:5	5	1,375	26,000	95	2,330	55
AF3	1:3.5	5	1,900	26,000	190	2,330	85
AF4	1:3.5	5	950	8,900	42	515	35

The effect of the lower impedance of the primary winding of the AF4 transformer is indicated by the decrease in amplification at low frequencies. Both the AF3 and the AF4 transformers cut off at about 8,000 cycles. The small *resonance peaks* are due to the effect of internal capacity and leakage inductance.

The effect of a strong radio signal is to reduce amplification. This occurs because a strong signal causes an increased current to flow in the grid circuit. This current flows through the secondary winding of the transformer and acts so as to reduce the voltage developed.

A condition of resonance at 5,000 cycles per second or more does not produce a very noticeable effect on the reception, because the efficiency of the loud-speaker at such frequencies begins to drop off. A condition of resonance at moderately low frequencies may be detected by laboratory measurements but, if small, does not perceptibly affect the performance of the amplifier.

The performance of a multistage amplifier may differ considerably from the frequency characteristic of a single transformer. Interstage coupling may increase the effect of resonance conditions (page 83), and the coupling resulting from a common supply for the plate voltage may cause a considerable change in amplification at low audio frequencies.

Part 4

RADIO-FREQUENCY AMPLIFICATION

Advantages of Radio-frequency Amplification.—The efficiency of a detector tube is greater for strong than for weak radio signals, because the efficiency varies as the square of the signal voltage. An example will serve to illustrate this action. If the amplitude of a radio-frequency signal is increased five times, its amplitude after detection is twenty-five times as great. If two stages of radio-frequency amplification are used, each giving a voltage amplification of 5, the signal amplitude at the input of the detector is twenty-five times as great, and that at the output of the detector, six hundred and twenty-five times as great. Finally, if two stages of audio-frequency amplification are used, each giving a voltage amplification of 5, the total amplification is $625 \times 5 \times 5 = 15{,}625$.

Function of Radio-frequency Amplifier.—The three factors which enter into radio-frequency amplification are (1) sensitivity, (2) selectivity, and (3) fidelity of reproduction. *Sensitivity* measures the extent of the response to signals of the frequency to which the receiver is tuned. *Selectivity* is the ability of the receiver to differentiate between signals of different frequencies. *Fidelity of reproduction* is determined by the response of the receiver to the frequency range of the side bands. This is for the reason that when a carrier wave (page 34) is modulated at audio frequency, the following three frequencies are present: (1) the carrier frequency, (2) the carrier frequency plus the audio frequency, and (3) the carrier frequency minus the audio frequency. The last two are called the *side bands.* If the fidelity is to be good, the side bands must be fully reproduced. The radio-frequency amplifier must select the desired frequency and must amplify the carrier frequency with its side bands. The resonance curve (page 83) must not be too sharp at the top or the side bands will be cut off. On the other hand, if the resonance curve is too broad, interference may be caused by the amplification of other frequencies.

Resistance Coupling.—At high frequencies, such as 500,000 cycles per second (500 kilocycles or a wave length of 600 meters), the impedance of the grid-to-filament circuit consists largely of the reactance of the grid-filament capacity which may be several thousand ohms. The disadvantage of this is that the capacity reactance of the grid-filament circuit is so small that it has the effect of a short circuit on the coupling resistance and, therefore, decreases the amplification. The blocking condenser (page 33) must have a capacity such that its reactance is smaller than the grid-filament capacity reactance as stated above. This shows that the capacity of a blocking condenser for use at high frequencies may be made smaller than that of one for use at low frequencies. A resistance-coupled amplifier for high-frequency work is similar to one for audio frequency, except that the blocking condenser must be smaller. The distributed capacity of the coupling resistance should be as small as possible; otherwise, it would reduce the impedance of the coupling unit and thus diminish the amplification. With ordinary vacuum tubes a resistance-coupled radio-frequency amplifier does not give satisfactory performance at frequencies above 300,000 cycles per second (1,000 meters). Furthermore, such an amplifier is noisy because it amplifies audio frequencies as well as radio frequencies.

Impedance Coupling.—At 500,000 cycles (600 meters) the inductance of the 30,000-ohm reactance used with a UX-201A tube is 0.01 henry, and that of the 400,000-ohm reactance used with a UX-240 tube is 0.1 henry. It is difficult to build an inductance of this amount without iron so that its internal capacity is small and its size is not large. The difficulty introduced by the distributed capacity (page 86) is that excessive amplification exists at a frequency equal to the natural frequency of the coupling unit.

The performance of an amplifier using inductance alone is not satisfactory when used for short wave lengths. If a condenser and inductance in parallel are used, they may be tuned to the required frequency. With such a construction the value of inductance may be low because the tuning is accomplished by the condenser, but the impedance of the unit may be high. Tuned amplification of this kind is especially useful for radio-frequency amplification because of the great selectivity which it provides.

An amplifier of the inductance-coupled type, just as one of the resistance-coupled type, amplifies audio frequencies as well as radio frequencies and hence has *no selectivity.*

Transformer Coupling.—For radio-frequency amplification it is customary to use air-core transformers (although satisfactory iron-core transformers have been developed) with a one to one ratio. On very long wave lengths a step-up ratio has been found advantageous.

If two so-called *low-loss circuits* are coupled "loosely" by means of a transformer with a primary winding of few turns having an inductance of several microhenrys, and a secondary winding of many turns having an inductance of about 200 microhenrys, the voltage amplification is increased because of the step-up ratio and the tube amplification. A circuit of this kind, however, gives maximum amplification at only one frequency and poor amplification at adjacent frequencies. The amplification curve (page 136) may be flattened considerably by the use of close coupling, high resistance windings, and by designing transformers so that their resonance peaks (page 83) are staggered. In order to obtain a circuit which gives more uniform amplification than the untuned circuit over a band of frequencies, a variable tuning condenser having a maximum capacity of about 0.0004 microfarad is used across the secondary winding of the transformer. Such a circuit is called a *tuned radio-frequency amplifier.*

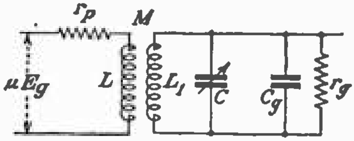


Fig. 43.—Equivalent circuit of radio-frequency stage of radio receiver of Fig. 39.

Voltage Amplification.—The circuit arrangement of a tuned radio-frequency amplifier is shown in Fig. 39. The equivalent of one of these radio-frequency stages is given in Fig. 43. The expression for the voltage amplification according to the principles and notation in Sec. II is

$$\frac{(2\pi f)^2 M L_1 u}{R_e r_p + (2\pi f M)^2}.$$

From this expression it is seen that the voltage amplification varies with the amplification factor u of the tube, the inductance of the primary winding L in *microhenrys,* the inductance of the secondary winding L_1 in *microhenrys,* the plate resistance r_p of the tube, and the effective resistance of the secondary circuit R_e. The mutual inductance in *henrys* M between L and L_1 is equal to $k\sqrt{LL_1}$ in which k is the coefficient of coupling. R_e is the total series resistance of the secondary circuit and is equal to the L_1 coil resistance (3.4 ohms) plus the equivalent resistance of r_g. The equivalent resistance of r_g is $(2\pi f L_1)^2/r_g$.

Example.—In order to illustrate the use of the expression for voltage amplification, assume that f = 500,000 cycles, $k = 0.3$, L = 35 microhenrys, L_1 = 250 microhenrys, $u = 8$, r_p = 10,000 ohms, and r_g = 1,000,000 ohms. Then the equivalent resistance of $r_g = \frac{(6.28 \times 500{,}000 \times 250)^2}{10^{12} \times 10^6} = 0.62$ ohms and $R_e = 3.4 + 0.62 = 4$ ohms, approximately. The mutual inductance $M = 0.3\sqrt{35 \times 250} = 28$ microhenrys. The substitution of these values in the expression for *voltage amplification* on page 369 gives

$$\frac{(6.28 \times 5 \times 10^5)^2 \times 28 \times 250 \times 8}{\left[4 \times 10^4 + \left(6.28 \times 5 \times 10^5 \times \frac{28}{10^6}\right)^2\right] \times 10^6 \times 10^6} = 11.6.$$

It is important to keep enough negative grid-bias voltage on the grid circuit of the tube so that the resistance r_g of the grid-filament circuit may be high.

Resonance Curve.—The shape of the resonance curve depends on the effective resistance of the secondary circuit, on the coupling between the coils, and on the grid-plate capacity of the tube, which couples the input and output circuits. Increased coil coupling increases the secondary-circuit resistance and has the effect of broadening the resonance curve and diminishing the selectivity. Amplification improves as the coupling is increased until the best point is reached, beyond which it slowly decreases. The degree of coupling generally used is well below the best value to obtain stability and selectivity. The tuning of the secondary circuit is broadened at high frequencies.

Because of the grid-plate capacity, the output circuit, under the usual load conditions, reacts on the input circuit. The feed-back action (page 304) is greater at high frequencies and tends to offset the broadened tuning. The effect is equivalent to the addition of a condenser and resistance across the secondary circuit. The constants of the output circuit determine whether this resistance has a positive or a negative effect. The action of a negative resistance is to offset the losses in the secondary circuit. When the losses in the secondary circuit are offset in this manner, the tuning is made sharper unless the negative resistance supplies all the losses, in which case the circuit will oscillate.

Tubes for Radio-frequency Amplification.—A tube having a fairly high output resistance may be used efficiently for radio-frequency amplification. The limiting factor as regards the permissible tube resistance is the increase in resistance of the secondary or tuned circuit. Ample voltage amplification, that is, good sensitivity, is obtained with a high-resistance tube which is coupled closely to a tuned secondary circuit, but the selectivity is poor because of the increase in effective resistance of the circuit. A low-resistance tube can be used with less coupling than a high-resistance tube, with improvement in selectivity; but if a low output resistance results from decreasing the amplification factor, the sensitivity is reduced and the drain on the B battery is increased.

Methods of Stabilizing to Avoid Oscillation.—There are several methods of stabilizing a circuit so that it will not oscillate. Two common methods are shown in Fig. 44. In one of these methods the grid return is varied by a potentiometer (page 121) in such a way that a positive grid-bias voltage may be applied to the grid. A current then flows in the grid circuit and has the effect of decreasing the resistance between the grid and the filament and increasing the effective resistance of the tuned circuit. The main disadvantages of this method are the heavy plate current which flows when the grid is positive and the increased damping of the tuned circuit. The other method utilizes an adjustable potentiometer, shown by the dotted lines, connected across the tuning condenser. Adjustment of the potentiometer varies the voltage applied to the grid and thus serves as a control of amplification and stability.

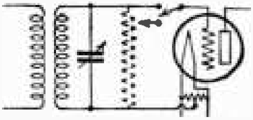


FIG. 44.—Method of stabilizing circuits by the use of grid-bias voltage to prevent oscillation.

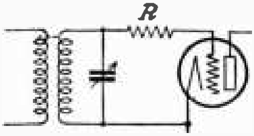


FIG. 45.—Method of stabilizing circuits by the use of grid resistance to prevent oscillation.

A better method than either of the two above is shown in Fig. 45 where the grid circuit has a resistance R of which the value is from 100 to 800 ohms. The decrease in amplification caused by the use of the resistance R is more pronounced at high than at low frequencies, which is an advantage because the feed-back increases with the frequency. A disadvantage, however, is introduced by the broader tuning due to the greater damping (page 35) of the circuit.

The insertion of resistance in the positive (+) B lead may be used to secure stable operation by lowering the effective plate voltage. The advantage of this method is the sharper tuning which is possible because there is no increase in the damping of the resonant circuit.

Adjustment of the filament resistance of a radio-frequency amplifying tube will serve to maintain operation below the point of oscillation.

The best method of obtaining stability is to *neutralize the capacity* of the tube by means of another capacity. Two ways of connecting this capacity are the *Rice method* and the *Hazeltine method.* The Rice method is shown in

Fig. 46. The center of the input coil is grounded, so that the coils must be carefully arranged. Otherwise, the balance obtainable may be upset by capacity coupling between the coils. The capacity effect may be minimized by increasing the spacing of the coils or by using a shield between them. Various forms of windings such as the toroid and the figure-eight coils have been devised to reduce the external magnetic field. Some decrease in sensitivity may be expected when this circuit is used because the input voltage applied to the tube is half of that obtained across the tuned circuit.

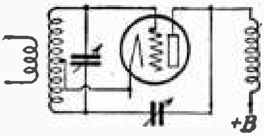


Fig. 46.—Rice method of stabilizing by neutralizing the capacity of a tube by another capacity.

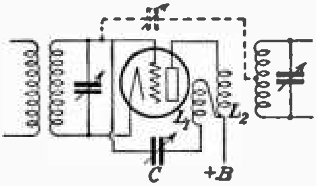


Fig. 47.—Hazeltine method of stabilizing by neutralizing the capacity of a tube.

The coils L_1 and L_2 required in the Hazeltine method, shown in Fig. 47, have a double-wound primary coil which is used to obtain close coupling. An "alternate" connection may be made by omitting L_1 and connecting the variable condenser C as indicated by the dotted lines. In this case L_2 must be placed adjacent to the lower portion of the secondary in order to obtain close coupling. The secondary coil may be wound outside the primary coil to reduce the capacity coupling between the primary coil of one stage and the secondary coil of the preceding stage. The tube in the first stage of the set is *neutralized* by tuning to a radio signal, turning out the filament, and adjusting the *neutralizing condenser* until the minimum volume of the signal is obtained. Then the filament is lighted again and the procedure is repeated for the tube in the next stage. Either of the last two methods is nearly independent of frequency over the usual range of frequencies used in broadcasting. Another device, known as the "reversed tickler circuit," utilizes a tickler coil (page 40), in the plate circuit, this coil being connected so that its effect on the grid circuit opposes the regeneration (page 403). The object is to balance an inductance against a capacity with the result that the adjustment varies with the frequency of the radio signal.

Push-pull Amplifier.—The push-pull arrangement of tubes shown in Fig. 48 is intended to minimize the distortion produced by the harmonics (page 72) of the radio-signal voltage. In this arrangement each tube can deliver more undistorted power than if only one is used, the combined output being several times that of a single stage. Tubes used in this way must be "matched" if best results are to be obtained. The grids of the tubes receive a grid-bias voltage from the C battery connected to the midpoint of the secondary winding of the T_1 transformer. If an alternating current flows in the primary winding of the transformer T_1, one of the grids is positive when the other is negative, and *vice versa*. The plate current in one tube is increasing, therefore, while that in the other is decreasing. The secondary windings of the output transformer T_2 are connected in such a way that the resultant plate current is proportional to the difference of the plate currents from the two tubes. The result of this is that the distorting components are balanced and eliminated. For use with a *cone type of loud-speaker* (page 128) the output transformer T_2 has a "step-down" ratio of about 2:1. For a *dynamic loud-speaker* (page 129) a ratio of about 30:1 is necessary to provide an equivalent resistance that has a value which is twice the resistance of the plate circuit of the tube.

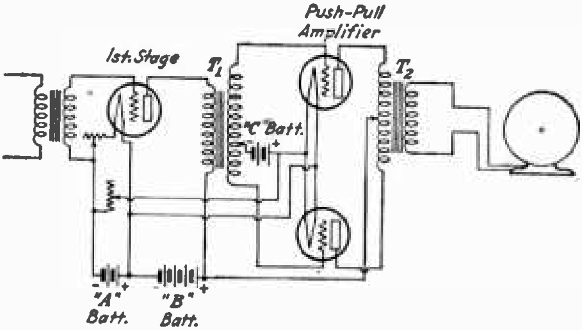


FIG. 48.—Push-pull arrangement of tubes in amplifier.

It is claimed that the use of impedance coupling instead of transformer-input coupling to a push-pull amplifier eliminates another source of frequency distortion, because there is no iron core to be magnetized by the current in the plate circuit.

Number of Stages.—In the types of amplifiers which have been described, the number of stages which can be used is limited. This is due to the fact that the magnetic and electrostatic stray fields developed in the last stage act on the circuits of the preceding stages. Such interaction, together with the internal capacity coupling of the tubes, allows a feed-back of the amplified energy to the input circuits which may lead to the generation of oscillations in the amplifier with resultant howling and noises. Special methods may be used to minimize the effect of such feed-back.

Distortion in Power Tubes.—Two causes of distortion will be considered here: first, the distortion due to the curvature of the plate voltage-plate current curves (page 289) at low values of plate current; second, the distortion resulting from the flow of grid current.

The effect of distortion due to the curvature of the curves is shown by an inspection of the plate voltage-plate current curves in Fig. 49. While these curves do not indicate actual conditions of operation, because they are taken with no current in the plate circuit, the procedure outlined next may be used to determine the behavior of tubes with a plate load.

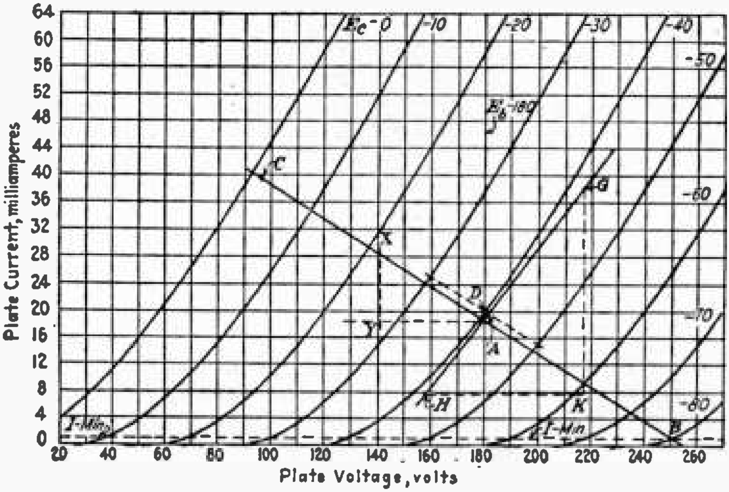


FIG. 49.—Curves showing the effect of distortion.

The plate current-plate voltage curves of the UX-171A type for various grid voltages are given in Fig. 49. When a plate voltage of 180 volts is applied, the tube operates along the vertical line at 180 volts. The value of the plate current for a grid bias of −40 volts is found to be 20 milliamperes at the intersection of the vertical line and the "bias" line. Now, if a signal voltage having a peak amplitude of 10 volts is applied to the grid, the range of the operation of the plate current is along the vertical 180-volt line from its intersection with the −30-volt bias line to that with the −50-volt bias line. The positive swing of the grid produces an increase in plate current of 18 milliamperes, but an equal negative swing produces a decrease of only

14 milliamperes. This effect is due to the increased curvature at low plate voltages of the plate current-plate voltage curve and causes distortion by introducing into the output current a second-harmonic component (page 72) which did not exist in the impressed signal voltage. The effect of the curvature increases rapidly as the amplitude of the signal voltage is increased. At low values of plate current the curvature is much greater, and, therefore, the instantaneous value of plate current must not come close to zero. Under the load conditions given in the following paragraphs, the minimum value of instantaneous plate current for satisfactory reproduction is taken to be 1.0 milliampere. This is indicated by the dotted line at the bottom of Fig. 49.

When, however, the resistance load is very high, the range of plate current is no longer on the vertical voltage ordinates, and the line representing the conditions of operation is then swung, about the "operating point," away from the vertical, until it is nearly parallel to the 20-milliampere line. This new line of operation intersects all of the equidistant curves at the same angle so that it is clear that the distortion due to the curvature of the characteristic curve is eliminated. The power output, however, is decreased and approaches zero in the limiting case.

When the load resistance is lower than in the preceding case, an intermediate condition is obtained. This may be shown graphically by drawing the "load line" for a given load resistance in the plate circuit. Thus in Fig. 49 the line CAB represents the operation of the tube at a grid bias of -40.5 volts with a plate load resistance of 3,900 ohms. This load line is located by the "operating point" and has a slope equal to the reciprocal of the load resistance. If this figure had been made with a scale of ordinates in amperes, the slope of the load line would be given by 1/3,900, and for a milliampere scale the slope becomes 1,000/3,900 or $^{10}/_{39}$. If one point A on the load line is known, any other point X may be located by using this value of the slope, by the method of drawing through A a horizontal line AY equal to 39 on the scale of abscissas, and at Y drawing a vertical line YX equal to 10 on the scale of ordinates. Then through the points A and X the required load line CAB can be drawn.

In the first part of this discussion the distortion occurring with no plate-load (resistance) was shown for operation with a grid bias of -40 volts. The effect of the plate load of 3,900 ohms in decreasing this distortion is evident from a consideration of the load line through the point D at -40 volts. With no plate-load resistance a 10-volt radio signal causes the plate current to range from 18 milliamperes in one direction to 14 milliamperes in the other. The same signal voltage along the 3,900-ohm load line causes a range of plate current of 5 milliamperes in each direction. This shows that under these operating conditions the effect of the *second harmonic* (page 72) is not appreciable.

The second cause of distortion is that due to a flow of current in the grid circuit. It has been shown that the distortion resulting from the negative swing of the grid voltage on the lower portion of the characteristic curve having a considerable curvature is eliminated by using a very high plate-load resistance. If, however, the impressed grid voltage is too high, it may cause a swing which extends beyond the curve for $E_c = 0$ in Fig. 49. When this happens, a grid current flows. As the grid becomes more positive the grid current increases quite rapidly and the grid-to-filament resistance of the tube is decreased. This decrease, however, occurs only when the grid swings positive and, consequently, a very uneven resistance load results on the transformer; this unevenness of the load produces distortion. The conditions of operation should be such that the grid is always negative with respect to the filament.

Maximum Power Output.—The conditions for maximum power output are limited by the extent to which the output is considered as undistorted. The two forms of distortion discussed on page 374 must be quite severe in order to affect the quality of reproduction so that it is perceptible to the listener. A distortion of 5 per cent is quite imperceptible to the listener and, hence, may be allowed, especially because only a relatively small power increase is obtained if the distortion is greater. Undistorted power output, then, may be considered as the amount of power which is obtained when the input-signal voltage does not become greater than the value producing a 5 per cent distortion due to the introduction into the power output of harmonics of the second and higher degrees (page 72).

It has been shown that the power output is a maximum when the resistance of the external load $R_0 = r_p$ the plate resistance of the tube. In this explanation, however, the distortion which is introduced is neglected. To avoid excessive distortion the grid "swing" must be limited; that is, the minimum value of plate current must be greater than 1 milliampere.

Investigations (*Proc. Phys. Soc.* (London), vol. 36; *Proc. Inst. Radio Eng.*, vol. 14) indicate that a maximum undistorted power output is obtained when the load resistance $R_0 = 2r_p$, with the plate and grid voltages adjusted to their best values. The maximum may occur at a different relation between R_0 and r_p if the applied voltages are not set to the best values; that is, the best load is found to have a certain value at a given plate voltage; now, if the grid-bias voltage is reduced in order to allow a moderate decrease in plate voltage without a sacrifice in output, the best value of the load resistance is less than that found before. This is shown in Fig. 50 in which the maximum output of the UX-120 tube is found at $R_0 = 6{,}500$ ohms; that is, $R_0 = r_p$. The grid-bias voltage for the UX-120 tube at 135 volts is 22.5 volts. With this value, the battery voltage may fall to 120 volts before the output is affected very much. At 120 volts the best load is found to be $R_0 = 2r_p$.

If a grid-bias voltage of more than 22.5 volts is used with a plate voltage of 135 volts, a greater power output than that shown in Fig. 50 may be obtained with the higher load resistance. The relations between power output and load resistance for the UX-112A and UX-171A tubes also are shown in Fig. 50.

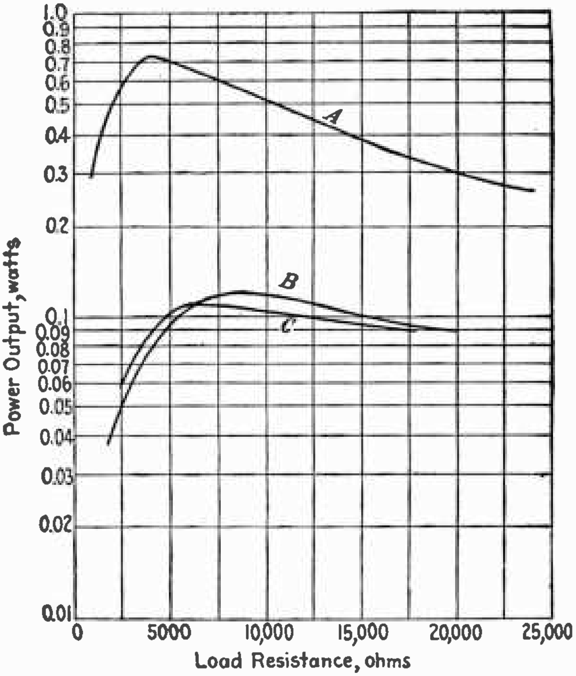


FIG. 50.—Variation of power output with load resistance. Curve *A* for UX-171A tube with grid bias $-40\frac{1}{2}$ and *B*-battery voltage 180 volts. Curve *B* UX-112A tube with grid bias -9 and *B* battery 135 volts. Curve *C* UX-120 tube with grid bias $-22\frac{1}{2}$ and *B* battery 135 volts.

Determination of Power Output and Distortion.—For a UX-171A tube the maximum plate voltage to be supplied is 180 volts and the grid-bias voltage is -40.5 volts. Determinations of the best load resistance, the power output, and the second-harmonic distortion may be made from the curves in Fig. 49.

The value of 3,900 ohms for the load resistance was taken after a consideration of the plate resistance of the tube. This tube resistance may be read directly from the curve of plate resistance against grid-voltage at a plate-supply voltage of 180 volts, or it may be obtained from the slope of the plate current-plate voltage curve at the point *A*. The tube resistance at the operating conditions represented at *A* is equal to the reciprocal of the slope of the curve at *A*. To get the curve slope at *A*, a line *GH* is drawn through *A* parallel to a tangent to the curve for $E_c = -40$ volts. If a triangle such as *HGK* is constructed, the slope of the curve is given by *GK*/*HK*, and the reciprocal of the slope, or the tube resistance, is *HK*/*GK*. Numerically, this tube-plate resistance is equal to $\frac{216.5 - 158.5}{0.038 - 0.008}$ or 1,950 ohms. A load resistance of twice the tube resistance is, therefore, 3,900 ohms.

The power output is equal to the product of the effective values of the alternating plate voltage and the alternating plate current. These values are determined by the intersection of the load line *CAB* with the line of minimum plate current. Thus in Fig. 49 the load line intersects the line for minimum plate current at the point *B* which falls on the curve for $E_c = -80$ volts. This corresponds to a *maximum* negative grid swing of 80 − 40.5 or 39.5 volts. A positive swing from the point *A* would extend to the point *C* on the curve for $E_c = -1$ volt, as 40.5 − 39.5 = 1.0 volt. The fluctuating plate voltage as defined by these voltage limits has a value of 250 volts at the point *B* and 96 volts at the point *C*. The alternating component of this fluctuating voltage has an amplitude of $\frac{250 - 96}{2}$ or 77 volts and an effective value of 0.707 × 77 or 54.4 volts. The fluctuating plate current defined by these limits has a value of 0.001 ampere at *B* and 0.039 ampere at *C*. Its *alternating component* has an amplitude of $\frac{0.039 - 0.001}{2}$ or 0.019 ampere and an effective value of 0.0134 ampere. The power output, therefore, which is the product of the effective values of voltage and current, is equal to 54.4 × 0.0134 = 0.73 watt or 730 milliwatts.

The second-harmonic distortion (page 375) depends on the difference between the average fluctuating current and the steady plate current. It may be stated as a percentage of the fluctuating plate current by the expression

$$\text{Distortion} = \frac{\frac{1}{2}(I_{\max} + I_{\min}) - I_0}{I_{\max} - I_{\min}}.$$

The meaning of the various terms in this equation is shown in Fig. 51. Numerically, the distortion $= \frac{\frac{1}{2}(0.039 + 0.001) - 0.0185}{(0.039 - 0.001)} \times 100 = 3.9$

per cent. There are several ways of reducing this distortion, such as decreasing the input signal voltage, increasing the load resistance, or slightly decreasing the grid-bias voltage and at the same time reducing the input voltage. Such changes, however, also reduce the power output.

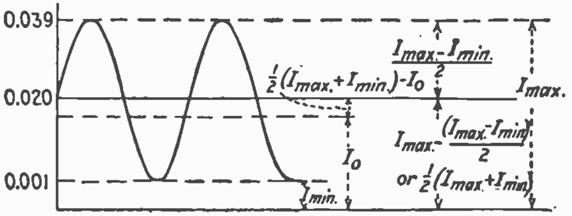


FIG. 51.—Graphical representation of the factors determining distortion in tubes.

The maximum undistorted power output of a number of tubes in common use is given in the table on page 383.

The calculation of the output characteristics for other types of tubes such as the UX-120, UX-222, UX-201A, UX-112A, and UX-245 may be made from groups of curves showing the variations of plate current with plate voltage as in Figs. 52, 53, 54, 55, and 55*a*.

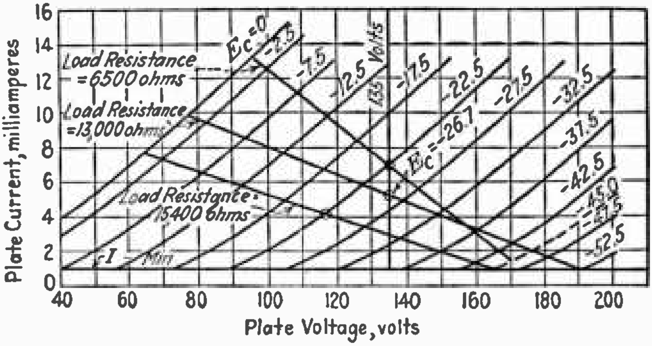


FIG. 52.—Curves for calculating power output for UX-120 tube.

Voltage Amplification of High-resistance Vacuum Tubes.—The curves showing the variations of plate current with plate voltage in Fig. 56 may be used for computing the plate current, the voltage across the tube, and the voltage amplification of a UX-240 tube under various conditions of opera-

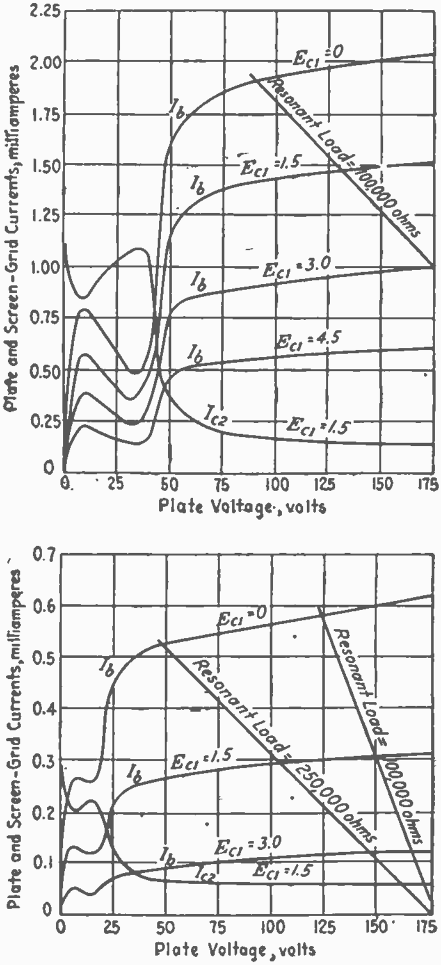


Fig. 53.—Curves for calculating power output for UX-222 tube for grid-screen voltage +45 volts and also $+22\frac{1}{2}$ volts.

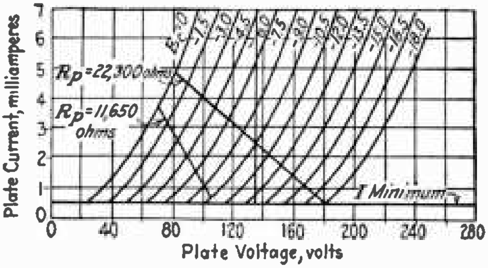


FIG. 54.—Curves for calculating power output for UX-201A tube.

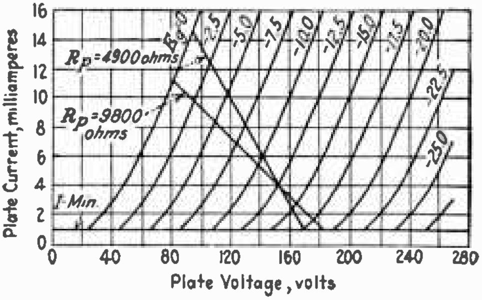


FIG. 55.—Curves for calculating power output for UX-112A tube.

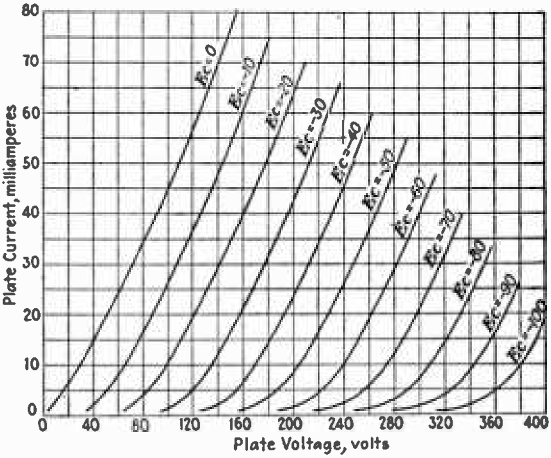


FIG. 55a.—Curves for calculating power output for UX-245 tube.

tion. The voltage amplification per stage with a plate-supply voltage of 180 volts and a plate-resistance unit of 0.3 megohm is determined with the aid of a load line, as, for example, the line *AB* which is drawn at the bottom of the 180-volt ordinate parallel to the reference line for a plate-resistance unit of 0.3 megohm. The tube has a range of operation along the line *AB* as the grid voltage is varied from zero to the point of "cut-off" which occurs at $E = -6$ volts. A value of grid-bias voltage should be chosen near the middle of this range in order that the "swing" of the grid toward the $E_c = 0$ line may be approximately equal to its swing toward the point of cut-off. In this case the proper grid-bias voltage is -3 volts, and the *point of operation* is at *C*. If now an alternating voltage having a maximum value of 1 volt is impressed on the grid circuit, the grid will swing from the line corresponding to $E_c = -2$ volts to the one for $E_c = -4$ volts.

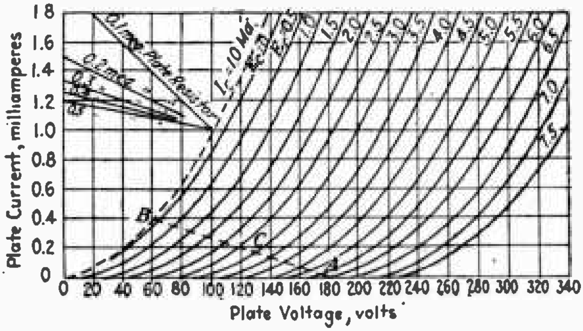


FIG. 56.—Curves for calculating plate current, voltage across tube, and voltage amplification for UX-240 (high resistance) tube.

The load line intersects the grid-bias voltage line for $E_c = -4$ volts at the point where $E_p = 147$ volts and the line for $E_c = -2$ volts at 108 volts. The voltage amplification *A* may then be found from the relation

$$A = \frac{147 - 108}{4 - 2} = 19.5 \text{ per stage.}$$

The voltage across the tube is 130 volts and the plate current taken by the tube is 0.165 milliampere. Figure 57 shows the curves of voltage amplification and direct-current voltage across the tube which have been calculated in this way. One set of curves is for a plate-supply voltage of 135 volts and the other for 425 volts. The plate-resistance unit used with

TABLE XXX.—MAXIMUM UNDISTORTED OUTPUT OF VACUUM TUBES

Type	Plate voltage	Grid voltage	Amplification factor	Plate current, milliamperes	Maximum alternating input voltage, effective volts	Best load resistance, ohms	Maximum, undistorted power output, watts
UX-199......	90	− 4.5	6.5	2.5	3.18	15,250	0.007
UX-199......	90	− 7.5	6.45	1.3	5.30	32,000	0.014
UX-201A.....	90	− 4.5	8.5	2.0	3.18	15,000	0.014
UX-201A.....	90	− 6.0	8.4	1.2	4.24	30,000	0.017
UX-201A.....	135	− 9.0	8.4	2.55	6.36	22,000	0.055
UX-226......	135	−12.0	8.2	3.0	8.48	20,000	0.060
UX-226......	180	−16.5	8.2	3.8	11.58	20,000	0.160
UY-227......	135	− 9.0	8.2	5.0	6.36	20,000	0.055
UY-227......	180	−13.5	8.2	6.0	9.54	18,000	0.140
UX-120......	135	−22.5	3.3	7.0	15.9	6,660	0.105
UX-112A.....	90	− 4.5	8.0	5.2	3.18	5,700	0.029
UX-112A.....	135	− 9.0	8.0	7.2	6.36	7,000	0.137
UX-112A.....	157.5	−10.5	8.0	9.3	7.42	9,000	0.181
UX-112A.....	180.0	−13.5	8.0	9.0	9.54	8,800	0.308
UX-171A.....	90	−16.5	3.0	11.0	11.58	4,000	0.105
UX-171A.....	135	−27.0	2.9	16.0	19.10	4,000	0.320
UX-171A.....	180	−40.5	2.9	20.0	28.60	4,000	0.710
UX-210......	135	− 9.0	7.5	5.0	6.36	15,000	0.064
UX-210......	250	−18.0	7.5	11.5	12.72	11,000	0.340
UX-210......	400	−35.0	7.5	16.0	24.80	11.000	1.340
UX-231......	135	−22.5	3.5	8.0	15.90	4,000	0.170
UX-245......	180	−33.0	3.5	26.0	23.40	3,800	0.750
	250	−50.0	3.5	32.0	35.46	3,800	1.600
UX-250......	250	−45.0	3.8	28.0	31.91	4,200	0.900
UX-250......	350	−63.0	3.8	45.0	44.68	3,800	2.350
UX-250......	400	−70.0	3.8	55.0	49.64	3,600	3.250
	450	−84.0	3.8	55.0	59.57	3,600	4.050

NOTE.—The values given in this table are based on three assumptions: (1) No current is permitted to flow to the grid, (2) the impedance of the load is adjusted for the best value to suit the tube, (3) a distortion of not more than 5 per cent is introduced by the effect of the second harmonic.

such high voltages must have a sufficiently large value to limit the voltage on the tube to 180 volts. The advantages of using such high voltages are that the amplification per stage is increased and that the distortion caused by the second harmonic is decreased.

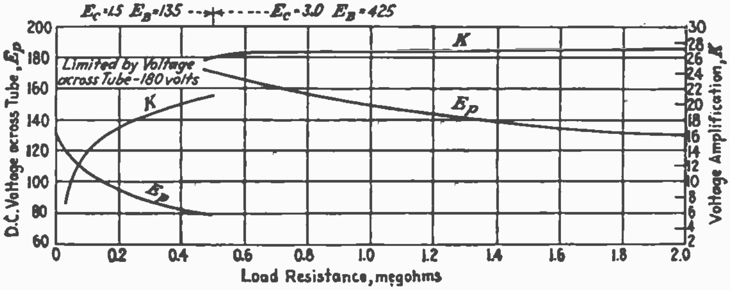


FIG. 57.—Curves of calculated voltage amplification and voltage across UX-240 tube.

Test for Distortion.—When a distorting component is present in a fluctuating plate current, it may be detected by the indication of a direct-current ammeter which is connected into the plate circuit as the input voltage is varied. If there is not enough external series resistance in the plate circuit to minimize this distortion, the ammeter will show an increase in reading as the input voltage increases, as, for example, on a loud radio signal. As the amount of resistance is increased, the change in the reading of the ammeter becomes less and less on loud signals, showing that essentially distortionless amplification is being obtained.

Loud-speaker as a Load.—In a radio receiving set for the reception of broadcasting, the usual impedance load on the last amplification tube is a loud-speaker, which requires a relatively large amount of power in order that it may produce a satisfactory volume of sound. The direct-current resistance of the coils of the average loud-speaker is about 1,000 ohms; but the impedance of a loud-speaker, that is, its resistance to the varying plate current of the output tube, is much higher. This value of impedance of a loud-speaker may vary from 1,000 ohms at zero frequency to 30,000 or 40,000 ohms at 5,000 cycles per second. The average impedance of a loud-speaker, such as the Western Electric, is about 4,000 ohms. As improvements have been made in the range of frequencies over which the loud-speaker responds, the sensitivity of the device has been reduced, with the result that an increase in power is necessary. Hence, the necessity for a determination of the power available and the distortion introduced under various load conditions. With such information, the type of tube and loud-speaker may be chosen for best results.

Although the calculations in the previous paragraphs were carried out with a resistance load to simplify the solutions, they may be applied directly with sufficient accuracy for practical design work. The results which have been computed for a range of resistance loads may be used for the corresponding impedance range of the loud-speaker over the useful band of audio frequencies.

A tube having a maximum undistorted power output of at least 0.1 watt should be used with a loud-speaker of average sensitivity for home reception. A lower power output will cause appreciable distortion. An available power output up to 0.5 watt is very desirable, if the required B-battery power can be supplied conveniently. With such additional reserve power the quality of reproduction is not affected if the volume is increased, or if the sensitivity of the loud-speaker is poor, or if the B voltage is less than the rated value, as in the case of run-down dry batteries.

Tubes with low plate resistances give the best quality of reproduction, unless the output transformer is made with a step-down ratio. This construction, however, is not practical unless ample power output is available, as with the UX-210 tube when it is operated at a high voltage. The UX-171A tube gives the best quality of reproduction with the magnetic loud-speakers because its plate resistance is less than that of any other tube operating at voltages under 200 volts. The plate resistance varies but little over a wide range of B voltage, and, therefore, the quality of reproduction is not affected much by plate- and grid-voltage changes, provided the tube is not overloaded by setting the volume control of the receiving set so high that the input voltage becomes excessive.

Choice of Power Tubes.—The factors which should be considered in the selection of a power tube are (1) the input voltage at the detector, (2) the required amount of power output, and (3) the available supply of power.

The solution of this problem is simplified by the use of the curves (General Radio Company) in Fig. 58 showing the relation between the power output and *peak* grid voltage for a number of tubes used for amplification. It is assumed that a peak voltage equal to the grid-bias voltage may be used and that the amplification per stage is equal to $0.9 \times u \times$ the transformer ratio. Further, it is assumed that the voltage in the plate circuit of the detector is equal to 0.3 volt.

The curves show that for a power output greater than 10 milliwatts, the input voltage must be in excess of 3 volts; that is, when considerable power is desired, the power tube cannot be operated directly from the detector. For input voltages up to 10 volts the UX-112A tube is better than the others.

The use of the curves may be illustrated by several *examples*. The following method will show how a "power stage" is added to a one-stage audio-frequency amplifier which has a UX-201A tube and a transformer with a ratio of 1:2.7, when there is no restriction on the power supply. Under these conditions, the signal voltage available at the primary of a second transformer is 0.3 × 2.7 × 0.9 × 8 = 5.8 volts. If this second transformer has also a ratio of 1:2.7, the voltage at the grid of the power tube is 5.8 × 2.7 = 15.7 volts. A UX-112A tube would be overloaded by this voltage. At such a low input voltage, however, other tubes would not provide a greater output than could be obtained by operating the UX-112A tube at a slightly reduced input voltage to avoid overloading. If, on the other hand, the second transformer has a ratio of 1:5.95, the input voltage becomes 5.8 × 5.95 = 35 volts, which is suitable for a UX-210 tube; but if the plate-supply voltage had been limited, a UX-171A tube or two of these tubes in parallel would be used.

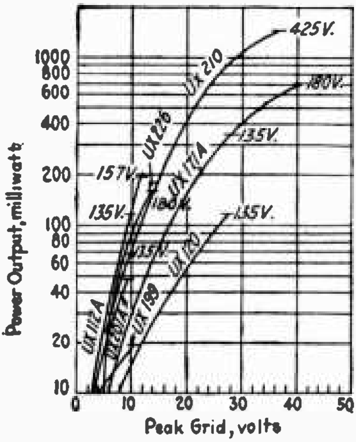


FIG. 58.—Curve showing relation between power output and peak grid voltage of amplification tubes.

Again, a power tube may be selected for a battery-operated receiving set using 3-volt tubes with an available plate supply of 135 volts, the receiver having a transformer with a ratio of 1:2.7 in the first stage, and another transformer with a 1:6 ratio in the second stage. In this case, the voltage at the grid of the power tube is 0.3 × 2.7 × 0.9 × 6 × 6 = 26 volts. Here, the battery requirement limits the selection to a UX-210 tube which would be overloaded by a grid input of 26 volts. It is necessary, therefore, to use either a reduced voltage input or a low-ratio transformer in the second stage. If it is possible to have a separate power stage, with alternating-current supply for the power-tube filament and no restrictions on plate voltage, a UX-210 tube could be used. High plate voltage could be avoided by a parallel or push-pull connection.

The last *example* illustrates the design of a complete amplifier using a UX-210 power tube. The curve for the UX-210 tube shows that a voltage input of 35 volts is necessary. Then, the required *gain*, that is, the ratio of the voltage in the grid circuit of the power tube to the voltage in the plate circuit of the detector tube, is 35 ÷ 0.3 = 117. A combination of a transformer with a 1:2.7 ratio, a UX-201A tube, and another transformer also with a 1:2.7 ratio gives a gain of 53, which would not be sufficient. A transformer with a 1:2.7 ratio combined with a UX-201A tube and a second transformer with a 1:6 ratio gives a gain of 118, which is just sufficient but is undesirable because no factor of safety is provided. A stage of impedance coupling does not give so much voltage amplification as a stage of transformer coupling. A combination of a double-impedance coupling and a UX-201A tube in the first stage, a double-impedance coupling and a UX-201A tube in the second stage, and a double-impedance coupling in the third stage gives a gain of about 49 which would not be sufficient. A similar combination with the last impedance replaced by a transformer with a 1:2.7 ratio gives a gain of 147 volts. An even better arrangement is obtained if a transformer with a 1:6 ratio is substituted for the impedance coupling in the combination just described, so that a gain of 330 is obtained, this voltage being high enough to permit the operation of the detector tube with a lower signal voltage than in the other cases.

Part 5

USE OF VACUUM TUBES AS OSCILLATION GENERATORS

Explanation of Action as an Oscillator.—The three-element vacuum tube, connected in a suitable circuit, may be used as an *oscillator* to establish and maintain an alternating current of constant frequency. The constants of the circuits may be designed to cover a frequency range of from one cycle per second to several hundred million per second. The oscillating vacuum tube is practically the only device available for providing a supply of high-frequency power above 50 kilocycles. The usual detector or amplifier tube may be used as an oscillator, but for large outputs of power an *oscillator tube* is necessary.

The operation of simple continuous-wave radio-transmitting sets (page 455) as well as that of heterodyne receiving sets (page 408) depends on this action. In laboratory and industrial work the vacuum-tube oscillator finds application as a source of pure alternating current of constant amplitude. The production of such an alternating current depends on the control which the grid voltage exerts on the plate current; that is, a small amount of energy applied to the grid controls a large output from the plate battery. Several mechanical illustrations of this action may be given. Thus, a steam hammer is controlled by applying a very small force to the steam valve through an operating handle. The steam valve allows the boiler pressure to act. The action may be made automatic by an arrangement which moves the valve when the hammer reaches the end of its stroke. Here, a portion of the power in the controlled circuit is put back into the controlling circuit to maintain the action. In the case of the vacuum tube, the grid corresponds to the steam valve and the plate-battery voltage corresponds to the steam pressure.

Another mechanical illustration is that of the action of a clock. As the pendulum swings it works the escapement which permits the main spring to deliver a push to the pendulum during each swing in such a direction as to increase the extent or amplitude of the swing. When the friction of oscillation becomes equal to the impulse given by the spring, the amplitude of oscillation will stop increasing and remain constant. In the case of the vacuum tube, the grid corresponds to the clock escapement, the plate battery corresponds to the main spring, and the current in the oscillating circuit, which is connected to the plate of the tube, corresponds to the pendulum. The current in the oscillating circuit reacts on the grid so as to change the value of the voltage across the grid circuit. This change in grid voltage produces a change in the plate-battery current, which, in turn, acts on the oscillating circuit so as to increase the oscillating current. This action continues until a balance is reached between the losses due to radiation and heat and the power supplied by the tube. Beyond this point, the amplitude of the oscillating current remains constant in value.

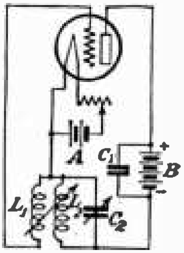


FIG. 59.—Simple oscillator for producing alternating current.

Simple Oscillator.—If a certain portion of every oscillation produced in the plate circuit is put back into the grid circuit in the correct time relation, the pulsating-current wave generated in the plate circuit will be continuous.

A simple arrangement for producing an alternating current by the use of a vacuum tube is shown in Fig. 59. The inductance L_2 and the condenser C_2 have values such that their natural period of vibration corresponds to the desired frequency. The inductance, or the capacity, or both, may be variable if it is desired to change the frequency of the current. The inductance coil L_1 which is coupled to L_2 receives some energy from the oscillating circuit L_2C_2. The coupling coils L_1 and L_2 must be connected in such a manner that the oscillations in the grid circuit assist those in the plate circuit. The degree of coupling must be such that the small amount of energy transferred to the grid circuit will, when amplified, maintain the variations of current and cause the plate oscillations to be continuous. The first electrical disturbance in the oscillating circuit might be caused by a movement of electrons in the tube as a result of a change in the capacity of the circuit, or because of the flow of a small current when the A or the B battery circuit is closed. These weak oscillations in the oscillating circuit will induce an alternating voltage in coil L_1 which acts on the grid and produces variations in the plate current flowing through the oscillating circuit. If the coupling between the coils is correct, the original oscillations are *reinforced.* Although the amplitude of the current during the first cycle may be small, the additive effect of the feed-back (page 304) action increases the amplitude of each successive wave. This increase continues until the energy generated is just sufficient to maintain a current of a certain strength. Beyond this point a pure unvarying wave of alternating current is produced in the coil L_1 or any other coil in a circuit coupled to the plate circuit. Usually, the constant state is reached in a very small part of a second after the operation of the tube is started. The frequency of the alternating current then flowing in the circuit is very nearly that of the natural period of the oscillating circuit. The operation of the tube is quite like that of a regenerative amplifier, because the tube actually amplifies the small amount of energy transferred from the plate circuit to the grid circuit.

A current in the plate circuit sets up, in the L_2C_2 circuit, a voltage which is 90 degrees out of phase (page 74) with the plate current, provided that the resistance of the L_2C_2 circuit is very small. The oscillating current in the L_2C_2 circuit is in phase with the voltage in this circuit because the L_2C_2 circuit is considered to be non-reactive at the frequency of oscillation. The oscillating current induces in the grid coil L_1 a voltage which is 90 degrees out of phase with that current; that is, the plate circuit reacts on the grid circuit in such a way that the induced grid voltage is in phase with the plate current.

Detection of Oscillating Condition.—The most accurate and absolute test to determine when a tube is oscillating is to use a sensitive radio ammeter in the oscillating circuit. The meter will show a reading when the oscillating current is established.

In the circuit of a transmitting set the value of the alternating current generated may be obtained by an ammeter placed in series with the condenser in the plate circuit shown in Fig. 60. The ammeter placed in this way can indicate only alternating current; but as it is placed in the coil circuit it shows the value of the continuous plate current even if the circuit does not oscillate. The ammeter indicates a value of $\sqrt{I^2 + I_p^2}$ where I_p is the steady portion of the plate current and I is the effective alternating current. Usually the value of I_p is small compared to I, so that the ammeter readings are practically the same in the coil circuit as in the condenser circuit.

The amount of alternating current generated by an oscillating tube in a receiving set is too small to be read on the scale of any but an expensive ammeter. Ordinarily it is necessary merely to determine whether the tube is oscillating and not the amount of current. For this purpose a simple test is sufficient. If one finger is kept on the filament side of the condenser in the grid circuit, as shown in Fig. 61, and another finger is touched to the grid side of the condenser, there will be a click in a pair of telephone receivers in the plate circuit when oscillations are being produced and another click when the finger is removed. The circuit is not oscillating if no click is observed.

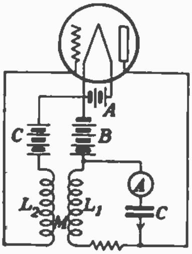


FIG. 60.—Ammeter in series with condenser in plate circuit to read plate current.

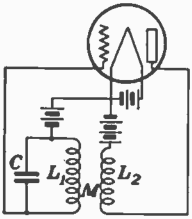


FIG. 61.—Simple test for oscillation.

As the coupling is increased in a regenerative receiver (page 403), a critical value is reached at which oscillations begin. At this point a slight "plucking" sound may be heard in the telephone receiver.

Typical Oscillator Circuits.—There is a great variety of circuits in which the plate circuit is coupled back to the grid circuit in such a way as to supply a small amount of power to the grid and make the surplus available for use in an external circuit in the form of continuous oscillations.

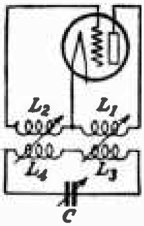


FIG. 62.—Meissner oscillating circuit.

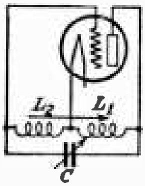


FIG. 63.—Hartley oscillating circuit.

This feed-back action (page 304) can be obtained by the use of (1) direct coupling from the plate back to the grid circuit, (2) inductive coupling, or

(3) electrostatic coupling. The main requirement for continuous oscillations is that the voltage induced in the grid circuit must produce variations in the amplitude of the plate current which are sufficient to maintain the voltage in the grid circuit.

A number of the usual arrangements are shown in Figs. 62 to 66. In Fig. 63 L_1 and L_2 may be coupled together if desired, and in Fig. 64 such coupling is usually necessary in order that the voltage applied from the plate circuit may maintain the oscillations. In Fig. 65 the coupling is necessary in order to obtain the control of the grid voltage because L_2 is not in the oscillating circuit. A reversal of the coil connections in these circuits (except the "Colpitts," Fig. 66) usually will change the phase relations.

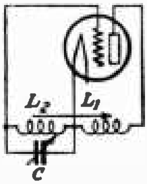


Fig. 64.—Tuned-grid oscillating circuit.

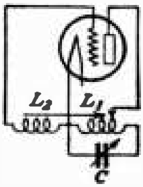


Fig. 65.—Tuned-plate oscillating circuit.

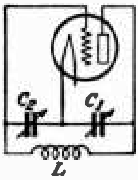


Fig. 66.—Colpitts oscillating circuit.

Conception of Negative Resistance.—In an ordinary oscillating circuit, the circuit resistance in ohms is proportional to the rate of energy consumption in the circuit. In an oscillating circuit used with a vacuum tube, as described above, the tube through its operation "feeds back" energy to the circuit. The rate of such feed-back may be considered as a *negative* resistance which tends to neutralize the ohmic resistance of the oscillating circuit. If this negative resistance is less than the ohmic resistance of the oscillating circuit, the oscillations are damped. The extent of this damping, however, is less than if no negative resistance is introduced. If the negative resistance is equal to the ohmic resistance, the oscillations are maintained indefinitely once the process is started. If the negative resistance is greater than the ohmic resistance, the circuit will start oscillating of itself. The amplitude of oscillations will increase until the capacity of the circuit to supply energy is reached.

Requirements for Oscillations.—Some of the general conditions for oscillation have been stated. In order to examine the requirements more in detail, it is necessary to consider the character of the plate current and the influence of the constants of the circuit.

The varying plate current may be taken to consist of two parts, a direct current and an alternating current. It is this alternating current in the oscillating circuit which gives rise to the voltage acting on the grid and maintaining the oscillations. In order to bring this about, the alternating plate current and the grid voltage must be in phase; that is, when the alternating plate current reaches its maximum positive value, for example, the total value of plate current is high and the oscillating current must act through the grid coupling in such a manner that the grid voltage is at a positive maximum. If the voltage applied to the grid produces, by means of feed-back, an equal or greater voltage on the grid, the tube will oscillate.

A determination of the effect of the circuit and tube constants upon the requirements for oscillation may be made in a simple manner. A circuit such as that of Fig. 64 may be used with the assumption that the oscillations are small in value, that the impedance of L_1 is small compared to the tube resistance r_p, and that the characteristic curve (page 291) is a *straight line.* The alternating plate current then is

$$I_p = \frac{uE_g}{r_p}$$

where E_g is the alternating voltage applied to the grid and u is the *amplification factor.* The voltage induced in the grid circuit by means of the *mutual inductance M* depends on this plate current I_p and is equal to I_pwM or, by substitution, $uE_gwM \div r_p$. This voltage causes a current to flow through the resistance R of the tuned-grid circuit equal to uE_gwM/Rr_p. This feed-back current multiplied by wL_2 or by $1/wC$ gives the value of the voltage E_g' impressed on the grid through the feed-back action; that is, $E_g' = uE_gM/Rr_pC$. The tube will oscillate if E_g' is equal to or greater than E_g. Since

$$\frac{E_g'}{E_g} = \frac{uM}{Rr_p},$$

the condition for oscillation is given by the statement that uM/Rr_pC must be equal to or greater than 1; that is, the tendency for the generation of oscillations is increased by increasing u or M or decreasing R or r_p or C.

The circuit shown in Fig. 65 requires a somewhat different expression for the oscillation requirements. In this case, the oscillating circuit L_1C has a resistance R. In a freely oscillating circuit like L_1C, when not connected to a tube, the resistance R determines the action. It may be shown that the oscillating circuit L_1C of Fig. 65, however, behaves as if its resistance were $R + \frac{L_1 + uM}{Cr_p}$; that is, the oscillating-circuit resistance is increased by an amount $\frac{L_1 + uM}{Cr_p}$. The quantities L_1, C, u, and r_p are positive, but

M may be either positive or negative, depending on the coupling connections between the coils. If M is positive, the equivalent resistance of the oscillating circuit is increased and the damping of oscillations is more rapid than would be the case in a freely oscillating circuit. If M is negative, the equivalent resistance is decreased and may be made equal to zero or even negative. In order that the quantity $\frac{L_1 + uM}{Cr_p}$ may be equal to $-R$, the term M must be equal to or greater than

$$-\frac{Cr_p}{u}\left(R + \frac{L_1}{Cr_p}\right).$$

A comparison of these two relations indicates that oscillations occur more readily when the oscillating circuit is in the grid circuit than when it is in the plate circuit. If the equivalent resistance is negative, the amplitude of the oscillations increases up to the energy limits of the tube. Beyond this point the amplitude is constant and the current has a frequency of $f = \frac{1}{2\pi}\sqrt{\frac{R + r_p}{r_p L_1 C}}$. As the term $\frac{R}{r_p}$ is generally small, the frequency is very nearly equal to the *natural frequency* of oscillation of a freely oscillating circuit L_1C, which is given by $f = \frac{1}{2\pi}\sqrt{\frac{1}{L_1C}}$.

Frequency of Oscillation.—When the grid circuit is connected to an outside source of power, the tube will reproduce in the plate circuit the frequency which has been impressed on the grid circuit. But when the tube is self-excited by coupling the grid and the plate circuits together, the frequency on the grid is the same as that which is produced in the plate circuit. The frequency of operation then is determined by the electrical constants of the circuit and corresponds to the natural frequency of a mechanically vibrating body. This critical frequency is known as the *resonant* or *natural frequency*.

The frequency of oscillation of the circuit shown in Fig. 63 is

$$f = \frac{300{,}000{,}000}{1{,}884\sqrt{(L_1 + L_2)C}}$$

where f is the frequency in cycles per second, L_1 and L_2 are the inductances of the coils in microhenrys and C is the capacity of the condenser in microfarads. If there is any magnetic coupling between the coils and if M is the mutual inductance of the two coils, the expression for frequency becomes

$$f = \frac{300{,}000{,}000}{1{,}884\sqrt{(L_1 + L_2 + 2M)C}}.$$

Constancy of Oscillating Frequency.—The frequency of the oscillations is affected to some extent by the resistance of the grid and the plate circuits and the amplification of the tube. A change in the filament current or in the plate voltage, therefore, will affect the frequency sometimes as much as one per cent. After the transmitter has been in use for an hour or two, and if there is not much drain on the batteries, the change in frequency may be as low as a few cycles per second in an hour.

Frequency Control with Piezo-electric Crystal.—The vacuum-tube transmitter used in broadcasting must generate a constant frequency. Accurate maintenance of frequency is possible by the use of a piezo-electric crystal control if the temperature of the crystal is kept constant.

Certain crystals such as quartz possess the property of developing an electric charge when they are put under pressure, and *vice versa;* that is, they change in shape under the action of an electrostatic field. Consequently, the frequency of oscillation of a vacuum tube may be controlled by the mechanical vibration of a quartz crystal.

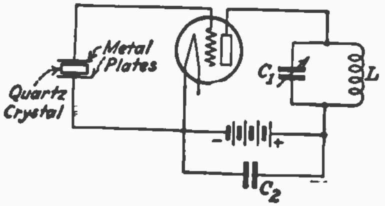


FIG. 67.—Device for frequency control with quartz crystal.

This effect is obtained by an arrangement such as that of Fig. 67. The condenser consisting of a small disk of quartz between two metal plates is placed in the grid circuit of a vacuum tube. If an alternating potential difference is established between the two plates of the condenser, the crystal will vibrate, mechanically at its natural period. When the plate circuit is tuned electrically to the same frequency as that of the crystal the circuit will oscillate and the variation of the capacity C_1 does not affect the frequency of oscillation. A small *master oscillator* of this kind may be used to excite a large power tube and thus to control the frequency accurately.

Variation of Oscillation with Coupling.—As the coupling between the coils of the circuits in Figs. 62 to 66 is made looser, a greater alternating current in the coil L_1 is required for a given alternating grid voltage induced in the coil L_2. Thus, as the coupling is reduced, the oscillation increases until the plate current varies between the saturation value and approximately zero, as shown in Fig. 68. When the condition of stable oscillation has been reached, the oscillating current has a value of $\frac{I_s}{2w}\left(CR + \frac{L_1}{r_p}\right)$ where I_s is the saturation current. Since the plate current cannot increase beyond this upper value, an additional reduction of the coupling will decrease the induced grid voltage until the action stops.

A different result is obtained as the coupling is increased. Under this condition, the oscillations decrease and stop when the coupling is too tight. The best value of coupling, then, for allowing oscillation to be greatest, is between the upper and lower limits, at each of which the oscillations reduce to zero.

When the coupling between tuned circuits is close, oscillations of two different frequencies may take place. When the direct-coupled circuits are used, harmonics (page 72) are found in the antenna current. Harmonics are not generated at frequencies below the fundamental; or in other words, at wave lengths higher than the fundamental. Consequently, it is advantageous to sacrifice efficiency, when coupled circuits are used, so that the interference may be decreased.

In some cases, the presence of another oscillation frequency is caused by the distributed capacity (page 86) of coils, the inductance of the wiring, and the tube interelectrode capacities (page 303). This difficulty is minimized in a capacity-coupled circuit as in Fig. 66, because the capacities of the tube electrodes and of the wiring are in parallel with the circuit condensers. Similarly, the circuit arrangement in Fig. 63, in which the internal grid-plate capacity of the tube is in parallel with the capacity C of the oscillating circuit, is suitable for use at high frequencies.

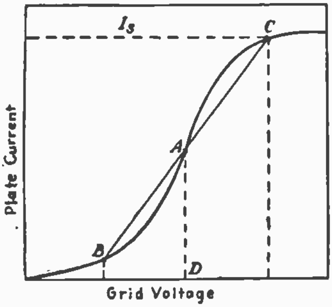


FIG. 68.—Curve showing variation of oscillation with grid voltage.

In most circuits, the coupling between the input and output circuits is adjusted by changing the *mutual reactance* (page 39). When a change in coupling, however, depends on a change in capacity, as in the circuit of Fig. 66, the frequency of the oscillating circuit is affected. One way of avoiding this difficulty is to insert, in series with the inductance, another condenser which may be used to regulate the frequency.

Variation of Oscillation with Grid Voltage.—The operating point A in Fig. 68 is taken at the midpoint of the characteristic curve. Then, if the mutual inductance M has the value given above, the oscillations will start and the grid voltage will vary about the original value D. When the amplitude of oscillations increases until the plate current varies over the line BC, a stable condition is obtained.

Now, if the grid-bias voltage is made more negative so that operation is at the lower end of the characteristic curve, the mutual conductance u/r_p (slope of the curve at the operating point) decreases. This may affect the conditions for oscillation to such an extent that the generation of oscillations will not take place unless the coil coupling is increased.

If a still greater negative grid-bias voltage is used, so that operation takes place on a horizontal part of the curve, the mutual conductance is zero. If the oscillating circuit is started in some way, an alternating voltage is induced in the grid circuit. Variations of this grid voltage, however, do not cause any variations of the plate current. Consequently, the oscillations die away and the tube does not operate.

In practice, however, the grid is not negative enough at all times with respect to the filament to prevent the flow of grid current. For example, when a grid condenser and grid-leak resistance are used to keep the grid negative, the grid becomes positive during a part of the cycle. If the plate becomes *less* positive as the grid becomes *more* positive, the flow of grid current increases, and if, at any instant, the highest positive grid voltage approaches the value of the lowest plate voltage, the plate current is decreased considerably. Consequently, saturation seems to occur at a value of plate current which is lower than the normal value.

It should be noted that the output power increases with the square of the alternating voltage applied to the grid for *small* values of voltage. For *large* values of grid voltage, however, the output power may not vary *directly* with the grid voltage.

Variation of Oscillation with Plate Voltage.—With a given plate voltage, only a certain portion of the filament emission can be utilized, but, with a given emission, an increase in plate voltage increases the output up to the limit of the tube.

The expression which has been given for the condition necessary to generate oscillations may be stated in another form; that is M must be equal to or greater than $\frac{r_p}{u}\left(CR + \frac{L_1}{r_p}\right)$, or $\frac{u}{r_p}$ must be equal to or greater than $\frac{1}{M}\left(\frac{L_1}{r_p} + CR\right)$. The term $\frac{u}{r_p}$, which is the mutual conductance of the tube, is proportional to the plate voltage. The term $\frac{1}{M}\left(\frac{L_1}{r_p} + CR\right)$ also is proportional to plate voltage. Then, since u/r_p must be at least equal to $\frac{1}{M}\left(\frac{L_1}{r_p} + CR\right)$, oscillations will not be generated if the plate voltage is below a value which is determined by the quantities L_1, C, R, r_p, and M.

Practical Arrangement of Circuits.—The location of batteries in a transmitting circuit introduces several matters which must receive consideration. A diagram of a simple Colpitts circuit is shown in Fig. 69. No direct current can pass through the oscillating circuit from the plate to the filament because of the blocking action of condensers C_1 and C_2. The choke coil L_p passes the direct current of the plate battery but blocks the high-frequency portion of the plate current which flows through the oscillating circuit and maintains the oscillations. The inductance of the choke coil is made high so that its impedance may be several times the plate resistance of the tube. The filament is insulated from the plate voltage by the fixed condenser C_g. The capacity of C_g is chosen large enough so that it does not have much effect on the operation of the oscillating circuit. An accumulation of negative charges on the grid is prevented because of the leakage path provided by the grid-leak resistance R_g and the choke coil L_g. The antenna is represented by C_1 with the ground connection near the filament. The coupling to the grid circuit is obtained by the condenser C_2, increased capacity giving decreased coupling. Adjustment of the load resistance is accomplished by moving the tap on the coil L.

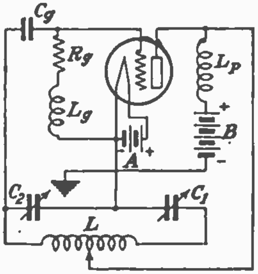


FIG. 69.—Colpitts oscillating circuit arranged for practical operation.

The batteries should be grounded to the same point which is used for grounding the tube circuit. For this reason the batteries and the antenna ground are usually located near the filament. If a ground at another point is used for the batteries, another circuit due to the capacity of batteries to ground will be set up parallel to the oscillating circuit with consequent loss of power and a possible reduction of oscillations.

Circuits for the generation of currents of high frequencies of the order of several hundred million cycles per second are simplified considerably. Sufficient inductance for such circuits is provided by the inductance of the connecting wires, and the internal grid-plate capacity of the tube constitutes the necessary capacity. In fact, the interelectrode capacities of a tube determine, for the most part, the upper limit of frequency which may be obtained.

Conditions for Maximum Current.—The current in the oscillating circuit can be made a maximum when the load in the plate circuit is the proper one for the tube that is used. The load in the plate circuit of an arrangement such as that in Fig. 65, for instance, depends on the inductance L_1, the capacity C, and the resistance of the oscillating circuit to high-frequency currents. The *load resistance* has a high value when the inductance L_1 is large or when the capacity C and the circuit resistance are small; that is, if C is a low-capacity antenna and if the radio-frequency resistance of the circuit is small, the radio-frequency resistance of the load may be above the maximum value for the tube in question. Under these conditions, oscillations will be generated but the current value will not be a maximum. The load resistance may be decreased by adjusting the tap on L_1 so that less inductance is included in the plate circuit. On the other hand, if the capacity of the antenna is high or if the radio-frequency resistance of the circuit is large, the current will have a maximum value when the tap is adjusted so that more inductance is included in the plate circuit. If the filament voltage or the plate voltage is changed, a readjustment of the plate inductance must be made to suit the load to the new operating conditions. Excessive grid voltage may be avoided by adjusting the control for the coupling of the inductance coils.

If the power output of a tube is plotted against the equivalent resistance of the oscillating circuit at the frequency of resonance, it will be observed that the power output has a maximum value when the equivalent resistance is equal to the plate resistance of the tube. The ratio of inductance to the capacity of the oscillating circuit can be determined, if the value of equivalent resistance is known. It is necessary to keep in mind the fact that a condition of maximum output power does not correspond to a condition of maximum efficiency.

Efficiency of Oscillator Tubes.—The efficiency of a vacuum-tube oscillator may be expressed as the ratio of output power to input power. The power expended in heating the filament is not included; in high-power oscillator tubes this quantity is comparatively small, but in low-power tubes it may be greater than the output power. The output power, which usually defines the rating of a power tube, is the product of the square of the radio-frequency current and the radio-frequency resistance of the oscillating circuit. The input power, supplied by the plate battery, is the product of the battery voltage and the battery current. Thus, in the case of the UX-210 tube, which is rated at 7.5 watts, the plate current is 0.06 ampere at a plate voltage of 350 volts, when the tube is oscillating. The efficiency is

$$\text{Eff.} = \frac{\text{output}}{\text{input}} = \frac{7.5}{0.06 \times 350} = 0.357 = 36 \text{ per cent.}$$

Under the best conditions of operation, and when the grid voltage varies about a point near the center of the characteristic curve, half of the battery power is taken in overcoming the internal resistance of the tube, and the other half the resistance losses in the oscillating circuit. Under these conditions, the tube as a transformer of direct current into *pure* alternating current has a theoretical limit of efficiency of 50 per cent. A negative grid-bias voltage may be applied, however, so that the grid voltage varies about a point on the lower bend of the curve. If the plate current flows only during that part of the cycle when the alternating grid voltage is positive, the average plate current is reduced. When the plate takes current, the plate voltage is reduced because of the voltage drop through the external load. Consequently, the amount of power dissipated in the tube itself is decreased. Input power, however, as used in determining tube efficiency, consists of the power dissipated in the tube and of the power supplied to the oscillating circuit. Under these conditions of operation, then, the input power and, in turn, the efficiency, is increased. But as efficiency increases, the output power decreases. The power, in watts, used up in heating the plate is called the *plate dissipation*. The tube should be operated so that the difference between the input and output is not more than the safe plate dissipation as recommended by the manufacturer for continuous operation.

The efficiency of low-power oscillator tubes is about 20 to 35 per cent; of medium-power tubes, about 40 to 60 per cent; and of high-power tubes about 85 per cent. It is obvious, of course, that efficiency varies, also, with the adjustment of the circuit.

Suppression of Oscillations in Multistage Amplifiers.—In an amplifier-tube circuit the internal grid-plate capacity of the tube acts as a feed-back capacity and thus permits the generation of continuous oscillations. This action increases when the frequency of the oscillations generated is high, because then the reactance of the internal grid-to-plate capacity is small. Such feed-back interferes with the proper operation of the amplifier. Oscillations, of course, may be generated, also, because of the action of stray fields upon various parts of a receiver. In many cases, such oscillations may be avoided by shielding the apparatus properly, by placing the units so that their fields do not interlink, or by connecting them so that their fields are reversed.

Several methods of suppressing or minimizing the generation of oscillations due to the internal capacity of a tube have been mentioned on page 371. It will be of advantage to review these briefly, keeping in mind the action of the tube as an oscillator.

The first general method consists of increasing the resistance of the grid circuit, the plate circuit, or both, by inserting a resistance unit. When the resistance thus introduced is greater than the negative resistance due to the feed-back action, the generation of oscillations is suppressed.

Another method, which is similar, depends upon the application of a small positive grid-bias voltage to the grid of the tube. This allows a current to flow in the grid circuit, resulting in an energy loss to counterbalance the introduction of energy into the circuit through feed-back. The disadvantages of this general method are (1) increase of losses in the circuit, and (2) decrease in selectivity.

Another method has the effect of neutralizing the oscillations. The generation of oscillations is favored when the coupling between the grid and the plate circuits is negative, that is, when the equivalent resistance of the grid circuit is less than the resistance of the actual circuit. If, however, a coupling of the opposite kind, referred to as a *positive coupling*, is established between the grid and the plate circuits, its value may be so chosen as to neutralize the effect of the negative coupling. Several types of this method have been mentioned previously. It is well to remember that the use of the screen-grid tube as well as the application of the superheterodyne scheme of reception obviate the need of compensating for the interelectrode capacity of the tubes. It is this characteristic of the screen-grid tube which may lead to its usefulness as an oscillator, because the adjustment of the tuned circuit affords a more positive control of the frequency.

SECTION VIII

RADIO RECEIVING SETS. BROADCASTING AND COMMERCIAL TYPES

Crystal Receivers.—A receiving set using a crystal detector and "head phones" has a range of only a few miles, but under certain conditions it is preferable to a vacuum-tube receiver because of its low cost, absence of operating expense, freedom from maintenance troubles, and good quality. The circuit diagram of a crystal receiver is shown in Fig. 1, a high single-wire antenna (page 180) about 150 feet long being used. The coil L consists of a few turns of heavy wire and has a variable inductance, while the coil L_1 which has many turns of fine wire is arranged so that its coupling (page 35) with the coil L can be varied. This coil L_1 has an inductance of about 200 microhenrys. The condenser C has a variable capacity with a maximum value of about 0.00050 microfarad. The crystal detector D may be one of the types described on pages 124–126. The head phones which are connected as shown are of the high-resistance type and respond to a current as small as one-millionth of an ampere. If a radio signal, consisting of a series of damped (page 91), high-frequency currents, such as are sent

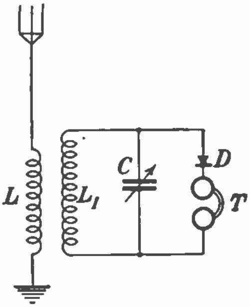


FIG. 1.—Circuit diagram of crystal receiver.

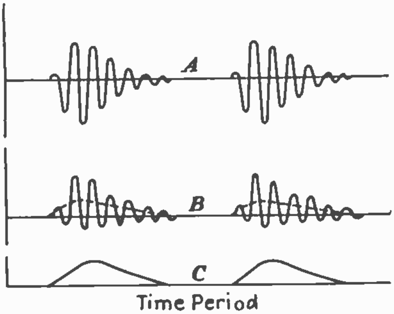


FIG. 2.—Voltage and current wave forms in antenna.

out by a spark transmitter (page 456), sweeps across the antenna, it induces in the antenna a voltage having the form shown at *A* in Fig. 2. A pair of head phones are connected in parallel with a condenser. The condenser is used to by-pass the high-frequency currents around the high impedance of the head phones. The crystal detector *D* has the property of allowing a much greater current to flow through it in one direction than in the other; and, consequently, the form of the current wave flowing in the antenna is as shown at *B* in Fig. 2. The *average antenna current* for one wave train is indicated by the dotted line. The movement of the diaphragms of the head phones will correspond to the form of the average antenna current flowing through them, giving one impulse for each wave train of the signal. Without the crystal detector *D*, there would be no movement of the diaphragm and, therefore, no audible signal.

The crystal receiver is actuated by the current induced in the antenna, and only a small portion of this current passes through the head phones. Under average conditions of operation, the field strength must be at least one millivolt per meter of elevation of the antenna in order to obtain a satisfactory volume of sound from the head phones.

One-tube Receiver.—The circuit diagram of a receiving set using a single three-element vacuum tube as a detector is shown in Fig. 3. The capacity of the grid condenser is usually 0.00020 microfarad. The grid leak may be of the variable type, or a fixed resistance of about two megohms may be used. The values of the A- and B-battery voltages depend on the type of vacuum tube that is used and may be determined from the table of vacuum tubes on page 296.

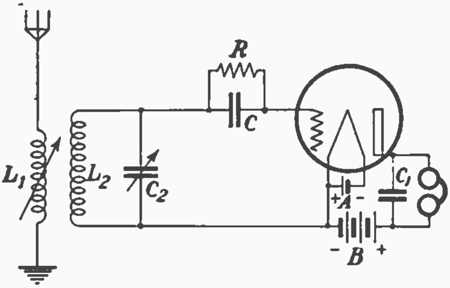


FIG. 3.—Circuit diagram using three-element vacuum tube as detector.

A three-element vacuum tube when used as a detector in a receiving set is more reliable and sensitive than a crystal detector, and the tuning of the circuit of a single-tube receiver is not so broad as that of a crystal receiver. The relative sensitivity may be based on a comparison of the antenna currents for a given volume of reception. On this basis the ordinary vacuum-tube detector gives satisfactory reception on an antenna current about one-fifth of that required for a crystal detector.

Regenerative Receiver.—The circuit diagram of a regenerative receiver is shown in Fig. 4. The plate circuit is coupled to the grid circuit by the coil L_3, known as a *tickler coil* (page 40), with an inductance of about 10 to 20 microhenrys. The variations of the current in the plate circuit thus strengthen the signal current in the grid circuit by providing a feed-back (page 304) which is in phase with the grid voltage. By means of this feed-back arrangement a vacuum tube used as a regenerative detector may be a hundred times as effective as a crystal detector. The coupling between the plate and grid coils is variable and must be of the right polarity. An increase in *regeneration*, obtained by tightening the tickler coil coupling has the effect of decreasing the resistance of the tuned circuit. If the coupling is increased beyond a certain critical value, the resistance of the tuned circuit is said to become "negative" and the circuit goes into oscillation.

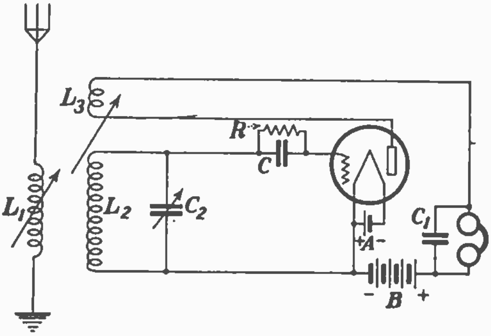


Fig. 4.—Circuit diagram of regenerative receiver.

The impedance of the tuned circuit consists of reactance and resistance. The reactance of the circuit at a given frequency is made zero by the adjustment of the condenser when the circuit is tuned. The resistance of the tuned circuit is decreased by increasing the coupling of the plate coil to the grid coil. Consequently the impedance of the circuit becomes very small and allows the flow of a large current. Beyond the value of *critical coupling* (page 88) the circuit goes into oscillation, and a local current is generated which interferes with the current due to the radio signal. This oscillating current flows also in the antenna circuit to which it is transferred by induction, and the antenna current radiates a radio wave of a frequency determined by the constants of the tuned circuit. Although the amount of power radiated is very small, it interferes with all the radio receiving sets in its immediate vicinity and may be heard as far as a mile away. If the tickler coupling is set below the value at which oscillations are produced, as the receiver is tuned, no interference will result.

A number of other arrangements are in use for the control of regeneration. The tickler coil may be fixed in relation to the grid coil but connected to a variable condenser for the purpose of tuning. An arrangement quite similar to this is used extensively in *short-wave receivers* (page 438). In the tuned-plate method, regeneration (page 403) is effected through the grid-plate capacity of the tube and is controlled by a variometer (page 40) in the plate circuit. In the resistance-control method, a variable resistance is used in a shunt circuit with a fixed tickler coil and a condenser.

Trend in Receiver Design.—A radio receiving set must be sensitive enough to have a range of several hundred miles with an antenna of ordinary length and height. At the same time it must be selective enough to tune out a strong local radio signal on an adjacent wave length. If it is too selective, however, the quality of reproduction will be impaired because the high notes of music and the speech consonants are cut off. In order that the side bands (page 368) may not be lost, a channel of frequencies having a "width" of about 10,000 cycles per second is necessary in the reception of music and speech.

The quality must be such that audio-frequency signals are amplified equally without distortion at any of the audible frequencies. For average reception an undistorted power output (page 376) of at least 0.1 microwatt is needed, but for good reproduction of very low notes at least 1.0 microwatt is necessary. In most cases at least two stages of radio-frequency amplification are used. The several tuned circuits which are thus provided and the voltage amplification obtained in this way serve to give the necessary selectivity (page 40) and sensitivity (page 409). The voltage amplification in the radio-frequency stages may range from 50 to 10,000, depending on the type of receiving set.

In an audio-frequency amplifier with transformer coupling, a voltage amplification of 20 to 30 per stage may be obtained. In most receivers a power tube (page 311) is used in the output stage (page 367) which can deliver 1 watt or more of undistorted power. One type of loud-speaker is rated at a maximum power input of 10 watts. If the voltage of the input power supplied to the detector tube is high, it is possible to eliminate the first audio-frequency tube and deliver the output power of the detector tube directly to the power tube.

As an indication of probable developments in this direction, it is interesting to note that the pentode (page 308) or five-element vacuum tube has been used to serve as both a detector tube and an "output" tube.

Amplification Unit—Decibel.—It has been customary to express amplification in terms of the voltage, but efforts are being made to adopt the transmission unit which now is called the *decibel* which expresses the amplification in terms of *power*. The formula for the number of transmission units (T.U.) of amplification is

$$\text{Amplification in T.U.} = 10 \log_{10} \frac{P_2}{P_1}$$

where P_1 = the power before amplification, in watts,

P_2 = the power after amplification, in watts.

Thus if the ratio $P_2 : P_1$ is 1,000, or, in other words, if the power is increased 1,000 times, then,

$$\text{Amplification in T.U.} = 30 \text{ decibels.}$$

Radio-frequency Amplifier.—A circuit diagram of a simple tuned radio-frequency amplifier of three stages is given in Fig. 5. Interstage coupling (page 87) is generally obtained by the use of air-core transformers. The secondary coils of these transformers should have an inductance of 200 microhenrys and the condensers which are used with them in the tuned circuits should have a capacity of 0.00030 microfarad; the primary coils should have an inductance of about 10 microhenrys. Fairly close coupling is used between the primary and secondary coils of the transformer. In some receivers the antenna is directly connected to taps on the coil of the first tuned circuit. In others an untuned antenna coil is used and is coupled closely to the grid coil. A few receivers of this type make provision for tuning

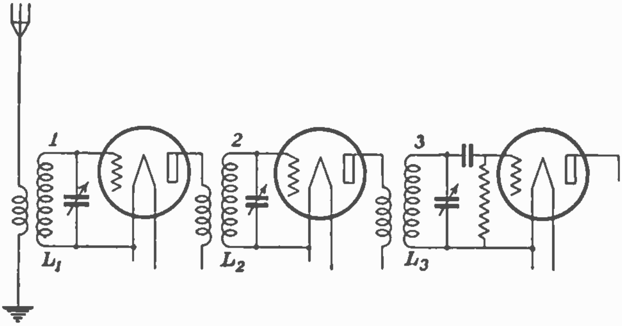


Fig. 5.—Circuit diagram of tuned radio-frequency three-stage amplifier.

the antenna circuit. The difficulty with this circuit is that the tubes tend to set up oscillations in the tuned circuits. Such oscillations produce a marked decrease in amplification. The oscillations are caused by interstage feed-back (page 304), through magnetic and capacity coupling, and through the capacity of the tubes, between the plate and the grid circuits.

Prevention of Feed-back.—The magnetic coupling between the stages can be eliminated if the three coils are arranged so that they have no mutual inductance. This is done either by placing them with their axes at any angle of about 58 degrees to the base line or by locating them so that the axis of each coil is at 90 degrees with each of the others. Both the magnetic and the capacity coupling is eliminated by enclosing each coil in a copper covering which is grounded. Considerable space must be allowed between each coil and its copper covering to avoid impairing the tuning of the circuit.

The effect of the interelectrode capacity (grid to plate) of the UX-201A type of tube is more troublesome as a cause of feed-back than the other two effects. This grid-to-plate capacity, although it has a value of only about 10 micromicrofarads, passes a voltage from the plate circuit into the grid circuit which causes oscillations and interferes seriously with the degree of amplification.

A number of circuit arrangements have been devised to prevent undesired oscillations. For tubes of the UX-201A type the more common of these circuits include the use of grid-circuit resistance, the application of a positive grid-bias voltage, and the introduction of an opposing voltage on the grid. The method of *superheterodyne reception* (page 408), may also be included in such circuits, because it allows the operation of the circuit at a frequency which does not produce excessive feed-back. The use of the screen-grid tube in these circuits may be mentioned also, although here it is the construction of the tube itself which is responsible for a very low capacity in the tube from the grid to the plate.

Regenerative feed-back may be provided in a neutralized (page 371) radio-frequency amplifier by coupling a tickler coil from the plate circuit of the detector tube to the secondary winding of the transformer in the preceding stage. In an arrangement of this kind the antenna will not radiate any radio waves due to oscillations in the tuned-grid circuit of the detector stage, because of the blocking effect of the neutralized stages between this point and the antenna.

Reflex Amplification.—A system of amplification which was developed to reduce the number of tubes required in a multistage receiver is shown in Fig. 6. The radio signal first passes through a number of stages of a radio-frequency amplifier, is detected in a separate stage, and is then returned through some of the radio-frequency stages to obtain audio-frequency amplification. Thus, in Fig. 6 the audio component of the detector plate current is returned through an audio transformer to the grid circuit of the third radio-frequency tube. The audio component of the plate current of this tube goes through an audio transformer to the last (audio-frequency) tube and thence to the loud-speaker. The five tubes used in this way allow three stages of radio-frequency amplification, a detector stage, and two stages of audio-frequency amplification. It is assumed that a tube is capable of such double duty because of the wide discrepancy in the frequencies involved. This use, however, limits the adaptability of the tube to the reception of high frequencies. Suitable fixed condensers are placed across the audio-frequency transformer windings to by-pass radio-frequency currents. The use of these condensers reduces the transformer efficiency and introduces audio-frequency distortion.

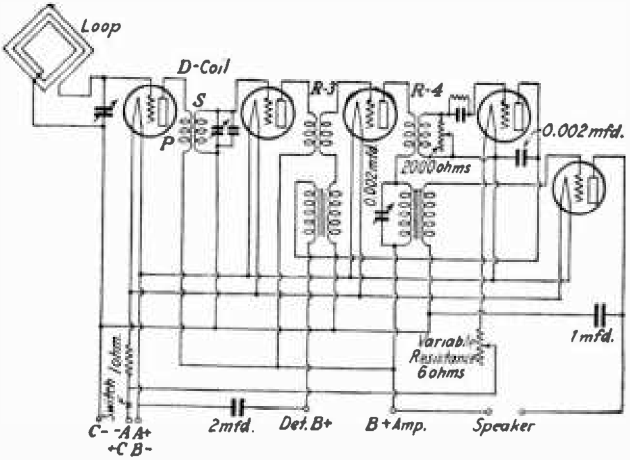


FIG. 6.—Circuit diagram of reflex receiver.

The inverse reflex system was devised to equalize the load on the grids of the various tubes. In a receiver having three radio-frequency tubes, the audio-frequency plate current is returned to the last or third radio-frequency tube and thence to the second tube; that is, the third radio-frequency tube serves also as the first audio-frequency tube and the second radio-frequency tube serves also as the second audio-frequency tube. Since two stages of audio-frequency amplification are ordinarily used, only two tubes may be eliminated by this method regardless of the number of radio-frequency stages in the receiver.

In reflex amplification, although a tube may perform double duty, the actual overall voltage amplification is less than that obtained with single-duty tubes. Considerable difficulty is usually experienced with reflex receivers in attaining stability.

Superheterodyne Receiver.—The operation of a multistage radio-frequency amplifier is effective over only a limited frequency range (page 407). In the superheterodyne receiver the high-frequency alternating current of the received signal is transformed into an alternating current of lower radio-frequency, called the *beat" frequency*, which is better suited to the amplifier. This is done because the tendency to oscillation as a result of the interelectrode capacity of the tubes is less at the lower frequencies. One detector tube is required to reduce the high frequency to the intermediate frequency and another to reduce the intermediate frequency to the audio frequency. The first detector tube may be coupled to a separate oscillator or it may be self-oscillating. The oscillating frequency, combining with the carrier wave of the radio signal, gives a beat frequency of 50 kilocycles per second, for example, which is passed on to the intermediate-frequency amplifying stages, these stages being tuned to this intermediate frequency. The output of the intermediate-frequency amplifier is passed on to the second detector tube in which the intermediate-frequency current is de-modulated, after which it is then passed on to the audio-frequency amplifying stages. A second oscillator tube must be used in connection with the second detector tube for the reception of continuous-wave signals (page 35). Beat frequencies of from 30 to 180 kilocycles per second have been used. At 50 kilocycles the reactance of the grid-filament capacity of a vacuum tube is high enough so that it causes very little interference with the action of the amplifier.

The first oscillator tube radiates energy from the antenna unless it is preceded by a properly balanced circuit. In one type of superheterodyne circuit the interference from such radiation is reduced by operating the oscillator so that its second harmonic is used as the locally generated frequency. In this way the amount of radiation is reduced and the frequency of the radiated energy is outside the range of broadcasting.

If a signal having a 1,500-kilocycle carrier wave is being received, the oscillator tube should be adjusted to generate a current having a frequency of about 1,550 or 1,450 kilocycles. This current, combining with the 1,500-kilocycle carrier current, gives a beat frequency of 50 kilocycles per second. In the detector circuit this beat current is "detected" and passed on to the intermediate-frequency amplifying stages. The side bands (tone modulation, (page 411)) of the intermediate-frequency current have the same width as on the signal current. The intermediate-frequency stages are designed to have sharp frequency characteristics over a band of frequencies having a width of about 8 to 10 kilocycles. If the tuning of the intermediate-frequency amplifier is too sharp, the upper portions of the side bands are cut off. If, on the other hand, the intermediate stages tune broadly, they will pass beat frequencies just below and also above the 50-kilocycle current which are due to the interaction of unwanted carrier waves and the current from the oscillator; that is, an interfering signal which is 10 kilocycles off the desired carrier produces a beat frequency of 40 or 60 kilocycles, which will pass through if the intermediate tuning is broad.

It should be noted that a superheterodyne designed in this manner has several disadvantages, unless it is provided with filter circuits of the proper kind. First, there are two settings of the control device for the local oscillating frequency, either of which in combination with a given carrier frequency will give the required beat frequency. Secondly, for a given oscillating frequency, there are two carrier frequencies which will combine with it to give the same beat frequency.

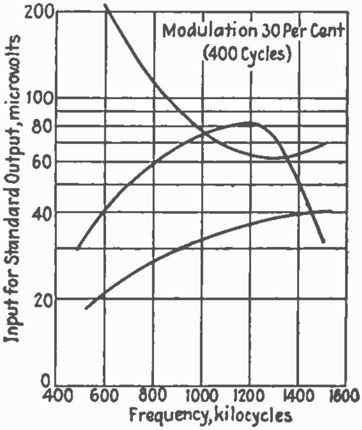


FIG. 7.—Typical sensitivity curves.

Standard of Sensitivity.—The sensitivity of a receiver is a measure of how many millionths of a volt are needed in the antenna circuit to deliver satisfactory sounds at the loud-speaker. There is, of course, a very large variety of types of antennas (page 181), and there are differences of opinion as to what are satisfactory sound effects.

In order to be able to measure receivers, the Standards Committee of the Institute of Radio Engineers have designated 50 milliwatts of power available at the loud-speaker terminals as being a satisfactory standard. The sensitivity, then, is the number of microvolts in the antenna circuit which are necessary to give this output to the loud-speaker.

The arbitrarily selected *standard antenna* which is used in measurement work is an antenna of 4 meters effective height, 25 ohms resistance, 200 micromicrofarads capacity, and 20 microhenrys inductance. Such a standard antenna may easily be constructed artificially (except as to height). By connecting to this antenna a standard "signal" generator (page 627) and the radio receiver to be tested, the sensitivity of the receiver may be measured in terms of microvolts. The number of microvolts necessary to give a standard signal, divided by four to compensate for the height, gives the sensitivity in microvolts per meter of the height of the antenna. A diagram of several typical sensitivity curves is shown in Fig. 7.

Measure of Selectivity.—Selectivity is that property of a radio receiver which enables the user to separate desired programs from undesired ones.

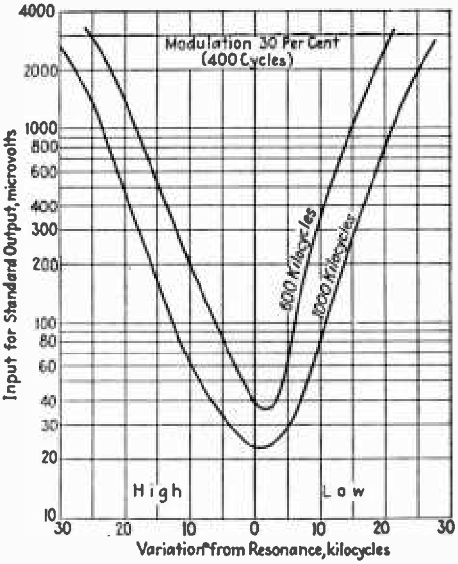


FIG. 8.—Selectivity curves.

It is measured by adjusting the frequency of the standard signal generator with respect to the point of the maximum radio signal in steps of, say, 10 kilocycles per second and then increasing the voltage delivered to the antenna until a standard signal (page 409) is again obtained. This method gives a measure of the strength of an interfering signal which has the same response in the loud-speaker as the desired signal. Several points taken on each side of the maximum signal point may be plotted in the form of a curve which will show how strong a neighboring signal must be and how close in frequency it must be to cause interference. This property of a receiver varies with the frequency; that is, a receiver is not so selective at 200 meters (1,500 kilocycles) as it is at 500 meters (600 kilocycles).

It would be desirable if this variation of selectivity with frequency could be avoided and a receiver made as selective when the wave length is 200 meters as when it is 500, but thére is no known means of doing this. A receiver can, however, be made *too selective,* not from the point of view of separating stations, but because of effects on music and speech reproduction. If the selectivity of a receiver is increased when tuned for a wave length of 500 meters, the high notes in music and speech will lose in sound volume in proportion as the selectivity is increased, and all semblance to true reproduction will be lost. A typical curve of selectivity is shown in Fig. 8.

The selectivity curves of several types of receivers show that the most selective receiver is the *superheterodyne,* followed, in order, by the tuned *radio-frequency receiver* with three stages, the *regenerative receiver* with a single-circuit tuner, the *non-regenerative receiver* with a double-circuit tuner, and, finally, the non-regenerative receiver with a single-circuit tuner. The frequency characteristics, however, appear in the opposite order, meaning that the non-regenerative receiver with a single-circuit tuner gives practically "flat" amplification (page 366) of frequencies in the audible range, but the superheterodyne "cuts off" most of the higher frequencies. A receiver having ideal characteristics would show a flat selectivity curve over a range of about 10 kilocycles per second. It is this cutting off of the *side bands* (loss of consonants) that causes the unnatural character of reproduced speech which is especially noticeable in high-pitched voices.

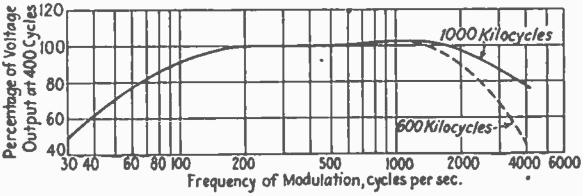


Fig. 9.—Fidelity curves.

Determination of Fidelity.—The faithfulness with which a loud-speaker reproduces all of the notes of music and speech is called fidelity. The standard point of reference has been set at 400 cycles per second. To obtain the data for a curve of fidelity of a loud-speaker, its audio output is measured at all frequencies from 30 cycles to 5,000 and then plotted, using the output at 400 cycles as 100 per cent. Frequencies below 60 cycles and above 4,000 have been found to have little or no musical value. A typical curve of fidelity is shown in Fig. 9.

Band Selectivity.—If the coupling between two tuned circuits is decreased, the "humps" in the resonance curves move more closely together, so that the shape of each of the curves approximates that of the selectivity curve (page 410) which is sought for a radio-frequency amplifier. If a selectivity curve is flat and has a width of about 10 kilocycles per second, the higher frequencies of the side bands (page 411) will not be cut off. An adaptation of this method is shown in Fig. 10 which shows the tuned circuits between the stages. The coupling between the coils of the transformers T_1 and T_2 is loose (page 87) and must be adjustable to allow the same selectivity at low as at the high frequencies. The control for the setting of the condensers is arranged to vary also the coupling between the coils.

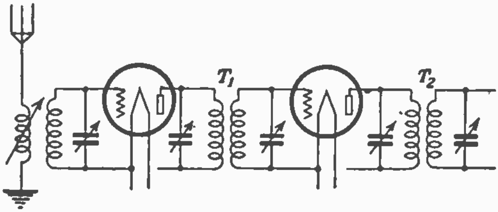


FIG. 10.—Tuned circuits in radio-frequency amplifier for "band selectivity."

Detector Tube.—For grid-circuit rectification, in which the detector tube is arranged with a grid leak and grid condenser, the amplitude (page 168) of the radio-frequency signal impressed on the grid circuit must be limited to one volt. Greater amplitudes will cause serious distortion. If plate-circuit rectification is used with no grid condenser or grid leak, a radio signal having an amplitude as high as several volts will not cause much distortion. On the other hand, detection by the latter method is less efficient than the one first mentioned.

Audio-frequency Amplifier.—To preserve the natural quality of the voice and of musical instruments, an audio-frequency amplifier must amplify equally all frequencies from 50 to 8,000 cycles per second. In many receivers, however, the audio-frequency amplifier is designed to cut off at about 4,000 cycles. This is done to reduce interference from other broadcast channels and does not affect the fidelity of speech to any considerable extent.

Audio-frequency amplifiers are classified according to the type of circuit used to couple one stage to the next. The three main methods of coupling audio-amplifier tubes are (1) transformer coupling, (2) impedance coupling, and (3) resistance coupling. There may be various combinations of these methods.

Comparison of Types of Amplifiers.—The types of amplifier couplings arranged in the order of decreasing values of voltage amplification per stage are (1) transformer coupling, (2) inductance coupling, and (3) resistance coupling. At the low frequencies, the inductance-coupling type with an inductance leak gives several times the amplification of the resistance-coupled type. The resistance-coupled amplifier gives less distortion than the other types but requires about twice as much B-battery voltage to make up for the loss of voltage in the resistance. The inductance-coupled type has a frequency characteristic which is not much better than that of a transformer-coupled amplifier, and its amplification is much less. In general, transformer coupling has the widest application.

Distortion in Audio Amplifier.—The several types of distortion may be classified as loss of certain frequencies, overemphasis of frequencies, and introduction of harmonics. The low frequencies are not transmitted by an amplifier stage when the load in the plate circuit of a tube is not matched to the plate resistance of the tube. This condition occurs when the primary winding of the transformer is too small or when the coil of an impedance coupling device has too few turns.

Overemphasis of frequencies occurs when the coupling device has a point of resonance (page 83) in the broadcast range. Usually this condition is due to the distributed capacity of the coil windings. Such distortion may sometimes be remedied by shunting a fixed condenser or a high resistance across the secondary winding.

Harmonic distortion occurs when the amplifier introduces new frequencies which are harmonics of the input current. This condition results when a tube is overloaded and also may be due to saturation of the transformer core.

Volume-control Methods.—A volume-control device located in the audio-frequency amplifier is not satisfactory, because it may permit the detector tube to become overloaded and thus cause distortion, especially when the broadcasting from a high-power station is being received. A better location for volume control is in the radio-frequency amplifier. There are several places in the circuit at which the volume control may be applied, as shown in Fig. 11. The device used is a variable-resistance unit *R*. The arrangement shown in *a* of the figure is satisfactory, except that as the resistance is reduced to decrease the volume it acts to lower the selectivity of the first radio-frequency transformer. If the resistance is put in series with the antenna coil, selectivity is not affected when the resistance of this device is increased to reduce the volume. The disadvantage of the latter method is that the volume cannot be brought to zero. The resistance *R* may also be placed across the primary winding of one of the radio-frequency transformers. A 10,000-ohm variable resistance may be used in volume-control devices of this kind.

Another satisfactory arrangement for volume control is to use a resistance across the secondary coil of a tuned circuit, instead of the primary as in the former cases. This arrangement, as shown in *b* of Fig. 11, requires the use of a resistance of about 100,000 ohms and gives practically the same results as the arrangements already described. This type of volume-control device may be placed in the input circuit of the detector stage without appreciably affecting the selectivity. In a detector stage using a grid leak and condenser both the resistance of the input circuit and the selectivity have low values.

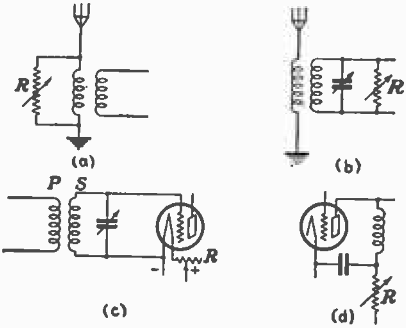


FIG. 11.—Volume control in radio-frequency amplifier.

A good type of volume-control device for receiving sets operated by batteries utilizes a filament rheostat as shown in *c* of Fig. 11. Filament-current control is satisfactory on weak radio signals and does not appreciably affect the quality of reproduction. On strong signals this form of control introduces distortion. To avoid this difficulty, filament control is frequently applied only to the tubes in the radio-frequency amplifier stages. The reduced emission current increases the plate resistance and thus may be used to control amplification. Unfortunately, this device cannot be used on receivers with alternating-current tubes, because a variation of the filament current in a UX-226-type tube causes a humming noise, and in a UY-227-type tube the emission lags behind the filament-current change and produces distortion. A large resistance in series in the plate circuit of a radio-frequency stage as shown in *d* of the same figure is satisfactory for receiving sets which are operated by batteries. In receiving sets operated by a power unit (page 425) however, such a resistance, as it is increased, reduces the current taken by the tubes in the radio-frequency stages and thus increases the voltage on the other tubes.

The shunt-resistance type of volume control is shown diagrammatically in Fig. 12. The purpose of this arrangement is to by-pass a certain portion of the plate current. It consists of a potentiometer (page 121) having a maximum value of about 2,000 ohms connected across the primary winding of the transformer in the plate circuit of the last radio-frequency amplifying tube. An adjustable contact is connected to the plate circuit of the tube. Full volume is obtained with the contact at *A*, and no volume with the contact at *B*. A variable resistance used in place of the potentiometer does not produce equally good results because it has the effect of mistuning the circuit.

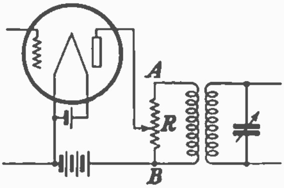


Fig. 12.—Volume control by shunt resistance.

In some receivers the antenna coupling and the audio amplification are reduced as well as the voltage amplification. The volume control for an amplifier when a *phonograph pick-up* (page 131) is used may consist of a variable resistance connected across the secondary winding of the first audio transformer. An alternative method is to use a potentiometer across the secondary winding with the adjustable contact serving as the grid return.

Another form of volume control using screen-grid tubes is described under "Modern Broadcast Receivers" (page 422).

Automatic volume control is obtained by the use of an additional tube which takes part of the radio-frequency current, rectifies it, and impresses the direct-current voltage output as a variable *C* or grid-biasing voltage on the grid circuits of the tubes in the radio-frequency stages. Consequently, a uniform voltage is impressed on the detector stage, producing uniform volume. A disadvantage of this device is that when severe fading occurs, the effect of the control is to raise the "noise background."

Tone Control.—Tone control changes the "frequency response" of a receiving set and thus affects the timbre of the reproduction, while volume control changes the output of sound. One method of tone control is to divert the higher-frequency currents from the loud-speaker. This is accomplished by a set of small by-pass condensers arranged so that they may be cut in or out of the circuit as desired. Another method utilizes a large variable resistance in series with a fixed by-pass condenser which has a capacity of about 1.0 microfarad.

Power-output Tubes.—In order that no distortion of a radio signal may be apparent, the output of the tube to the loud-speaker is arranged so that it is not more than 10 per cent of the input to the plate circuit of the tube. If the output power is increased beyond a certain value, the radio signal is distorted by the tube. This is explained by the fact that the relation between the grid voltage and the plate current is not a straight line. In fact, the distortion diminishes as the output is reduced. The power tube supplying the loud-speaker must be able to provide an *output* of power equal to ten times the average power to take care of any "peaks" that may occur. If it is assumed that a loud-speaker requires about 0.1 watt for average use, the power tube must have an *input* of 10 watts to take care of the peak loads. The maximum undistorted power output of a number of power-output tubes is given in the following table.

TABLE XXXI.—POWER-OUTPUT TUBES

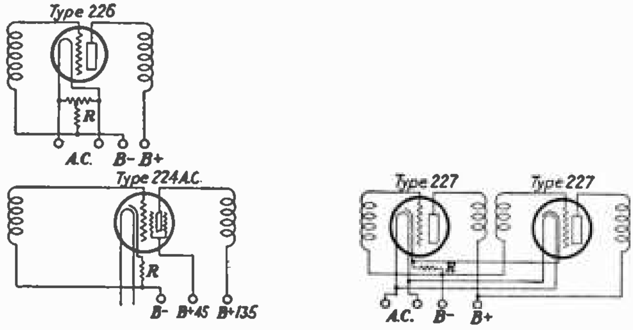
Type of tube	Plate voltage, volts	Grid bias, volts	Maximum output, milliwatts
120	135.0	22.5	110
112A	135.0	9.0	120
	157.5	10.5	195
171A	90.0	16.5	130
	135.0	27.0	330
	180.0	40.0	700
210	210.0	18.0	340
	300.0	22.5	600
	350.0	27.0	925
	400.0	31.5	1,325
245	180.0	33.0	750
	250.0	50.0	1,600
250	250.0	45.0	900
	300.0	54.0	1,500
	350.0	63.0	2,350
	400.0	70.0	3,250
	450.0	84.0	4,650

Grid-bias Voltage.—In order to obtain amplification without distortion it is essential that no current flows to the grids of the amplifier tubes. The normal voltage of the grid is determined by the value of the grid bias. When the radio-signal voltage is applied, the operating voltage of the grid fluctuates about the normal value. Thus, if the grid-bias voltage is 6.0

volts negative, and if the radio signal has a value of 5.0 volts effective or 7.0 volts maximum, the operating voltage of the grid swings from 1.0 volt positive to 13 volts negative. Signal distortion is caused because the grid circuit draws a current during the period the grid is positive. Severe distortion of this kind is noticed by a rattling sound from the loud-speaker. Since the value of grid-bias voltage depends on the amplitude of the radio-signal voltage on the grid of the tube, it is clear that little or no grid-bias voltage is required in the radio-frequency amplifier stages, but in the audio-frequency stages it is increased with each stage.

Thus the first audio-frequency tube may have a grid-bias voltage of 9 volts and the power tube as much as 100 volts. A UX-245-type tube with 250 volts on the plate circuit requires a 50-volt grid bias and takes a radio signal with an effective value of amplitude of about 36 volts, before there is any flow of grid current with consequent distortion. With this signal strength the maximum distorted power output is 1.6 watts, much more than is necessary for ordinary use.

Grid-bias Voltage for Alternating-current Tubes.—In radio receivers using tubes operated with alternating current, the grid-bias voltage for the tubes may be obtained by utilizing the voltage drop across resistances placed at the proper points in the circuit, as shown in the diagrams in Fig. 13. These diagrams indicate how the resistance unit should be located for tubes of various types, such as the UX-226, UY-224, and UY-227. In the case of the UX-226 tube the resistance *R* is connected from the middle of the filament to the negative B-voltage terminal, and in the case of the *heater type* of tube the resistance *R* is connected between the *cathode* and



(*a*) (*b*)

FIG. 13.—Diagrams of resistance units for grid-bias voltage for alternating-current tubes.

the negative B-voltage terminal. An examination of this circuit shows that the plate current of the tube must flow through the resistance to reach the filament or the cathode, as the case may be. The voltage drop across this resistance is equal to the plate current in amperes multiplied by the resistance in ohms. In other words the value of the necessary resistance is equal to the voltage drop divided by the current. When the value of the required grid-bias voltage and also the value of the plate current of the tube are determined, the required resistance is found by dividing the "bias" in volts by the current in amperes. Thus, if the grid bias is to be 40 volts and the plate current is 20 milliamperes or 0.02 ampere, the value of the required resistance is 40 ÷ 0.02 or 2,000 ohms. When one resistance unit is to provide the "bias" for several tubes of the same type, the calculations for the required resistance are similar. In the arrangement shown for two UY-227 tubes, the plate current of both tubes must flow through the resistance *R*.

Part 1

TYPICAL MODERN BROADCASTING RECEIVER

The receiver to be described is arranged for operation on 60-cycle alternating-current circuits having a voltage range of 100 to 130 volts. It may, however, be adapted to 25- or 40-cycle circuits and to operation at 220-volts, by means of special transformers. The circuit of this receiver includes three stages of screen-grid radio-frequency amplification and two audio-frequency stages with two UX-245 tubes in a push-pull (page 39) arrangement in the second audio-frequency stage.

The top rear view of the chassis of the receiver is shown in Fig. 14. In this view the condensers and the transformers are shown as they would be when their covers are removed. The complete circuit diagram is given in Fig. 15.

Sensitivity.—This receiver has a sensitivity (page 409) of between one and three microvolts per meter of elevation of the antenna over the entire range of broadcasting frequencies.

Selectivity.—An interfering transmitting station must be within 13 kilocycles at 500 meters and within 32 kilocycles at 230 meters, to cause interference in this receiver as loud as the desired radio signal.

Fidelity.—The receiver has 62 per cent as much "output" at 60 cycles per second and 25 per cent as much output at 4,000 cycles as at 400 cycles. The disadvantage of the lower output at 4,000 cycles is largely offset by the rising frequency characteristic (page 366) of the type of loud-speaker which is used, with the result that there is a fairly uniform response from the loud-speaker over the entire range of frequencies.

Antenna Coupling.—The coupling between the antenna and the grid of the first tube is made by means of a tuned circuit. The antenna compensating condenser (C_A, Fig. 15) is in the circuit across the first radio-frequency unit of the main tuning condenser and is connected in the same way as the succeeding two-plate alignment condensers (C_1, Fig. 15). This antenna compensating condenser is made variable so that it can be adjusted to compensate for the detuning effect of a closely coupled antenna circuit on the first radio-frequency stage. The size of the antenna affects the tuning of the antenna circuit, because the antenna has the effect of adding capacity to this circuit. Consequently, a part of the tuning of this circuit must be independently adjustable to secure accurate tuning of the antenna stage. This is accomplished by a small ten-plate antenna compensating condenser connected in parallel with the main unit of the gang condenser (C, Fig. 15). The antenna compensating condenser thus permits an increase in sensitivity and selectivity.

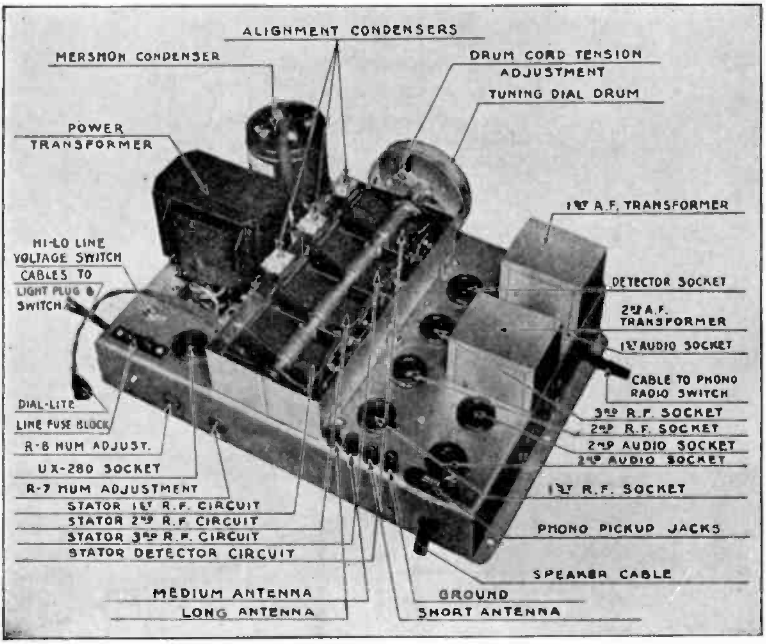
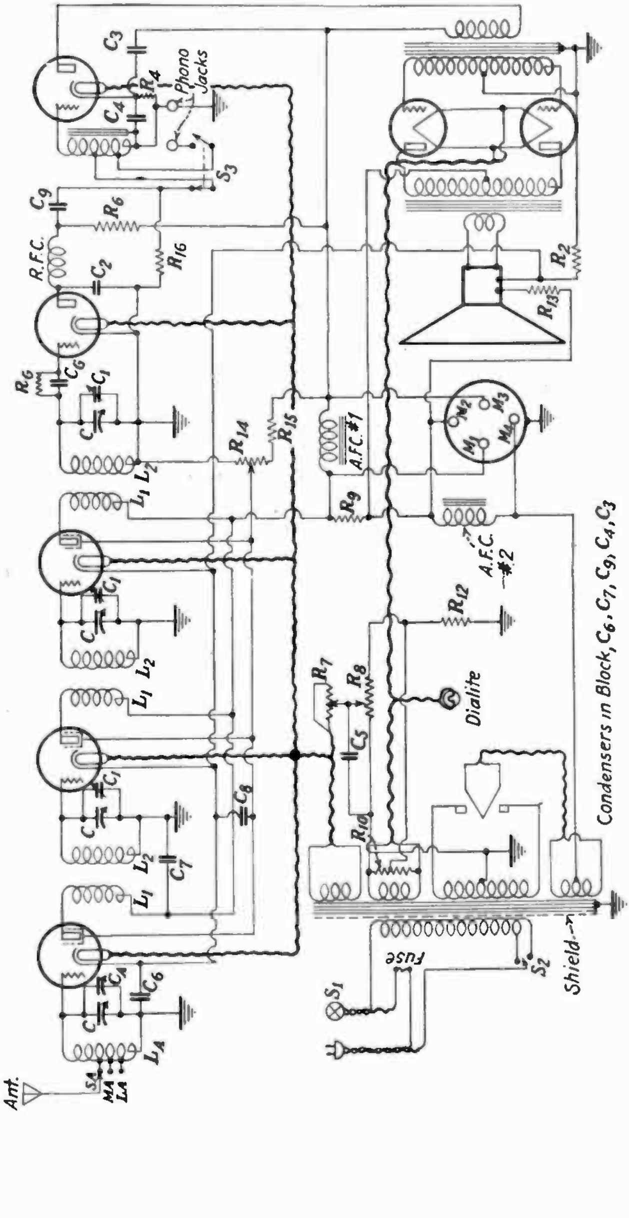


Fig. 14.—Chassis of alternating-current receiver. (*Amrad type* 80.)



Condensers in Block, C_6, C_7, C_9, C_4, C_3

FIG. 15.—Circuit diagram of alternating-current receiver.

With this type of antenna coupling the amplification from the antenna to the grid of the first tube is always less at high than at low wave lengths. The amplification varies from 4 at a wave length of 500 meters up to 20 at 200 meters for the middle antenna terminal and a standard antenna (page 410). Compensation is applied in the succeeding tuned stages to offset this variation.

Interstage Radio-frequency Amplification.—A departure from the conventional design of radio-frequency interstage transformers is necessary to make use of the properties of the screen-grid tubes. Instead of the ordinary type of primary winding consisting of a few turns wound at the lower end of the secondary winding, a primary coil of a large number of turns wound on a separate form placed at the top end of the secondary coil is used. This type of primary winding gives higher amplification at a wave length of 500 meters than at 200 meters and changes the relation of any feed-back coupling (page 304) due to the capacity between the leads. By this method, oscillation by such a coupling is prevented instead of being increased as is the case when small primary windings are used.

The amplification per stage varies from 30 at a wave length of 500 meters to 16 at 200 meters. The change in amplification is the reverse of that in the antenna stage, the result being practically uniform amplification over the broadcasting range. The overall radio-frequency amplification (to the detector) measures 23,000 at a wave length of 500 meters, 28,000 at 300 meters, and 20,000 at 200 meters.

Detector Circuit.—The grid-leak and condenser type of detector circuit is used, because it has been demonstrated by a large number of tests that the advantages of this type of circuit more than offset its disadvantages, as compared with the so-called "power-type" detection circuits (page 327), assuming, of course, that the rest of the receiver is designed to utilize the advantages, these being that (1) greater sensitivity is obtained without endangering the stability, as would be the case if this loss of sensitivity were made up by increased sensitivity in the radio-frequency amplifier; (2) overloading the detector tube is avoided, provided sufficient audio amplification is used so that the overload comes first on the power-output tubes (page 416); (3) quality of sound reproduction is not affected, as the selectivity of the radio-frequency tuning starts to cut off the high audio frequencies long before the grid leak and condenser start to cut them off; (4) because of greater sensitivity it is feasible to supply the power tubes with the maximum voltage they can handle before the last radio-frequency tube is overloaded.

The last of the enumerated advantages is of considerable importance, as in receivers using the screen-grid tubes for radio-frequency amplification, with a power tube used as a detector and only one stage of audio-frequency amplification, it is impossible even to approach the full power output of the power-output tubes for the reason that the last radio-frequency tube becomes overloaded and then limits the voltage which can be supplied to the detector tube and to the power-output tubes. The grid leak in the detector circuit has a resistance of 1.5 megohms, and the grid condenser a capacity of 0.00025 microfarad. The detector radio-frequency choke coil (page 95) acts with the by-pass condenser *C*2 (0.002 microfarad) to prevent the passage of radio-frequency currents through the audio-frequency amplification system.

Audio-frequency Amplification.—The power output of the receiver depends only on the limitations of the power tubes themselves and not on any of the preceding tubes.

Control of Volume.—The method of volume control is an application of the characteristic of the screen-grid tube by which the amplification may be controlled by means of the voltage impressed on the screen grid. The voltage on the screen grid is positive and has a value of approximately half the voltage on the plate. If the screen grid is at zero voltage it would almost completely block the flow of electrons to the plate. The higher the voltage on the screen grid (up to a certain limit) the more the amplification is increased.

Volume control is obtained by varying the positive voltage on the screen grids of the three radio-frequency tubes. The resistance unit *R*14 (50,000 ohms) is of the graphite rather than the metal type to avoid the possibility of corrosion in moist climates and the consequent noisy operation.

Filter System.—The parts of the power-supply unit (page 425) are designed to carry greater loads than are applied, and, consequently, the resistances used are operated at not more than half their rated current-carrying capacity. In the filtering system of this receiver two choke coils are used. An audio-frequency choke coil (A.F.C. No. 1) is inserted in the plate-supply leads in the circuits of the detector tube and the first audio-amplifier tube. It has a comparatively high inductance and low current-carrying capacity, with a direct-current resistance of 500 ohms. This unit isolates these circuits from any possible feed-back from the power-amplifier circuits and eliminates the common cause of audio-frequency howl, due to audio-frequency modulation (page 38) of the radio-frequency amplifier.

The main filter choke coil (A.F.C. No. 2) is connected in the high-voltage side of the B-voltage supply and carries the entire rectified direct current. This unit has a comparatively low inductance and high current-carrying capacity. Its direct-current resistance is 150 ohms. Across its terminals are connected the anodes *M*4 and *M*2 of the *Mershon condenser* (page 426). Both choke coils are shielded from the audio-frequency transformers.

Hum Adjustment.—Tests of the type UY-227 tubes when used as detectors show that considerable variation in the hum of this receiver is due to variations in the tubes and that these variations can be reduced if a positive voltage is applied to the heater filament with respect to the cathode. The amount of voltage required varies with the type of the tubes. For this reason two hum-adjusting potentiometers (page 121) are provided: One permits an adjustment of the positive voltage applied to the heater filament, and the other the "midpoint" on the heater of the tubes. "Hum adjustment *R*7" is a variable center-tap resistance of 20 ohms connected across the current supply of the heaters of the UY-224 and the UY-227 tubes. Its variable "center" tap goes to the ground connection of the receiver through the heater grid-bias voltage (page 36) control *R*8 and the by-pass condenser *C*5. This adjustment is set at the factory.

Hum adjustment *R*8 is a heater grid-bias voltage adjustment consisting of a 200,000-ohm potentiometer inserted across the ground connection and a direct-current voltage of 50 volts. This potentiometer varies the grid-bias voltage on the UY-224 and the UY-227 tubes in order to minimize and balance out the slight inherent hum produced in the alternating-current tubes themselves. By-pass condenser *C*5 (0.25-microfarad capacity) is connected between the ground and the common connection of the two hum adjustments. Whenever a new detector tube is installed this control may need adjustment.

Blocking Condenser.—The by-pass blocking condenser contains the units *C*3, *C*4, *C*6, *C*7, and *C*9. With the exception of *C*9, its units are used to by-pass radio-frequency or audio-frequency currents around resistances where common coupling might otherwise occur.

The unit *C*3 (1.0-microfarad capacity) is the plate-supply by-pass in the plate circuit of the first audio-frequency tube. Unit *C*4 (0.5 microfarad capacity) by-passes the grid-bias resistance *R*4 of the first audio-frequency tube. Unit *C*6 (1.0-microfarad capacity) is connected to the ground from the cathodes of the radio-frequency tubes. Unit *C*7 (1.0-microfarad capacity) is the plate by-pass condenser for the radio-frequency tubes. Unit *C*9 (0.5-microfarad capacity) is the coupling condenser between the plate of the detector tube and the first audio-frequency transformer.

Radio-frequency Transformers.—The transformers for the radio-frequency stages have a high impedance in the primary winding. The "plate" (primary) winding of each transformer (excepting the antenna coil) contains 200 turns of wire, wound closely on a small bobbin. This plate coil is placed at the grid or high-potential end of the "grid" coil to which it is coupled. Magnetic and capacity coupling is thus combined with the resonant effect ("peaked" at a frequency below the broadcast band) of the high inductance of the primary winding to give the receiver not only a high amplification with good *selectivity* but also relatively uniform *sensitivity* over the entire broadcast band. Complete shielding is obtained by means of the copper "cans" placed over each transformer and secured to a cadmium-plated steel subbase. Copper braid with attachments to the ground connection covers each plate lead, where it is exposed to possible coupling with other wiring. The primary coil of each transformer has a direct-current resistance of approximately 80 ohms. The normal direct-current resistance of the choke coil in the plate circuit of the detector tube is approximately 100 ohms. Each unit of the "four-gang" tuning condenser is shielded.

Detector and First Audio-frequency Circuits.—The coupling method used between the detector and the first audio-frequency amplifier circuits is of the "shunt-feed" type. It consists of a resistance of 100,000 ohms (*R*6) in the plate circuit of the detector tube, a tapped impedance (*A.F.T.*) in the grid circuit of the first audio-frequency tube, and a 0.5-microfarad condenser (*C*9) to couple them. The result of correct matching of these three units is a uniform amplification curve and satisfactory audio-frequency amplification.

Resistor Panel.—This unit contains the resistances *R*4, *R*6, *R*15, and *R*16. The resistance *R*4 (2,250 ohms) is in the grid-bias circuit of the first audio-frequency amplifying tube. The resistance *R*6 is in the plate-supply circuit of the detector tube to produce an alternating-current voltage "drop" across the coupling condenser *C*9 in proportion to the modulation of the incoming radio signal. The resistance *R*15 (21,000 ohms) is in series with the volume-control unit *R*14 to limit the maximum positive voltage across this unit to 80 volts. The resistance *R*16 (12,500 ohms) is connected across the input side of the first audio-frequency transformer and assists in maintaining the correct amplifying characteristic of the "audio" system.

First Audio-frequency Transformer.—This transformer is a tapped impedance connected in the grid circuit of the first audio-frequency amplifier tube. The following direct-current resistance values of the windings are given for reference when testing the circuits. Resistance between the ground (silver and red) and the grid (copper braid), 12,000 ohms; the ground (silver and red) and the detector tap (silver braid), 2,000 ohms; the ground (silver and red) and the "phonograph" tap (silver and copper), 20 ohms.

Second Audio-frequency Transformer.—This transformer consists of a single primary winding and a split secondary winding on a laminated treated-steel core. Each half of the secondary winding has the same number of turns and is connected to the grid of one of the UX-245 power tubes. For test purposes the following direct-current resistance values of the windings are given. The resistance between the B-plus tap (silver and copper) and the plate of the first audio-frequency tube (silver and red) is 1,600 ohms; between the secondary (center tap) winding (silver and green) and the grid of the UX-245 tube (silver braid), 4,800 ohms; between the secondary (center tap) winding (silver and green) and the grid of the

UX-245 tube (copper braid), 5,800 ohms. The overall resistance of the secondary winding (silver braid to copper braid) is 10,600 ohms.

Output Transformer.—The output transformer of the power stage is for use with the R.C.A. No. 106 loud-speaker. It has a split primary winding matched in impedance to the output of the two UX-245 power tubes. Each side of the primary winding connects to the plate of one of the power tubes, and its center tap connects to the plate-voltage supply. The secondary winding has only a few turns and is matched to the "voice coil" of the loud-speaker.

The direct-current resistances of the transformer coils are the following: The resistance between the primary center tap (green) and the plate of the UX-245 tube (one side) is 190 ohms; between the primary center tap (green) and the plate of the UX-245 tube (other side), 220 ohms; between the plate of the UX-245 tube (maroon) and the plate of the UX-245 tube (yellow), 410 ohms; between the terminals of the movable coil of the loud-speaker, about 0.8 ohm.

Loud-speaker.—The direct-current resistance of the field coil of the loud-speaker is 7,000 ohms. To adjust and recenter the cone of this loud-speaker, it is only necessary to unscrew slightly the machine screw on the tip of the cone, center the cone by hand, and tighten it again.

Power, Rectifier, and Filter Circuits.—High-voltage alternating current, delivered by the power transformer, is rectified by the UX-280 full-wave rectifier tube into pulsating direct current. It supplies from 100 to 128 milliamperes at about 300 volts. The rectified current then passes through the filter circuit represented by the audio-frequency chokes coils (A.F.C. No. 2 and A.F.C. No. 1) and the four-section Mershon filter condenser (page 426). The current leaves the filter circuit containing such a small alternating "component" that it is for all practical purposes a "pure" direct current. This is used for the B-, C-, and screen-grid voltage-supply circuits.

Power-transformer Connections.—At normal load the power transformer takes 90 watts from a 110-volt, 60-cycle line. This transformer has a tapped primary winding connected to the "Hi-Lo" switch ($S2$) so that high and low line voltage conditions may be readily met. This transformer has four secondary windings, two delivering 2.25, one 4.3, and one 600 volts. The two 2.25-volt secondary windings supply the heater and filament currents of the five heater-type tubes and the two UX-245 power tubes. The 4.3-volt secondary winding delivers filament current to the UX-280 rectifier tube. The 600-volt secondary winding is split into two 300-volt sections, each of which is connected to one plate of the rectifier. The center tap is grounded.

Resistor Panel.—This panel has two resistances, $R9$ and $R13$. The resistance of $R9$ is 5,000 ohms, which is in the plate-supply circuit of the radio-frequency detector tube and of the first audio-frequency tube. It is used to limit the plate-supply voltages to the required value. The resistance $R13$ of 1,500 ohms is inserted in series with the field of the loud-speaker on the high-potential side. This resistance limits the current taken by the field of the loud-speaker and also protects the rectifier tube from possible inductive surges which might at times originate in the high-inductance winding of the field coil.

Mershon Condenser.—The Mershon condenser is a non-puncturable filter condenser for use on the high-voltage rectified-current circuit of an eliminator (page 260) that supplies the receiver with its B and C voltages. This unit has usually a capacity of 52 microfarads. Each Mershon anode (positive terminal) is connected to a different point in the B-plus circuits and forms one of four separate condensers—two of 8- and two of 18-microfarad capacity. The copper case of the condenser is the common negative terminal which is grounded to the frame or the so-called *chassis* of the receiver.

The *Mershon condenser* consists of rolled aluminum electrodes in a copper case, the electrodes being covered by an oxide film. The unit as shown in Fig. 16 has *two anodes*. The dielectric is an aluminum-oxide coating formed electrolytically in the process of manufacture. The coated aluminum sheet is the *anode*. The *cathode* is the electrolyte, which is contained in a copper case to which electrical connection is made. All the anodes in the multiple condensers are shielded electrostatically to cut down the capacity between the electrodes. The anodes are also partially insulated within the solution (cathode) to increase the resistance between the electrodes. The case forms the common negative terminal for all the units within the condenser block and can be clamped to the eliminator base, thus making the frame act as a conductor at zero potential.

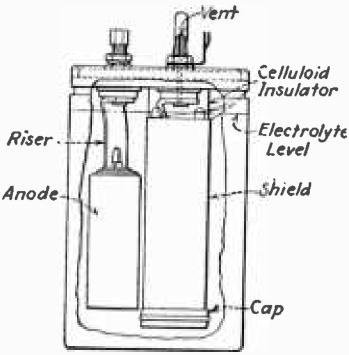


FIG. 16.—Mershon condenser.

Although the Mershon condenser will break down at an applied voltage of over 415 volts per unit, no damage will result unless the amount of leakage current and consequent heating of the solution by the electrodes causes the solution to boil. Instantaneous surges of voltage do not damage the film. Voltages as high as 1,000 will cause no particular harm unless the current is sufficiently large to cause heating, or unless high voltages are applied constantly over a relatively long time.

The following advantages are claimed by the manufacturers of the Mershon condenser for its use in *eliminator circuits:* (1) A large capacity is provided in a small space; (2) the high efficiency of the filters in this condenser when used in radio transmitters and B eliminators makes possible smaller choke coils and lower filter costs than with other types; (3) leakage current in this condenser increases as the peak voltage increases, thus improving its filter action; (4) this condenser is not subject to the same fatigue as paper condensers (continued operation on a direct-current hardens the film and improves it); (5) it is not harmed by high-voltage surges, because the film is immediately healed after rupture, on reapplication of a direct-current potential, which may be only a few milliamperes in value; (6) it is lower in cost than a paper condenser of the same voltage-breakdown rating; (7) it can be operated continuously nearer the breakdown-voltage point than a paper condenser; (8) it is completely sealed and is not affected by moisture.

The by-pass condenser *C*8 (1.0 microfarad) is connected between the cathodes and the screen grids of the UY-224 tubes to prevent electrical interference between the successive screen grids.

The grid-bias resistance *R*12 of 860 ohms in the power-tube circuit is connected between the middle tap resistance across the filaments of the two UX-245 power tubes and the ground connection of the chassis of the receiver. This produces a grid-bias voltage of 50 volts in the grid circuit of the power tubes. A resistance *R*2 of 31 ohms is in the grid-bias circuit of the UY-224 tubes.

The *R*10 center-tap resistance of 60 ohms is connected across the filament circuit of the two UX-245 power tubes. Its middle tap is joined to the ground connection through the grid-bias resistance *R*12.

Part 2

TROUBLE SHOOTING IN BROADCASTING RECEIVERS

The preliminary examination of a receiver giving trouble will often show the source of the difficulty. The following suggested procedure may be helpful:

Line Fuse Blows.—This may be caused by—(1) defective rectifier tube, (2) defective power tube, (3) power-line wire grounded to the chassis of the receiver, or (4) defective power transformer (items 3 and 4 are not likely to occur).

Tubes Do Not Light.—This may be caused by (1) fuse blown, (2) no line voltage at the socket, (3) short circuit in power cable or the socket plug,

(4) open circuit in power cable or the socket plug, (5) main power switch $S1$ on the "off" position (Fig. 15), or (6) open circuit in cable to the power switch $S1$ (Fig. 15).

Tubes Light but Signals Are Weak.—This may be caused by—(1) too low line voltage, (2) switch marked "phono-radio" on "phono" (Fig. 15), (3) weak or defective tube or tubes, (4) low or no voltage across one or more of the tubes, (5) poor tube-socket connection with prongs of a tube (due to dirt or grease on the prong), (6) incorrect tuning and adjusting for volume, (7) antenna fallen from antenna post, or (8) short-circuited lightning arrester, or otherwise grounded antenna.

Poor Selectivity.—This may be caused by (1) incorrect antenna connection (wrong antenna post), (2) neglect to adjust antenna compensator (C_A, Fig. 15) in tuning, (3) too long antenna for the location, or (4) high resistance or unusually long ground connection.

Poor Tone Quality.—This may be caused by (1) poor power tube, (2) switch marked "phono-radio" on "phono" when operating radio receiving set, (3) loud-speaker out of adjustment, or (4) volume control set too high for a strong radio signal (overloading power tubes).

Excessive Hum.—This may be caused by (1) "hum controls" $R7$ or $R8$ out of adjustment, (2) poor detector tube, (3) poor first audio-frequency amplifier or power tube, (4) poor socket contact of the tube with the tube prong, (5) switch marked "phono-radio" on "phono" and pick-up is not connected to the set, or (6) high-resistance ground connection.

Noisy Operation (definitely located as within the set—not outside).—This may be caused by (1) *microphonic* or similarly defective tube, meaning one which is affected by mechanical vibration, (2) dirty tube prong contacts, (3) loose connection on the antenna or the ground binding post, (4) tube not held firmly in socket, (5) control grid clip not making clean, strong contact, (6) loose connection in cable to the loud speaker, or (7) loose connection inside the chassis.

Detailed Tests.—In most cases, measurement of the voltages across the various tubes (as obtained with a portable test-set (page 114), or the equivalent voltmeters) will indicate in which circuit the trouble is likely to be found. It is then necessary only to trace through that circuit for its definite location

Part 3

SUPERHETERODYNE BROADCASTING RECEIVER

The radio receiver (called "Radiola 62") is of the superheterodyne type using seven UY-227 tubes and one UX-171A tube. A UX-280 tube is used in a socket power unit for supplying all grid and plate voltages. A dry-disk type of rectifier furnishes direct current to the field of the loud-speaker. The circuit consists of one untuned coupling stage, one tuned radio-frequency stage, a tuned heterodyne detector, two intermediate radio-frequency stages, an oscillator, a second detector, and a power amplifier. The sequence of tubes is shown in Fig. 17. The first tube is in an untuned stage of radio-frequency amplification. It is coupled directly to the antenna and the ground connection across a 2,000-ohm resistance and functions as a coupling tube to the antenna system. The second tube is in a stage of tuned radio-frequency amplification tuned by the first unit of the gang condenser (page 419). The third tube is in the tuned heterodyne detector stage which is tuned by the middle unit of the gang condenser. Either a grid-bias voltage or a grid leak and condenser may be used for this tube or the second detector tube.

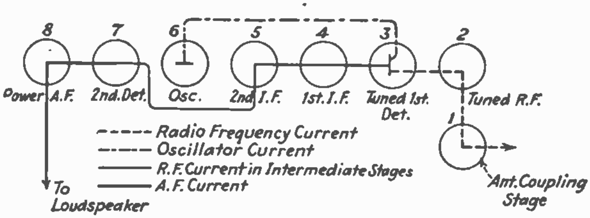


FIG. 17.—Tube arrangement in radiola superheterodyne receiver.

The fourth and fifth tubes are in the first and second intermediate-frequency stages. These stages are tuned to a frequency of 180 kilocycles per second, giving ample distance between the two peaks of the oscillator to eliminate any possibility of stations coming in at more than one point on the tuning dial. The transformers used in the intermediate-frequency amplifying stages may be of the air-core type, tuned by a condenser, or the fixed air-core type, or the fixed iron-core type. The transformers must pass a band of frequencies which has a width of twice the highest modulating frequency (page 408). In terms of frequency the width of the band is always twice the modulation frequency, but in terms of wave length the width depends on the carrier wave length. At high frequencies (short wave lengths) the band width in meters is narrow, but at low frequencies (high wave lengths) it is very wide. Consequently a transformer which is tuned sharply is satisfactory at short wave lengths but at long wave lengths it cuts off the side bands (page 411) and introduces distortion. The fixed-core type of transformer is tuned by the capacity of the coil for resonance over a range of frequencies. Although it tunes more broadly than the air-core type it is too sharp for work on long wave lengths. The iron-core type has broad tuning characteristics and allows a high degree of amplification with stability on low intermediate frequencies.

The three intermediate-frequency transformers used in this receiver are of the air-core type, with tuned primary windings and tuned secondary windings. The primary condenser is of the fixed type and the secondary condenser is adjustable. Adjustable condensers are provided for neutralizing the intermediate-frequency stages. The sixth tube is in the oscillator stage which is tuned by the third unit of the *gang condenser*. The oscillator circuit must have a fairly uniform output over its frequency range in order to obtain uniform sensitivity, for the reason that excessive output results in distorted reproduction. The oscillator must not produce harmonics or a station will be heard at more than one setting of the oscillator condenser. The operation of the oscillator condenser must not be affected by *body capacity*.

In the so-called *second-harmonic superheterodyne* the first detector tube is made to serve both as a detector and as an oscillator. A tickler coil (page 40) in the plate circuit is coupled to a coil and a condenser in parallel inserted in the grid circuit. This additional coil and condenser circuit is tuned to half the signal frequency plus or minus half the intermediate frequency. The regular grid circuit is tuned to the radio signal frequency. The "beat" frequency (page 408) is due to the combination of the second harmonic with the signal frequency. The tuning of one circuit has no affect on the other in the same stage, because the frequencies are widely separated. A station can be located at several places on the dial, because several harmonics are produced in the circuit.

Two trimming condensers are provided for adjusting the oscillator circuit to keep the beat note at the correct frequency for the intermediate stages. The seventh tube is in the detector stage. This tube operates with 160 volts on the plate, is provided with a grid-bias voltage, and does not use a grid leak and condenser. The output of this tube is sufficient to operate the power amplifier. The eighth tube is in the power-amplifier stage which is coupled by a choke-coil and condenser arrangement to the step-down transformer. The transformer is required to "match" the impedance of the output circuit (page 304) to that of the cone coil of the loud-speaker. The circuit diagram is shown in Fig. 18.

The series-supply arrangement is used to secure the proper grid-bias voltage for the grid circuits and the voltage for the cathodes and heaters. This is accomplished by sections of a resistance placed in the plate return lead. The volume control is a section of this resistance and it functions by varying the grid-bias voltage on the radio-frequency and intermediate-frequency stages sufficiently to give a positive control of the radio-signal strength delivered to the second detector tube.

A "bleeder" resistance of 20,000 ohms is provided across the supply circuit at the 135-volt position. The use of this resistance prevents any excessive rise in voltage that would otherwise occur upon the removal of all the tubes, or if some failure resulting in a reduced load occurred in the receiver.

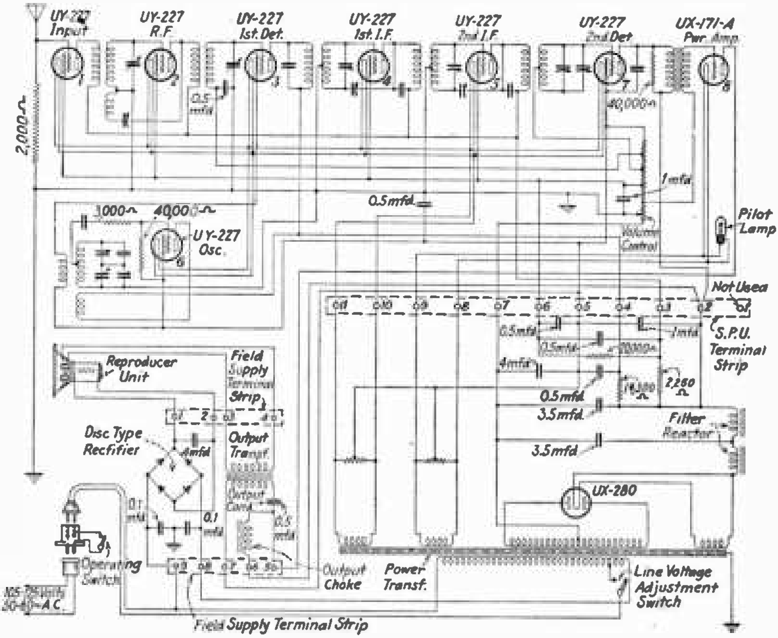


FIG. 18.—Circuit diagram for radiola superheterodyne receiver.

Part 4

COMMERCIAL WIRELESS TELEGRAPH RECEIVER

Type IP-501A

The commercial type of receiver called "IP-501A" is designed for the reception of radio-*telegraph* signals over the frequency range of 1,200 to 37.5 kilocycles per second (250 to 8,000 meters in wave length). This range may be extended to 16.7 kilocycles (18,000 meters) by the addition of an IP-503-type of loading unit. The receiver consists of an inductively coupled tuner, a vacuum-tube regenerative (page 348) or oscillating detector (page 349), and a two-stage audio-frequency amplifier. The circuit diagram is shown in Fig. 19.

Antenna Circuit.—The primary or antenna circuit consists of a primary inductance coil in series with a variable air condenser. The inductance is varied by a six-point switch which has blades arranged to short-circuit unused portions of the coil to reduce dead-end losses. The variable condenser is of the self-balanced type with a capacity range of 0.00008 to 0.0015 microfarad and is rotated through reduction gearing. The condenser dial is engraved with graduations from 0 to 180 degrees. It has also concentric half circles, over which a pointer is lowered or raised in response to the setting of the primary inductance switch. This arrangement permits the operator to make calibration marks on the antenna condenser dial which may be used later in tuning. Such calibration marks are good only for the antenna with which they are made.

Secondary Circuit.—The secondary inductance coil, like the primary loading coil, is bank wound with litz wire (page 151) on a threaded bakelite cylinder, and the winding is impregnated with a moisture-proof compound. This coil is provided with a six-tap switch and shunted by a variable air condenser of 0.00060- to 0.00075-microfarad capacity. The scale of the condenser is calibrated during manufacture. This calibration is correct when the coupling between the antenna and the secondary circuits is loose, when the detector tube is of the UX-201A type, and when the tickler coil (page 40) is adjusted so that the detector tube is just over the point of oscillation.

The secondary coupling coil is so mounted and rotated inside the primary coil, by the knob marked "Coupling," that the magnetic coupling is varied from a maximum to zero as the pointer swings over the 180-degree scale.

Tickler.—The tickler coil is of the variometer type (page 96), inductively coupled to a portion of the secondary winding and so proportioned as to control regeneration (page 403) and oscillation (page 404) over the wavelength range of the receiver. Rotation of the tickler knob controls the amount of energy fed back (page 304) from the plate to the grid circuit of the detector tube. In this way maximum radio-signal strength can be obtained by regenerative reception of spark (page 170) or interrupted continuous-wave (I.C.W.,) radio signals or by autodyne (page 348) reception of continuous-wave signals.

The push button marked "Oscillation test," when depressed, short-circuits the tickler coil, stops oscillations, and produces a loud click in the telephones of the receivers. If no click is heard when the push button is depressed, the tickler coil has not been "advanced" far enough to cause the detector to oscillate.

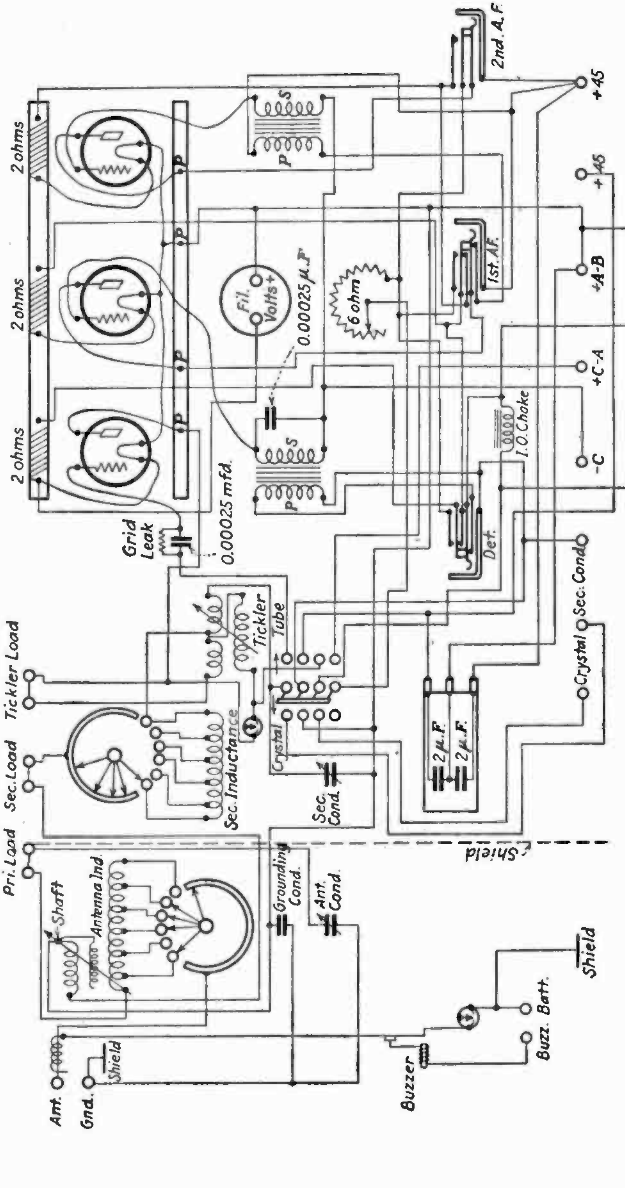


FIG. 19.—Circuit diagram of "IP-501A" receiver.

Crystal Detector.—If the batteries or all the tubes fail, a crystal detector may be connected across the binding posts marked "crystal." The anti-capacity switch is thrown to the "crystal" position and the telephone plug is inserted in the "det." jack. A buzzer is provided for use in adjusting the crystal detector.

Buzzer Circuit.—The push button mounted near the buzzer closes the circuit through the buzzer and a 1.5- or 2-volt external battery which is connected to the binding posts marked "buzzer battery." A wire from the buzzer is capacitively coupled to the antenna circuit so that when the buzzer is in operation a note is heard in the telephones if the crystal detector is in adjustment.

Vacuum Tubes.—Tubes of the UX-201A type are used, and shock-proof mounting is provided to reduce the noise from vibration. The tubes are utilized as follows: (1) detector, (2) first-stage audio-frequency amplifier, and (3) second-stage audio-frequency amplifier.

Filament Circuit.—One rheostat is provided to regulate the filament voltage of all the tubes. The telephone jacks are equipped with filament control contacts so that the insertion of the plug in any of the jacks lights the filaments of the desired tubes.

A small fixed resistance is placed in series with each tube to avoid serious voltage changes due to plugging tubes in or out. The indication of the filament voltmeter governs the adjustment of the filament voltage. The rated filament voltage of 5 volts for UX-201A tubes should not be exceeded. Many operators obtain satisfactory results at 3.5 volts and thus prolong the life of the tubes.

Installation.—Binding posts are provided for the antenna and ground connections. A current of 0.75 ampere at 6 volts for the filament circuit may be obtained from a storage battery, and the voltage for the plate circuits may be obtained from a 45-volt B battery. The binding posts for a C battery should be short-circuited. If 90 volts are applied to the plate circuits of the audio-frequency tubes, a 4.5-volt C battery is necessary.

Operation.—After the tubes have been inserted, the receiver is operated by moving the transfer switch to the "Tube" position. The telephone plug is inserted in the desired jack, and the filament voltage is adjusted to 5 volts by means of the rheostat. In order to tune to a known wave length, the operator sets the secondary condenser to the proper value and advances the coupling pointer to its maximum position at 180 degrees. Then the tickler control is adjusted until the detector just oscillates. The primary-inductance switch is set at the same point as the secondary-inductance switch. The primary condenser is rotated until a double click in the telephones indicates that the antenna circuit is in tune with the secondary circuit. If autodyne reception (page 348) is not desired, the detector must be kept from oscillating by a reduction of the tickler setting. Finally both the primary and the secondary condensers are moved back and forth to locate the position for loudest signals. If the coupling is decreased, sharper tuning is obtained and both the primary and secondary condensers must be retuned.

Adjustment of Coupling.—Loose coupling allows greater selectivity and sharper tuning but does not necessarily result in a reduction of the radio signal strength. For every wave length within the range of the receiver there is a value of coupling which will give the most satisfactory results as regards signal strength and sharpness of tuning. This value is called the *critical coupling*. Figure 20 shows how the selectivity and the strength of the received signal vary for different values of coupling. These curves were taken with the tickler coil at the zero position, and both the primary and the secondary circuits were tuned to 800 meters.

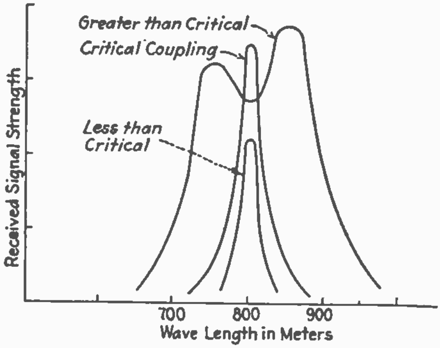


Fig. 20.—Variation of selectivity and signal strength for different couplings.

The curves indicate that as the coupling is made looser, the resonance curve becomes sharper or the selectivity is greater. If the coupling is less than the critical value, the radio-signal strength is reduced considerably. Close coupling makes the receiver resonant to two wave lengths at the same time, one below and one above the desired wave length. Such broad tuning is useful for "stand-by" reception. Critical coupling is obtained when the primary circuit produces no reaction on the secondary circuit.

Test for Critical Coupling.—The secondary condenser is set at the desired wave length and the tickler is advanced slightly beyond the point of oscillation. The primary condenser is rotated slowly back and forth. A double click will be observed in the telephones when the primary condenser passes through the point of resonance with the secondary circuit. These double clicks will merge into one faint click as the coupling is made looser. At this setting the receiver is adjusted for critical coupling. The value of critical coupling changes with the wave length.

The double-click sound in the telephones results from the sudden change of plate current when the detector stops and starts oscillating as the primary wave-length adjustment is moved over that at which the oscillating secondary is set. The greater the distance on the primary condenser dial between these clicks the closer the coupling between the circuits. Before this double-click indication can be obtained, the antenna must be connected so that the primary circuit is complete and can be put into resonance with the secondary, and also the tickler must be adjusted so that the oscillations of the detector are neither too strong nor too weak, and the value of coupling must be greater than critical.

Calibration of Primary Condenser.—The dial of the primary condenser can be calibrated after the receiver is installed, wired, and connected to its permanent antenna. Although calibration often is accomplished by tuning the receiver to distant transmitters, the entire primary dial may be calibrated by the double-click method. With the secondary dial set at the desired wave length, the tickler is advanced until the detector is oscillating. Then the coupling is adjusted for the critical value and the primary condenser can be marked at the point where the double clicks merge into one faint click. This process should be repeated for the principal wave lengths to be used.

General.—A form of volume control which can be operated rapidly is necessary when a powerful nearby transmitter suddenly starts to transmit. The filament rheostat may be used for this purpose.

After the secondary condenser is set for the desired wave length, the degree of regeneration depends on the tickler-coil position, the primary tuning, the primary-to-secondary coupling, and the setting of the filament rheostat.

When a so-called "break-in" system is used, the spacing of the safety protective gap of the receiver should not exceed the thickness of a sheet of newspaper. If the gap is too wide, the high voltage may jump into the receiver and burn the primary winding and switch.

If tube noises are caused by the vibration of a ship, it is helpful sometimes to interchange the detector and amplifier tubes.

When the buzzer battery is in use, it must be insulated from the ground and from the source of filament current. A single dry cell will serve as a buzzer battery.

Reception through static is improved by reducing the coupling to 40 to 60 degrees, detuning the primary slightly, and allowing the detector to oscillate. The noise from the loud crashes may be diminished by dimming the filaments to a point where the sensitivity is not seriously impaired.

IP-503 Loading Unit.—The long-wave loading unit consists of three *loading coils* (page 188) which are used to extend the wave-length range of the tickler coil, as well as the primary and the secondary circuits of the receiver to 18,000 meters. Three ranges of wave lengths are obtained by means of a control switch. The receiver may be used over its normal range of 250 to 8,000 meters by placing the wave-length control switch of the loading unit in the position marked "low," in order to short-circuit the loading coils.

For operation at wave lengths over 8,000 meters, the wave-length switch of the loading unit is set at the "medium" or the "high" position. The antenna and secondary inductance of the receiver are set to their maximums. The desired radio signal is then obtained by rotating the antenna condenser and the secondary condensers of the receiver. The coupling and tickler adjustments are made on the loading unit, and the controls on the receiver are used as before. The coupling and tickler coils of the loading unit may be locked in position to prevent loss of adjustment from vibration.

Part 5

TROUBLE SHOOTING IN TELEGRAPH RECEIVER

(Type IP-501A)

1. **Receiver Will Not Oscillate.**—This may be caused by a reversed B battery, or the adjustment of the tickler coil may be incorrect.

2. **Reception of Spark Signals Is Distorted.**—A reduction of the plate voltage may eliminate the distortion. The adjustment of the tickler coil may be incorrect.

3. **Poor Reproduction Such as Hissing or Howling.**—A detector tube which contains an excessive amount of gas (page 279) will cause hissing. Poor reproduction may result if the filament voltage is too high or if the adjustment of the tickler coil is incorrect. A frequent source of trouble is a poor connection or a defective grid condenser.

Part 6

INDEPENDENT WIRELESS TELEGRAPH RECEIVER

(Type A-1)

The wireless telegraph receiver, as shown in Fig. 21, consists of a variable inductance coil in three sections. A nine-point switch is provided to vary the inductance and to use one, two, or three sections of the coil. When the contact arm of the switch touches point 4 the second section of the coil is added, and the third section is added on point 7. Additional adjustment of the antenna circuit is obtained by means of the variable antenna condenser. Another variable condenser is used to couple the antenna circuit to the detector circuit. As the capacity of the coupling condenser is reduced, the coupling between the two circuits becomes looser. The adjustment of the crystal for maximum sensitivity is tested by the buzzer circuit.

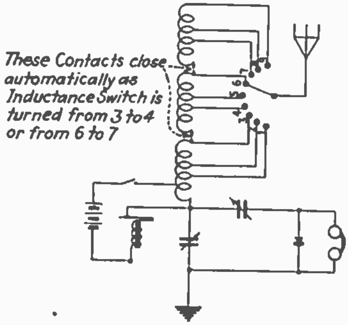


FIG. 21.—Circuit diagram of typical wireless telegraph receiver.

Part 7

SHORT-WAVE RECEIVER

(Type AR-1496B)

The short-wave receiver (type AR-1496B) is designed for the reception of continuous-wave or modulated radio signals which have wave lengths from 12 to 80 meters. The circuit as shown in Fig. 22 consists of a tuned radio-frequency amplifier, a regenerative detector, and two stages of transformer-coupled audio-frequency amplification. The stage of radio-frequency amplification increases the sensitivity and reduces the amount of radiation.

Tubes.—The UX-222 type of vacuum tube may be used in the radio-frequency stage, with a high-amplification tube such as the UX-841 for a detector and tubes like UX-210 as audio-frequency amplifiers.

Another arrangement is to use a UX-222 tube in the radio-frequency stage, a high-amplification tube such as the UX-240 as a detector, and UX-201A tubes as audio-frequency amplifiers.

Power Requirements.—When the UX-210 type of tube is used, an 8-volt storage battery is required. With this arrangement a short-circuiting resistance strip is inserted in the proper location back of the "plug-in" coils in the detector circuit. The voltage across the filaments of the UX-210 tubes is about 7 volts. A voltmeter and separate rheostat are supplied for adjusting the filament voltage of the UX-222 tube. The connection diagram (Fig. 23) indicates terminals for a negative grid-bias voltage of 18 volts; a detector voltage of 67.5 volts, plus; a screen-grid voltage of 43 volts, plus; a plate voltage of 135 volts, plus, for the radio-frequency stage; and 250 volts, plus, for the audio-frequency stages.

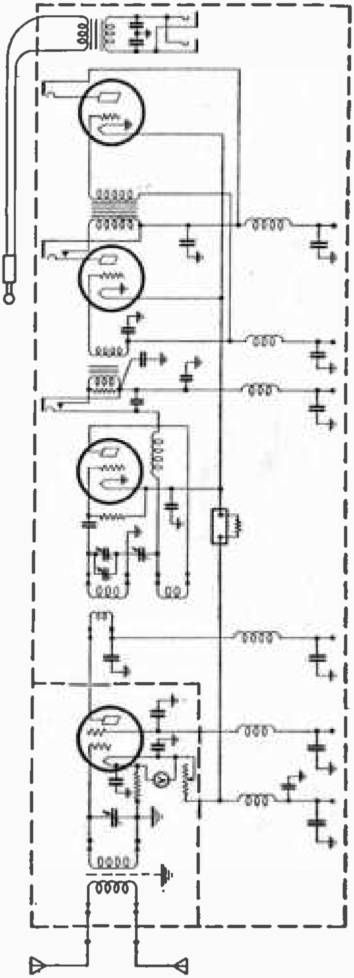


Fig. 22.—Circuit diagram of short-wave receiver (AR-1496-B).

When the UX-201A tubes are used, a 6-volt battery is required. In this case the resistance strip is removed. The voltage across the filaments of the UX-201A tubes is 5 volts. With this combination of tubes there is a grid-bias voltage of 9 volts, the detector plate voltage is 67.5 volts, the screen-grid voltage is 45, the plate voltage on the radio-frequency stage is 135 and also 135 volts on the audio-frequency stages. In either arrangement the negative terminal of the A battery, the B battery, and the positive terminal of the C battery are connected to the *A*, minus, binding post, which is to be grounded.

Radio-frequency filters are inserted in all the battery leads within the receiver. If it is desired to operate two or more receivers from the same battery supply, an audio-frequency filter system is put in to eliminate "cross-talk."

Plug-in Coils.—Four sets of plug-in coils are required to cover the wavelength range. The first set covers the range from 12 to 18 meters, the second from 17 to 28 meters, the third from 26.5 to 45.5 meters, and the

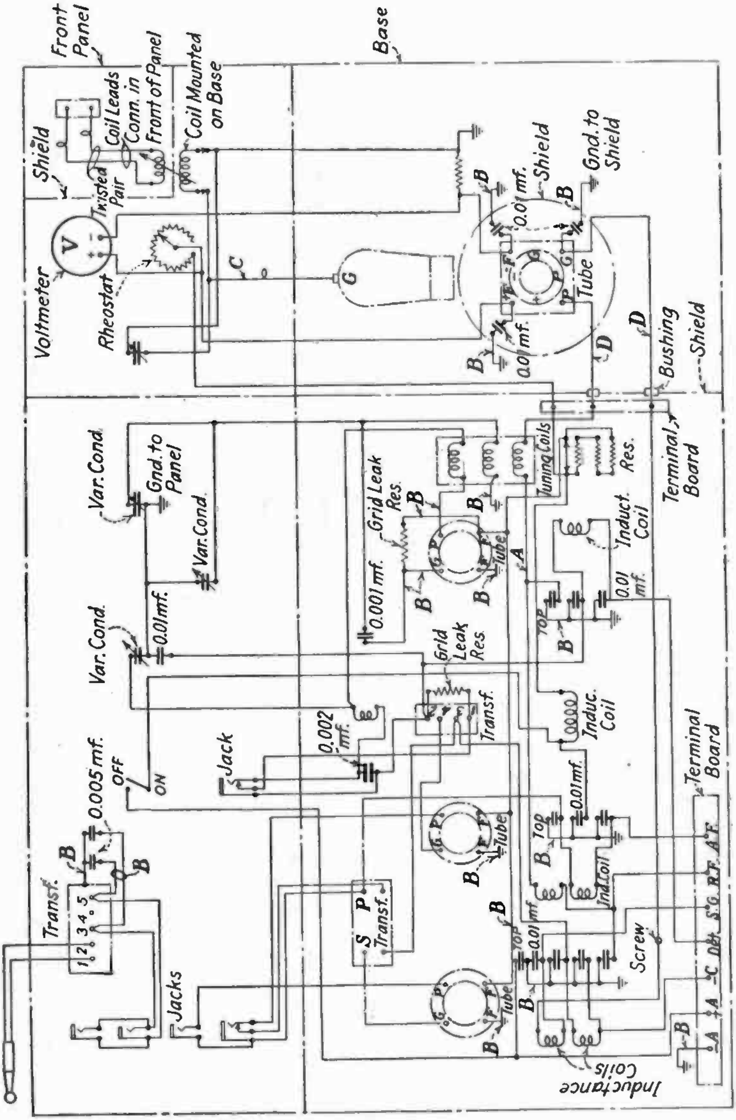


FIG. 23.—Diagram of connections of short-wave receiver (AR-1496-B).

fourth from 45 to 80 meters. One coil of a set is the radio-frequency plate-coupling coil; the other is the detector grid tuning coil together with the tickler. The number of turns on the radio-frequency coils of the first, second, third, and fourth sets is 3, 6, 11, and 19, respectively. The number of turns on the grid coils of the sets in the same order is 2, 4, 8, and 18.

Input Circuit.—The antenna system is connected to the input binding posts. A balanced and shielded input transformer is provided to permit operation from a transmission line. The use of the input transformer has the advantage that a change in antenna characteristics does not affect the frequency of the beat current, the tuning of the detector, or the degree of regeneration. The input coupling coil is designed so that it does not cause any unbalance of the transmission line.

Output Circuit.—The output of the receiver may be taken in several ways. The head phones may be plugged into the detector stage, the first audio-frequency stage, or the second audio-frequency stage. Or the external plug and cord connected to the primary winding of the output transformer may be plugged into the detector jack, the first audio-frequency jack, or the second audio-frequency jack, with the head phones in either of the two jacks for the head phones. The output transformer has a 2:1 step-down ratio. Two output circuits in parallel can be used on the output transformer.

With the UX-210 type tubes the output transformer is designed to work into a 1,200-ohm impedance, and with UX-201A tubes, into a 3,000-ohm impedance.

Controls.—Three tuning controls are provided: (1) input tuning, (2) detector tuning, and (3) regeneration (page 403). The tuning controls have a vernier drive which is variable from a ratio of 7.5:1 to a ratio of 20:1. A small vernier is supplied on the detector tuning condenser for a fine adjustment of the beat note. Other controls are provided for input coupling, for the filament voltage on the UX-222 tube, filament switch, and the four jacks.

Operation.—To "tune in" a continuous-wave radio signal the operator sets the tuning control at the desired point, keeps the input tuning in resonance by listening to the increase of the "background" noise, and maintains the regeneration slightly above the point of oscillation. The most sensitive setting of regeneration is the least amount which permits the detector to oscillate to the extent that a beat note can be heard. Volume may be reduced by increasing the regeneration of the tube above the critical value, by reducing the input coupling, or by the stage change jack system. To tune in a modulated signal the operator must maintain the regeneration near the point of oscillation but slightly below it. It should be noted that the regeneration and wave length increase with the dial setting.

Part 8

WESTERN ELECTRIC SUPERHETERODYNE BROADCASTING RECEIVER

The superheterodyne receiver (Western Electric No. 6204D) is designed for use in broadcasting stations and is to be operated from an antenna system tuned to 500 kilocycles per second (600 meters), while the broadcast transmitter is "on the air." It will detect and amplify radio-telephone signals, and radio-telegraph signals except those transmitted by continuous-wave apparatus. Radio signals may be received having a carrier frequency (page 34) differing by at least 10 per cent from the transmitting frequency. It consists of the 20-A filter unit, the 2-B tuning unit, and the 4-D receiver, as shown in the circuit diagram of Fig. 24.

Filter Unit.—The 20-A filter serves the purpose of preventing interference with reception due to signals from the radio transmitter of the station. The filter is tuned to have high impedance at the frequency of the transmitter but low impedance at the frequency which is to be received. When the controls have once been set to the operating frequency of the station, they need be changed only when the operating frequency is changed.

Tuning Unit.—The 2-B tuner is required to connect the 4-D receiver with the antenna system. It consists essentially of a transformer arrangement with variable coupling. By means of a switch in the primary side of the transformer the antenna can be connected directly to the primary winding, or through a variable loading inductance, or through an antenna tuning condenser in series with a loading coil (page 188). The use of the tuned antenna-circuit connection provides a greater degree of selectivity than would be obtained without it. The secondary winding of the transformer with its midpoint connection is attached to three binding posts on the 4-D receiver.

Receiver.—The 4-D unit is a receiver of the superheterodyne or double-detection type, designed for reception at frequencies from 375 to 1,580 kilocycles corresponding approximately to a wave-length range of 190 to 800 meters. It may be used with a loop or with an antenna in connection with the 2-B tuner. Tubes of the UX-215A type are used in the six stages. The filaments are in series and take a current of 0.25 ampere. They are controlled by one rheostat and operated on an 8-volt battery. A 45-volt battery supplies the plate voltage for all the tubes. When a plug such as is used with head phones is inserted in the output jack, the power amplifier which is connected to the output terminals is disconnected.

Theory of Operation.—The frequencies impressed on the antenna and delivered by the filter to the tuning unit cover the entire frequency range

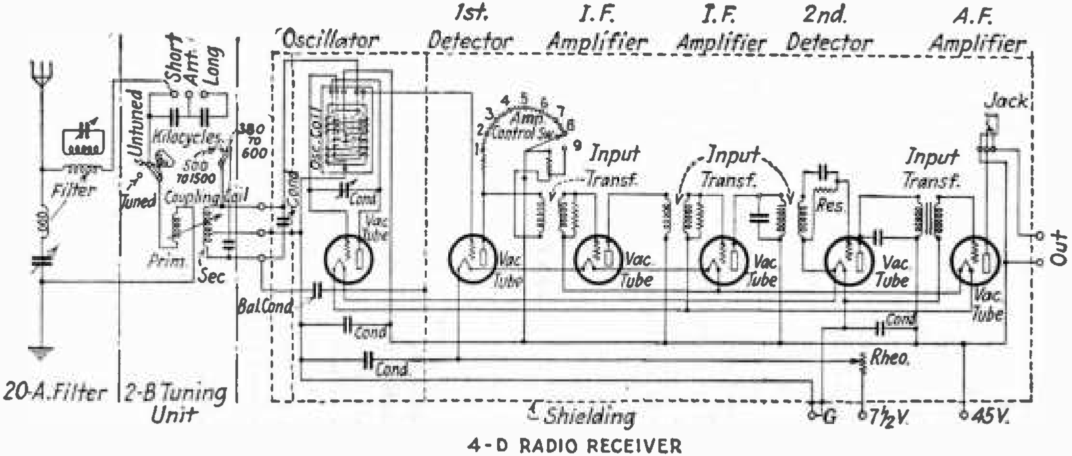


Fig. 24.—Circuit diagram of Western Electric superheterodyne receiver (6204-D).

with the exception of the band eliminated by the filter. These frequencies include static and signals from undesired stations as well as the desired signal, for example 750 kilocycles (400 meters). The tuning of the condenser in the tuning unit allows the selection of the desired signal frequencies together with other nearby frequencies.

The oscillator output is adjusted by the oscillator condenser to produce a frequency of either 793 or 707 kilocycles, each of which differs from the signal frequency by about 43 kilocycles. This frequency, together with the signal and its accompanying interference, interacts in the modulator or high-frequency detector tube. The resultant 43-kilocycle current modulated by the desired signal is passed on to the intermediate-frequency amplifier tubes. It then goes on to the low-frequency detector, which de-modulates the 43-kilocycle current and its side bands to reproduce the original speech-frequency signal. This is amplified in the output stage. The only adjustments necessary are those for carrying out the frequency change and for adjusting the degree of amplification.

Part 9

INTERFERENCE

(Radio Manufacturers Association, New York City)

The proper analysis of interference noises, with respect to their origin, constitutes the greater portion of interference elimination or reduction. The actual correction of the condition is usually a simple matter.

General Classification of Interference.—General interference may be classified first as that caused by atmospheric disturbances and conditions beyond the control of man; and, second, that caused by electrical and mechanical devices. Interference of the first type is not controllable and cannot be eliminated, although sometimes it can be reduced. Intense interference of the second type can be eliminated or reduced if the cause is determined.

Controllable interference may be divided into the following groups according to its source:

Power Circuits

a. Lines.
b. Insulators.
c. Lightning arresters.
d. Transformers.
e. Generators and motors.

Industrial Applications

a. Arc-light circuits.
b. Telephone and telegraph lines.
c. Converters.
d. Street cars and electric railroads.
e. Smoke and dust precipitators.
f. Motors.
g. Sign flashers.

Household Appliances

a. Electric pads or any similar thermostatically controlled devices.
b. Violet-ray machines or any high-frequency apparatus.
c. Flatirons or any type of resistance heaters.
d. Door bells, light switches and motors such as used on vacuum cleaners, washing machines, electric fans, etc.

Miscellaneous

a. *X*-ray machines.
b. Storage battery chargers.
c. Annunciator systems.
d. Stock tickers.
e. Ignition systems.
f. Electric elevators.
g. Electric furnaces.
h. Moving-picture equipment.
i. High-voltage test equipment.

A further and more complete group of devices causing interference is given below:

Arc lights.
Electric heaters.
Electric irons.
Electric ranges.
Automatic railway signals.
Electric curling irons.
Marceling outfits.
Soldering irons.
Waffle irons.
Shaving-mug heaters.
Percolators.
Dough mixers.
Soda mixers.
Electric typewriters.
Electric addressing machines.
Electric computators.
Farm-lighting systems.
Corroded or loose connections in radio set.
Printing presses.
Dust precipitators.
Hair clippers.

Vibrating rectifiers.
Mercury-arc rectifiers.
Flash signs.
Elevator controls.
Leaky cables.
Bad connections in lighting system.
Small motors.
Violet-ray machines.
X-ray machines.
Electric vibrators.
Electric meters.
Door bells and buzzers.
Annunciators.
Oil-burning devices.
Automatic towels.
Electric refrigerators.
Vacuum cleaners.
Motor brushes.
Starting commutators.
Telephone dials.
Telephone magnetos.
Electric cigar lighters.
Street-car switches.
Breaks in third rails of railway system.
Leaky transformer fuses.
Defective light sockets.
Dish washers.

Classification of Noises.—The kinds of interference manifested through the loud-speaker may be classed as follows:

- *a.* Crackles
  - Irregular
  - Regular
- *b.* Hums
  - Irregular
  - Regular
- *c.* Whistles and squeals
  - Irregular
  - Regular
- *d.* Clicks
  - Irregular
  - Regular

Irregular crackles or hums may generally be traced to power lines which are grounded or broken down or to leaky condensers in the radio receiver or in power supply. In the case of seasonal electrical storms, such noises may be due to an electric discharge across lightning arresters.

Regular crackles and hums may be due to motor generators of any description, to thermostatic devices and flashers, or to leaky or defective condensers and wiring in the radio receiver or power supply.

Whistles and squeals, either regular or irregular, are generally due to the *heterodyning* (page 36) of the carrier waves (page 34) of two or more broadcasting stations, which are operating on nearly the same frequency, or to a radio receiver which is being carelessly operated at the oscillating or regenerating point. This can also be traced to improper operation of the receiver in which the interference is noted.

Clicks, either regular or irregular, may usually be traced to telephone dialing systems or the operation of switches in or near the region of the radio receiver.

These classifications are necessarily general, because experience shows that many noises of entirely different characteristics may be emitted from the same kind of devices.

Tracing Interference.—The most important step in eliminating or reducing interference is to trace it to a definite point or device. If the radio receiver uses an antenna system the wire connecting it to the antenna and the wire joining it to the ground connection should be removed from their respective binding posts. A small piece of wire is then connected directly across the antenna and the ground binding posts. When the antenna system is thus removed, any interference which is being picked up outside the radio set itself is reduced or eliminated. If the interference continues with equal volume, an analysis of the radio set should be made.

Due to the selectivity and sensitivity of some radio sets, and to the frequency allocation of broadcasting stations, interference between stations may be noted upon certain nights and at certain hours. This condition, which depends on the factors mentioned, is not, however, always preventable, but a proper knowledge of the receiver and its operation may materially assist in reduction or elimination. The usual manifestation of this heterodyning of broadcasting stations is a "howl" or "gurgle," usually of constant intensity and tone.

Analysis of Interference Origin in Receiver.—The source of interference must be correctly analyzed by a thorough consideration of all possible interference producers and conditions. A systematic procedure as outlined will save much labor and time.

RECEIVERS OPERATED FROM BATTERIES

1. Check all batteries for loose connections or dust accumulation which might cause leakage of electric current and thereby noise.
2. Check all connections to radio receiver.
3. Check the relay (if one is used) for poor contacts.
4. Check the antenna system:
   Aerial. For swinging grounds or contact with other objects.
   Ground. For poor electrical or mechanical connections.
5. Check all tubes for loose elements and poor contact to sockets.
6. Check all connections in the radio receiver. If the receiver is several years old, look for poor electrical contacts at soldered joints, loose lugs and terminals on sockets and condensers, and dust in locations where leakage may occur.
7. Check all by-pass condensers for leaks or breakdown.
8. Check all jacks or switches for poor contact due to oxidized contacts or sprung leaves.
9. Check all possible connections, electrical or mechanical.

10. Check C-battery voltages; a B or C battery may cause much interference due to internal action as result of long use or faulty construction.

11. Check the B battery voltage.

RECEIVERS OPERATED FROM A, B, AND C ELIMINATORS

1. Proceed as suggested in the section above.
2. Check all contacts and connections in the A, B, and C power supplies
3. Check all condensers in power supplies. Much interference has been shown to originate from condensers which have been leaking or broken.
4. Check rectifying devices:

- *A*. Liquid type
  - 1. Acid
    - Electrodes
    - Solution
  - 2. Colloid
    - Electrodes
    - Solution
- *B*. Ionization type
  - Poor tube contact
  - Low rectified output
- *C*. Filament type
  - Poor tube contact
  - Low rectified output
- *D*. Dry type
  - Low rectified output
  - Poor contacts to rectifier

5. Check all resistances
   - Fixed
   - Variable

6. See that units are free from dust and moisture which might cause leakage.

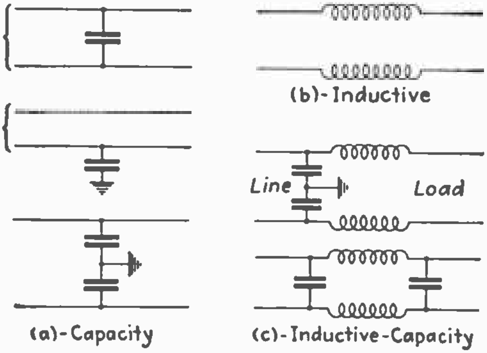
RECEIVERS OPERATED WITH ALTERNATING-CURRENT TUBES

1. Follow the two sections above where applicable.
2. Check all condensers, fixed and variable.
3. Check all tubes carefully.
4. Check all power devices such as transformers used for filament, plate, dynamic speaker supply, etc. Follow the regular procedure for checking B and C power units.
5. If a dynamic speaker is used, check the voice-coil (page 130) connections.

Types of Interference Filters.—The three general types of interference filters as indicated in Fig. 25 are (1) the capacity type, (2) the inductive or choke-coil type, and (3) the combined inductive-capacity type.

A filter of the capacity type may be used on all forms of electrical apparatus which produces radio interference. The flash voltage of such a condenser must be at least five times the highest working voltage of the apparatus with which it is used. For high-voltage apparatus this ratio is reduced to a value of about two. Capacity filters of the grounded type connected across an alternating-current light circuit will pass a considerable current to ground if their capacity is more than about 0.25 microfarad.

A filter of the inductive type is used to block undesired radio-frequency currents because of the high impedance which it offers. In an inductive-capacity type of filter the condenser serves also to by-pass any high-frequency currents. The inductance- or choke-coil type should have the coil wound with the proper size of wire in accordance with the table on page 13.



(b)-Inductive

(a)-Capacity

(c)-Inductive-Capacity

FIG. 25.—Types of interference filters.

Diagrams of Filter Systems.—No interference protection should be attempted without the authorization and instruction of a competent service man or power-company representative. Due caution here will save much inconvenience and possible injury or loss of life. The filter diagrams shown will affect only the device to which they are attached. Interference originating outside the house and transferred to the lighting circuits through the regular house wiring can be effectively reduced, or eliminated, only by a suitable filter at the house meter.

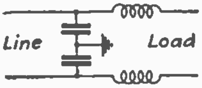


FIG. 26.—Filter system for door-bell and similar services.

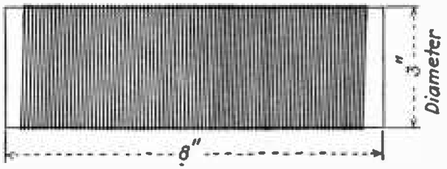


FIG. 27.—Choke coil (type IA).

When it is decided that the noise is due to outside causes, as from the electric light or transmission wires, the local power company should be asked for assistance in reducing or eliminating the interference.

The diagram of the filter system shown in Fig. 26 is suitable for *door-bell buzzer,* and *annunciator* systems. The condensers have a capacity of 1.0 microfarad each and the choke coil is of the type IA shown in Fig. 27.

Diagram *a* of Fig. 28 shows an arrangement intended for heating pads and *thermostatically controlled devices.* A type-IA choke coil is used. If no type of filter will prevent the interference, a variable resistance connected as shown at *b* in the figure may be used. This resistance should be adjusted to a point where the thermostat does not operate but the device is kept at a satisfactory temperature.

Several arrangements of filters for *motors and generators* are shown in Fig. 29. In *a* the condenser has a capacity of 1.0 to 4.0 microfarads. In *b* the condensers have a capacity of 0.1 to 5.0 microfarads each. In *c* the capacity of the condenser is 0.5 to 4.0 microfarads. In *d* a choke coil of type I (Fig. 34) is used and the condensers are of 0.5 to 4.0 microfarads capacity each.

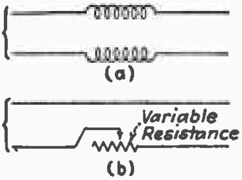


Fig. 28.—Filter system for thermostatic devices.

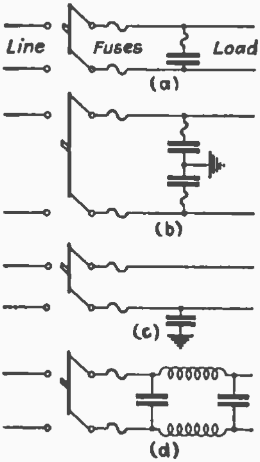


Fig. 29.—Filter systems for electric motors and generators.

A filter of the type in *a* of Fig. 30 is generally applicable to miscellaneous devices. The choke coil is of the IA type and each condenser has a capacity of 0.1 to 5.0 microfarads. If the interference cannot be cleared, it is advisable to try the filter in *b*, which may be designed to tune out the interfering frequency. A type-IA choke coil is used and the condenser has a capacity of 0.02 to 0.5 microfarad.

The filter in Fig. 31 is intended for oil burners in which the ignition plugs are in continual operation. The choke coil is of type IA and each condenser has a capacity of 0.1 to 5.0 microfarads. The frame of the motor and the casting of the furnace should be grounded.

Electric ice machines such as refrigerators using a belt-driven compressor develop interference due to a discharge of static electricity from the belt. This can be corrected if the *electric motor* and the *compressor* are grounded as shown in Fig. 32. The capacity type of filter uses condensers having a capacity of 0.1 to 5.0 microfarads each.

The filter arrangement for a motor-driven *sign flasher* is shown in Fig. 33. Type-IA choke coils are used and each of the condensers has a capacity of 0.1 to 5.0 microfarads.

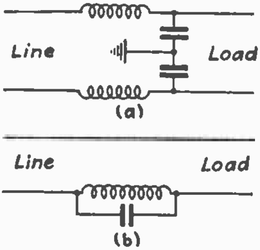


FIG. 30.—Filter system for miscellaneous devices.

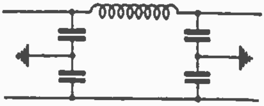


FIG. 31.—Filter system for oil burners.

Choke Coils for Filters.—The choke coil designated as *I* in the diagram of Fig. 29 is made by winding wire on a fiber, bakelite, or paraffin-treated wooden spool having a core diameter of $\frac{3}{8}$ inch, an outside diameter of $1\frac{1}{2}$ inches, and a winding space $\frac{7}{16}$ inch wide. The size of the wire used depends on the current to be used and should be selected in accordance with the table

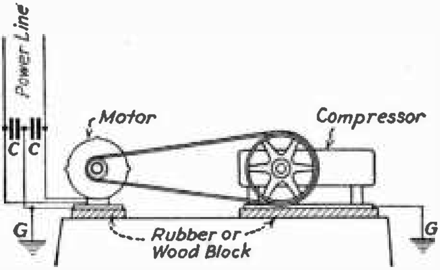


FIG. 32.—Method of grounding electric motor and compressor.

given on page 13. If enameled wire is used, it is best to wind the wire in layers with insulating paper between the layers. Spools wound with cotton-covered wire should be treated with shellac or insulating varnish and then baked. The number of turns is not critical, it being sufficient to wind the form full of the proper size of wire. A typical choke coil for a device requiring 5 amperes or less would be wound with approximately 560 turns of No. 18 B. & S. gage (page 12) double cotton-covered or enameled wire.

When a larger size of wire is used the spool dimensions should be increased. The drawing in Fig. 34 shows the appearance of a completed spool.

The choke coil designated as "IA" in the filters that have been described consists of a fiber, bakelite, or porcelain tube 3 inches in diameter and approximately 8 inches long. Only one layer of wire is wound on it. The wire size will depend on the number of amperes of current and should be taken from the wire table on page 13. If double cotton-covered wire is used, the layer should be treated with shellac or insulating varnish. A typical choke coil for circuits where the current does not exceed 5 amperes is wound with 150 turns of No. 18 B. & S. gage double cotton-covered magnet wire. The number of turns is not critical but when a larger size of wire is used the dimensions of the tube may be increased. The drawing in Fig. 27 shows a completed choke coil of the IA type. Both of the choke coils marked "I" and "IA" are of the air-core kind, and no iron should be placed in the spool or tube on which they are wound.

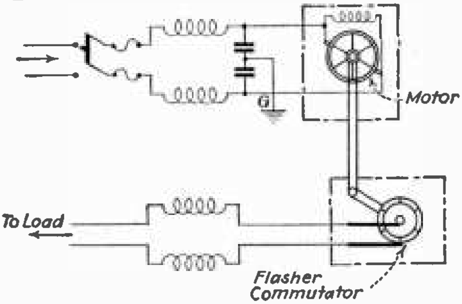


Fig. 33.—Filter system for sign flasher.

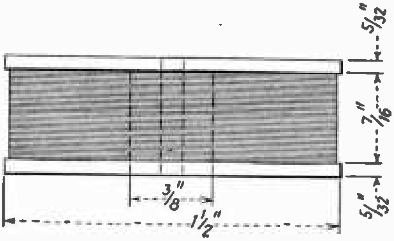


Fig. 34.—Method of winding choke coil (type I) for filter.

Assembled Filters.—A wide range of filters, as made by the Tobe-Deutschmann Corporation of Canton, Mass., is listed in Table XXXII. This gives a good indication of the sizes available as well as the use for which each type is designed.

TABLE XXXII.—DATA OF ASSEMBLED FILTERS

Type, name or number	Voltage		No. of wires	Watts	Form	Use
	Alternating current	Direct current				
Junior......	110	110	2	500	Capacitive	Small appliances such as cash registers using series-wound or universal motors, clippers, drink mixers, egg beaters, hair dryers, sewing machines, vacuum cleaners
10..........	....	110	2	5,000	Capacitive	Chargers, generators, house lighting plants, motors
11..........	110	....	2	5,000	Capacitive	Chargers, generators, house lighting plants, motors
20..........	....	220	2	10,000	Capacitive	Chargers, generators, house lighting plants, motors
22..........	220	....	2	10,000	Capacitive	Chargers, generators, house lighting plants, motors
23..........	220	....	3 wire 3 phase	15,000	Capacitive	Chargers, generators, house lighting plants, motors
	110–220	....	3 wire 1 phase		Capacitive	Chargers, generators, house lighting plants, motors
		110–220	3 wire		Capacitive	Chargers, generators, house lighting plants, motors
55..........	440 or 550	....	2	......	Capacitive	Generators, motors, and other electrical apparatus
56..........	440 or 550	....	3 wire 3 phase	......	Capacitive	Generators, motors, and other electrical apparatus
60..........	....	600	2	25,000	Capacitive	Generators, motors, and other electrical apparatus
Senior......	110	110	2	500	Inductive capacitive	Same as above for more intense interference, as from repulsion-induction motors
110-PO.....	110	110	2	500	Inductive capacitive	Household appliances such as battery chargers, dental motors, dish washers, electric refrigerators, electric signs, heating pads, oil burners, soda-fountain appliances, properly shielded violet-ray and diathermy apparatus, washing machines, and motor-generator sets such as are used for the operation of radio receivers, electric phonographs, neon signs, and certain types of electric refrigerators, also as a filter for the circuit supplying power to the radio receiver
131.........	110	110		1,000	Inductive capacitive	For large apparatus such as motors, generators, and transformers requiring inductive-capacitive filters
132.........	110	110		2,000	Inductive capacitive	
133.........	110	110		3,000	Inductive capacitive	
134.........	110	110		4,000	Inductive capacitive	
135.........	110	110		5,000	Inductive capacitive	

TABLE XXXII.—DATA OF ASSEMBLED FILTERS (*Continued*)

Type, name or number	Voltage		No. of wires	Watts	Form	Use
	Alternating current	Direct current				
221	220	220		1,000	Inductive capacitive	
231	220	220		2,000	Inductive capacitive	
232	220	220		4,000	Inductive capacitive	
233	220	220		6,000	Inductive capacitive	
234	220	220		8,000	Inductive capacitive	
235	220	220		10,000	Inductive capacitive	

SPECIAL UNITS

Type, name or number	Voltage		Watts	Use
	Alternating current	Direct current		
1-DOE	110	110	275	For mercury switch mechanism of Essco flashing traffic beacon
1-DOA	...	...	275	For mercury switch mechanism of flashing traffic beacon
1-DOC	...	...	275	For application to mercury switch mechanism of Crouse-Hinds flashing beacon
1-DOG	...	...	275	For mercury switch mechanism of General Electric flashing traffic beacon
NYL-4	110	110	4,000	Designed for application to four-circuit sign flashers handling not over 10 amperes per branch. Two or more of these units may be applied to a sign flasher operating from a 110- to 220-volt system. One filterette type NYL-4 should be used for each four-circuit section in a multiple-section flasher installation
DM-110-IGN	...	110	1,500	For application to 110-volt 1,500-watt direct-current Delco farm-lighting plant
DM-32-IGN	...	32	800	For application to 32-volt, 800-watt, direct-current farm-lighting plant
110PO	110	110	550	For application to Ritter dental motors
1 HFO	110	...	660	For application to diathermy apparatus such as Engeln, Acme-International, Victor, McIntosh, Fisher, and others, to be used in conjunction with Tobe high-frequency screen, 60 cycles
High frequency screen	...	...	.....	Specially designed for preventing radiation of radio interference created by diathermy apparatus. Must be used in conjunction with Tobe high-frequency filterette

SECTION IX

TRANSMITTING CIRCUITS

Purpose of Transmitting Apparatus.—Electric waves for radio communication are produced by the transmitting apparatus, power being supplied to the transmitter by some kind of electric generator. This power is changed into high-frequency currents which flow in the transmitting antenna (page 180) and cause electric waves to travel out into space. Such waves may be either damped or undamped. *Damped waves* consist of groups of oscillations recurring at definite intervals, with the amplitude of the oscillations in each group decreasing continuously. The number of these groups of waves per second is set within the audible range. Radio *signals* are produced by means of a sending key, which is used to make wave groups for a short or a longer length of time, as may be necessary to produce certain signal effects. An *undamped wave* consists of continuous oscillations with no change in amplitude (page 168).

Damped waves are generated by means of apparatus which depends on the action of some type of spark gap. The induction coil has been used where a low supply of power is sufficient and in emergency communication. Undamped waves may be generated by means of an arc converter (page 531), a high-frequency alternator (page 218), a static transformer (page 134), a frequency multiplier (page 465), or a vacuum tube.

Comparison of Damped and Undamped Waves.—The increasing use of undamped waves in radio telegraph communication is due to several advantages from their use as compared to damped waves. With undamped waves more channels of communication are available, because reception is much sharper and the resonance curve (page 83) has a steeper slope. There is also less interference, because the undamped wave is very even as compared to the damped wave. An undamped wave may be received by means of the beat method (page 408), which offers advantages in amplifying the signal and in adapting the pitch of the note to suit the operator and the conditions of reception. In general, it is claimed that for the same antenna current a greater distance range is possible with undamped than with damped waves.

Antenna Power Output.—The value of the current in the antenna may be expressed in terms of the capacity of the antenna, the voltage on the antenna, and the frequency, by the expression

$$I = 2\pi fCE$$

where I is the antenna current in amperes, f is the frequency in cycles per second, C is the capacity of antenna in farads, and E is the voltage on antenna in volts.

The antenna voltage is given approximately by the relation $E = I \div 2\pi fC$. The value to which the voltage can be increased is limited by economical considerations, and hence, for long-wave transmission, the only other factor which can be varied is the capacity of the antenna. This, in turn, must be considered in terms of a reasonable effective height, because the antenna capacity decreases as the height of the horizontal portion increases. For a given value of signal strength, the relation between the radiation and the *effective height of the antenna* is in inverse proportion; that is, with a high value of radiation, the antenna has a smaller effective height and has a high value of capacity at a medium elevation. Or, with medium radiation, the antenna has a greater effective height and has a medium value of capacity at a high elevation.

Part 1

SPARK TRANSMITTERS

Spark Apparatus.—When a condenser is discharged in a circuit containing inductance, *damped oscillations* are produced. Thus, if a condenser is placed in series with a spark gap as in Fig. 1, the condenser will cause a spark to jump across the gap if the voltage impressed across the condenser is high enough. It is only necessary, then, to produce a regular succession of such discharges. The high voltage may be applied to the condenser by means of a transformer. The primary winding P of a step-up transformer may be wound for 110 volts and the secondary winding for higher voltages up to 20,000. The oscillatory current in such a circuit does not discharge through the secondary winding of the transformer because of its relatively high impedance. Sometimes choke coils are placed in the leads between the transformer and the condenser as an additional means of protection to block the high-frequency current but to allow the flow of the low-frequency current for charging the condenser.

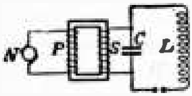


FIG. 1.—Condenser in series with spark gap.

The frequency of the generator which supplies power to the transformer, in this case, is 500 cycles per second. If the spark gap breaks down at the maximum voltage supplied by the transformer, the condenser will discharge one thousand times a second, once for the maximum value of the voltage in each direction. The number of sparks per second is the *spark frequency*. Every discharge of the condenser produces a group of oscillations in the circuit, each of which consists of alternations of current which are decreasing in amplitude.

Arrangement of Circuit.—The circuit diagram shown in Fig. 2 is for a 500-cycle transmitter using a "quenched" spark gap. The generator *G* delivers an alternating current at 110 to 220 volts and 500 cycles per second to the primary winding of the transformer *T*. This low voltage is raised to a high voltage ranging from 8,000 to 20,000 volts by the transformer, and this high voltage charges the condenser *C*. When the voltage across the condenser reaches a value which is high enough to break down the spark gap, the condenser will discharge through the gap and through the primary winding of the *oscillation transformer O*. This oscillating current which flows in the closed circuit including the primary winding of the oscillation transformer is *damped out quickly* to a value at which the spark gap will no longer break down. Then the circuit is open until the condenser voltage again becomes high enough to break down the spark gap.

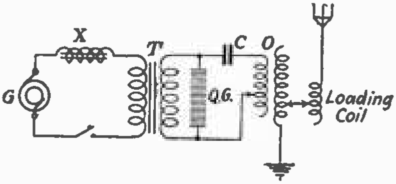


Fig. 2.—Circuit diagram for quenched spark-gap transmitter.

In order that there may be antenna radiation, some of the power in the oscillating circuit must be transferred to the antenna circuit. This transfer is made by means of the magnetic field of the oscillation transformer *O*, the voltage induced in the antenna circuit producing an actual flow of current. Less than half of the power from the oscillating circuit is passed on to the antenna circuit, the other half being used up in resistance and dielectric losses. The frequency of the oscillating current which flows in the closed circuit is determined by the value of the inductance and the capacity in that circuit.

Antenna Circuit.—The antenna circuit is considered as a simple oscillating circuit in which the condenser action is due to the capacity effect between the antenna and the ground. The current flowing in the antenna has the same frequency as the current in the closed circuit. This current is dissipated in overcoming the losses due to resistance, dielectric, and radiation. The portion of the current which is used in overcoming the radiation resistance is the only part that is useful in communication. Ordinarily this forms only one or two per cent of the total energy delivered to the antenna.

Coupling.—The transfer of energy from the closed circuit to the antenna circuit may be controlled by means of the magnetic coupling, Fig. 3, between them. The coupling may be either inductive or direct as indicated in Fig. 3, but the action is practically the same, although inductive coupling offers more flexibility in operation. Also, the use of inductive coupling decreases the transfer of harmonic frequencies (page 72) from the closed circuit to the antenna circuit. On the other hand, the apparatus and circuit with direct coupling is more simple.

In order that there may be an adequate transfer of energy from one circuit to the other, the product of the inductance and the capacity of the closed circuit must be equal to the product of the inductance and the capacity of the antenna circuit. It is necessary, however, to consider that there is an *interchange* of energy between the two circuits which is not desirable; that is, energy from the antenna circuit tends to return to the closed circuit unless the closed circuit is opened by means of a spark gap. The interchange of energy from one circuit to the other continues until the oscillations are damped out. This interchange of energy may be reduced if the coupling is made looser, but, on the other hand, an efficient transfer of energy is not possible with very loose coupling. If the current flowing in the closed circuit could be stopped quickly, the effect of induction from the antenna circuit would be considerably decreased. It is possible to establish this condition by the use of the multiple-disk "quenched" gap (page 457).

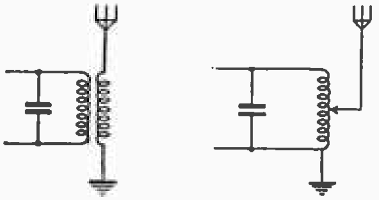


FIG. 3.—Circuit for magnetic and direct coupling.

Resonance Frequency.—In an alternating-current circuit the condition of resonance occurs when

$$2\pi fL = \frac{1}{2\pi fC}.$$

where f is the resonance frequency in cycles per second, L is the inductance of the circuit in henrys, and C is the capacity of the circuit in farads. Adjustments for resonance are made by changing the value of inductance or capacity. By utilizing the effect of resonance, it is possible to increase the voltage in the oscillating circuit to a value which is much greater than that due to the ratio of the number of turns in the windings of the transformer. Variation in voltage as the frequency is changed is indicated in Fig. 4. The circuit is not, however, tuned exactly to the operating frequency in order to avoid a ragged note. Even a slight detuning permits the production of a

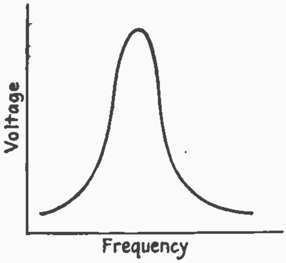


FIG. 4.—Variation in voltage with changes in frequency.

good note and at the same time allows enough resonance effect to properly charge the condenser.

If the generator voltage is reduced to the point where the spark gap breaks down only in every second half cycle, the note obtained has a frequency of 250 cycles per second or a pitch of "500."

Part 2

ARC TRANSMITTERS

The arc transmitter is used for radio communication, generally of the "C.W." (continuous wave) telegraph type (page 530), although the larger stations are also provided with a "chopper" (page 543) for "I.C.W." (interrupted continuous wave) communication.

Characteristics of Arc Transmission.—An arc transmitter without a chopper supplies a continuous current to the antenna and produces a wave which has a decrement of almost zero. Hand signaling does not have any appreciable effect on the decrement, but in high-speed signaling the decrement increases with the rate of signaling. This effect occurs because the oscillations in the antenna circuit reach their greatest amplitude gradually when the key contact is made, and then decrease again when the key circuit is opened.

Action of Arc Transmitter.—A circuit diagram of an arc transmitter is shown in Fig. 5. The complete transmitter consists of a generator, an arc converter, a loading inductance coil, and a signal system. The purpose of the arc is to change the direct-current power of the generator into the high-frequency power required for radio telegraph communication with continuous waves. The positive side of the arc is connected to the antenna circuit and the negative side to the ground. When the arc is open, the

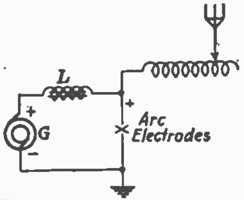


FIG. 5.—Circuit diagram of arc transmitter.

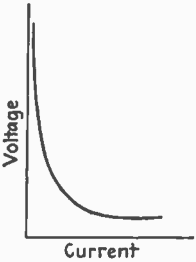


FIG. 6.—Relation of resistance of arc to changes in current.

current from the generator flows into the antenna circuit, charging it to a point where the voltage becomes sufficient to break down the spark gap between the electrodes of the arc. The arc is maintained by the current from the generator and the resistance of the arc is reduced with an increase in the current as indicated in Fig. 6.

The rapid increase in the resistance of the arc as the current decreases occurs because the current flow between the electrodes of the arc depends on the conducting path of the ionized gases. When the current is decreased to a low value the supply of ions is not sufficient to provide a conducting path of low resistance.

The arc is established by bringing the electrodes into contact and then separating them so that a flow of current results and the antenna circuit is slightly charged. When the charge on the antenna reaches a maximum value, the antenna current reverses its direction and begins to flow through the arc to the ground. The increase in the current flowing between the electrodes of the arc decreases the resistance of the arc and thus hastens the discharge of the antenna circuit. The flow of current from the antenna continues until the antenna circuit is charged in the opposite direction. Under this condition, the current begins to flow from the ground to the antenna, but since this opposes the generator current, the resultant current flowing through the arc is reduced gradually and becomes zero when the generator current balances the antenna current. When the arc is opened, the generator current flows into the antenna circuit, charging it to the point where the arc is again established.

The generator is provided at its positive terminal with a condenser type of protective device to by-pass any radio-frequency current to the ground and thus prevent it from entering and damaging its windings.

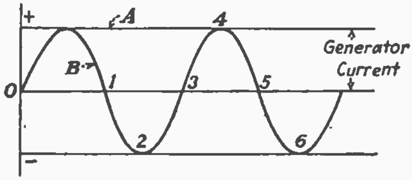


FIG. 7.—Relation between arc and generator currents.

Current Relations.—It is possible to deliver 50 per cent of the energy of the arc to the antenna when the wave form of the oscillating current is a sine wave (page 168) and when the arc is extinguished during each cycle. If the direct current has a value equal to the peak of the alternating current, the antenna current has a value which is equal to that of the direct current divided by $\sqrt{2}$ (page 73). The relation between the two currents which flow through the arc is shown in Fig. 7. The generator current is constant at a value indicated by the line A, and the antenna current is indicated by curve B. The effective value of the radio-frequency current is equal to its maximum value divided by $\sqrt{2}$. When the two currents are flowing in the same direction, the current through the arc reaches its maximum value of twice the generator current. When the currents are opposing each other and the alternating current reaches its maximum value, the current becomes zero and the arc is extinguished. If the radio-frequency current is equal to the direct current divided by $\sqrt{2}$, and if the same relation holds between the radio-frequency voltage and the voltage of the direct current, then the product of the current and voltage relations shows that the radio-frequency power is equal to half the direct-current power. This indicates a maximum efficiency of 50 per cent.

If the maximum value of the oscillating current is *less* than the direct current of the generator, the arc is not broken at any time. Although the "form" of such an oscillating current closely approximates a sine wave, the operation is critical and a good output of power is not easily produced. If, however, the maximum value of the oscillating current is *equal* to the generator current, the arc is broken periodically. Operation under these conditions is less critical and a greater amount of power may be put into the antenna than when the oscillating current is less than the generator current. In general, the best form of wave and the most satisfactory conditions of operation are obtained when the maximum value of the oscillating current is equal to or greater than the direct current.

Characteristics of the Arc.—An *arc converter* consists of one electrode of carbon or graphite and another of copper in an arc chamber and a device for producing a magnetic field. The space between the electrodes is de-ionized more quickly if the arc is surrounded by a medium having the property of high diffusion, such as hydrogen or hydro-carbon gases, and if a magnetic field is set up to act transversely on the arc. The field is produced by the choke coil L (Fig. 5) which serves also to block the high-frequency current from entering the generator. The arrangement shown for exciting the field is called *series excitation*. *Shunt excitation* has the advantage of flexibility but is more complicated. The strength of the field may be controlled by varying the number of turns of wire in the field and must be adjusted carefully for best results. Multiple arcs are formed if the field is too weak, and the arc lengthens too quickly if the field is too strong. Although a weaker field should be used with higher wave lengths, no change in field strength is necessary over the range of wave lengths in ordinary operation. In general, the field strength must be varied with the frequency.

The copper anode of the arc is water cooled to prevent the melting of the metal and to contribute to the de-ionizing of the arc. The cooling is necessary because half of the output of the generator is lost as heat in the arc. The graphite or carbon cathode must be rotated so that the surface is burned away evenly and the arc is steady. The copper electrode is connected to the antenna and also to the positive terminal of the generator. The graphite electrode is connected to the ground and to the negative terminal of the generator.

Methods of Signaling.—In arc transmission the output of the arc must be kept constant, and consequently signaling cannot be carried out by varying the output as in spark transmission (page 456). Two methods of signaling have been developed: (1) the *compensation method*, in which the length of the radiated wave is changed, or (2) the *uni-wave* method, in which the current in the antenna is diverted into a dummy circuit.

A diagram of a circuit in which compensation signaling is applied is shown in Fig. 8. When the key circuit makes and breaks, it causes a change in the effective inductance of the antenna which also affects the length of the radiated wave. When the key circuit is connected directly across a portion of the loading inductance, the effect of short-circuiting a few turns is to reduce the inductance of the antenna circuit and consequently to reduce the wave length. When the key circuit is connected inductively to the loading inductance, the effect of a current in the key circuit is to set up a field which acts to decrease the field of the loading coil, and hence decreases the inductance of the antenna circuit. The wave length is affected only when the key circuit is closed. A serious disadvantage of this method of signaling is that two waves are present. Either the long or the short wave may be used for signaling depending on the way in which the key is connected. Signaling with the long wave or "telegraph wave" has the advantage of constant adjustment. In signaling with the short or compensation wave, the effect of poor contacts or improper key action becomes more apparent in reception.

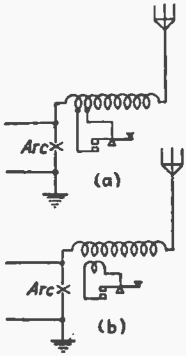


FIG. 8.—Circuit diagram for compensation signaling.

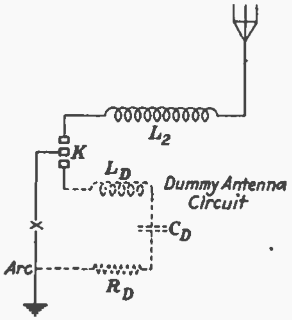


FIG. 9.—Dummy antenna circuit for uni-wave signaling.

Although reception is possible if the difference between the telegraph and compensation waves is less than one per cent of the transmitting wave, considerable interference between the two waves may be encountered.

The uni-wave method of signaling has been developed to avoid the difficulties due to the radiation of two waves as in the compensation method. It depends on the use of a dummy antenna circuit as shown in Fig. 9. When no transmission is going on, the output of the arc is transferred by means of the key to the dummy circuit. The wave length of the dummy circuit should not differ too greatly from that of the antenna circuit but it need not have the same value.

Coupling.—The arc circuit may be coupled inductively to the antenna circuit as indicated in Fig. 10 instead of being directly in the antenna circuit. The inductive coupling has the advantage that the arc circuit may be adjusted to give the best operating conditions and that harmonics (page 72) are almost entirely prevented from entering the antenna circuit. In this arrangement signaling is accomplished by short-circuiting a portion of the coupling inductance.

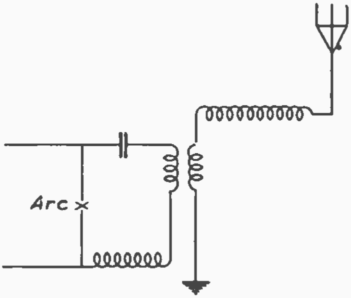


Fig. 10.—Inductive coupling of arc circuit to antenna circuit.

Part 3

HIGH-FREQUENCY ALTERNATORS AND FREQUENCY CHANGERS

Theory of Operation of High-frequency Alternators.—The construction of the high-frequency generator has been described on page 218. Such a generator is preferably coupled inductively to the antenna circuit, although direct coupling has been used.

The *Alexanderson* high-frequency *alternator* is of the inductor type (page 218), operating at about 22,000 cycles per second, 2,000 volts, and has been built in sizes up to 200 kilowatts. The movement of the slots on the rotor causes a variation in the reluctance (page 9) of the magnetic circuit. This results in a varying magnetic field around the armature windings. The frequency of the voltage induced in the armature windings depends on the number of poles, the speed of rotation, and the rate of change of the field. The speed is regulated by varying the supply voltage to the motor. A variable series reactance is inserted in the supply circuit and the magnetic saturation is controlled from a direct-current supply to correspond to the changes in speed. Then the voltage across the motor is changed so as to oppose changes in speed. The method of signaling is based on the variation of the antenna current and is suitable for hand signaling, high-speed signaling, and telephony. This effect is accomplished by means of a magnetic amplifier across the output side of the high-frequency transformer. The iron-core inductance of the amplifier is excited with a direct current and also carries the high-frequency current. The value of the high-frequency current in the antenna may be varied by changing the strength of the exciting current.

In the *Goldschmidt alternator* the frequency is increased by reflection. If a frequency of f_2 is generated with *direct-current* excitation, the use of *alternating-current* excitation at a frequency f results in the generation of two frequencies $f_1 + f_2$ and $f_1 - f_2$. If the exciting frequency f is equal to f_1 and to f_2, then the generated frequencies become $2f$ and zero. If another alternator, having similar characteristics and the same speed, is excited with this current at the frequency of $2f$, it will generate two frequencies of $2f + f = 3f$ and $2f - f = f$. It is possible to combine these several steps for frequency multiplication in one unit instead of using a number of separate machines. In the Goldschmidt alternator a direct current is used to excite the stator (page 217), and the rotor generates a current of frequency f. The field of this rotor current generates two currents in the stator, having frequencies of $2f$ and zero, which combine with the direct current provided for excitation. These two stator currents in turn generate currents in the rotor having frequencies of $3f$ and f. The phase of the generated current having a frequency f is opposite to the phase of the fundamental current of frequency f. This tends to eliminate the flow of currents of lower frequencies. A continuation of these reactions indicates that odd multiples of f are generated in the rotor, and even multiples in the stator. The reactance of the circuits must be designed so that the flow of currents of multiple frequencies is not impeded. Tuned circuits are provided for each frequency up to the desired value.

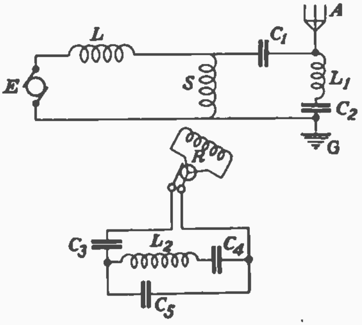


FIG. 11.—Transmitter with Goldschmidt alternator.

The circuit diagram of a transmitter using the Goldschmidt alternator is shown in Fig. 11. The stator winding S of the machine takes a direct current from the exciter E. The rotor winding R generates a current of frequency f which flows in the tuned circuit consisting of R, C_3, L_2, and C_4. By "reflection" a current of frequency $2f$ is generated in the winding S and flows in the tuned circuit consisting of S_2, C_1, L_1, and C_2 but is prevented from entering the generator E by the choke coil L. By another reflection a current of frequency $3f$ is generated in the winding R and flows in the tuned circuit consisting of R, C_3, and C_5. By a third reflection a current of frequency $4f$ is generated in the winding S and flows in the tuned circuit consisting of C_1, S, G, and the antenna A.

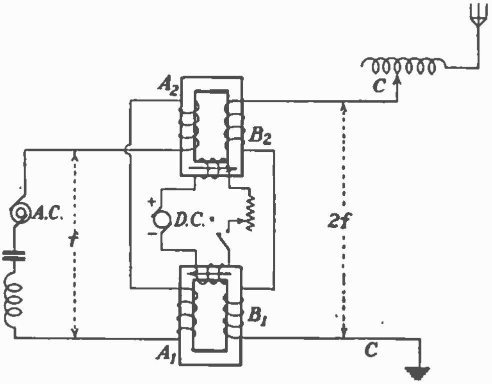


Fig. 12.—Frequency-multiplying static transformer.

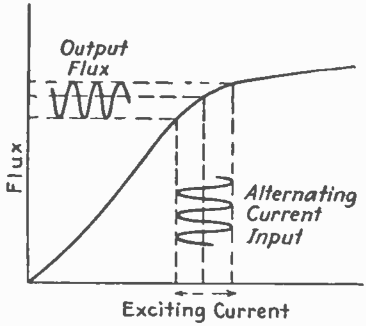


Fig. 13.—Magnetization curve of frequency-multiplying static transformer.

The frequency-multiplying static transformer such as is used by the Telefunken Company and in the Sayville Station on Long Island depends on the magnetization property of iron whereby an increase in the magnetizing force beyond a certain limit does not result in a corresponding increase in the flux (page 59). A transmitting circuit using this arrangement is shown in Fig. 12. The secondary windings of the two transformers are in series in the antenna circuit. The primary windings are in series in the generator circuit. The third windings on each transformer are in series and connected to a direct-current source of supply. The magnetic saturation of the cores is obtained by the application of the direct current, which is adjusted so that the flux is maintained at the bend of the magnetization curve shown in Fig. 13. The direct-current generator must be protected from high-frequency induced currents by means of a choke coil. The flux in the cores has the direction indicated by the arrows. The primary windings are connected in such a manner that when the alternating current in one winding is flowing in the same direction as the direct current, the alternating component in the other primary winding opposes the direct current. Only a small *increase* in flux occurs when the currents are in the same direction, because the core is saturated, but when the currents are opposed, the *decrease* in flux is much larger. When the variation of flux is high in one transformer

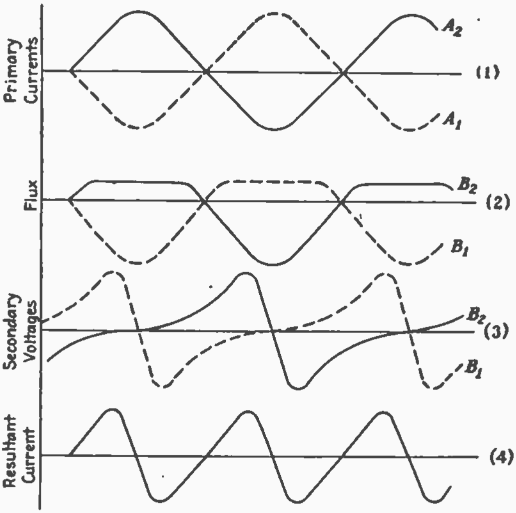


FIG. 14.—Flux and current variation in frequency-multiplying transformer.

it is low in the other. In Fig. 14 the heavy curve of drawing 1 indicates the current in the primary winding A_2 and the dotted curve indicates the current in A_1. The flux variations are indicated in the curves of drawing 2. The value of the voltage induced in the secondary windings depends on the rate at which the flux changes and is a maximum where the slope of the flux curve is steepest, as shown by the curves in drawing 3. The curve obtained by adding the two curves in drawing 3 may be used to indicate the form of the resultant current, as shown in drawing 4. This resultant current has a frequency which is twice as large as that of the fundamental current.

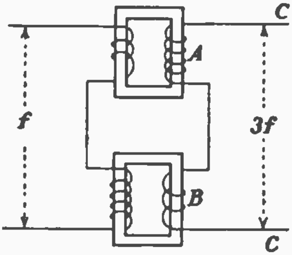


Fig. 15.—Arrangement of transformers for tripling the frequency.

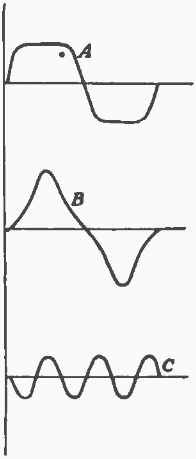


Fig. 16.—Wave form for tripled frequency.

The frequency may be tripled by the arrangement of transformers shown in Fig. 15. The direct-current magnetizing circuit which is used in the frequency doubler is not used. The proportions and connections of the windings are designed to give the wave form shown in Fig. 16.

Part 4

VACUUM-TUBE TRANSMITTERS

Advantages of Vacuum-tube Transmitters.—The vacuum-tube transmitter, like the arc transmitter, produces a continuous wave. This method of transmission, however, offers several advantages with respect to the purity of the wave form, the simple methods of keying, the flexibility in operation over a wide frequency range, and the modulation which can be effected readily for radio telephony or for interrupted continuous-wave telegraph transmission.

Types of Transmitters.—The most efficient of the three types of vacuum-tube transmitters is the C.W. transmission unit, which is used for telegraphy. Signals from such a transmitter are received by the *autodyne* (page 348) or *heterodyne* (page 36) scheme of reception. In radio telephony the radio-frequency continuous waves are modulated at audio frequency by the voice or music. The range in telephony is about one-fourth of that obtained with the same equipment on C.W. telegraph transmission. Signals from a radio telephone transmitter, like any damped-wave (page 168) signals, may be received by the ordinary method of detection. In I.C.W. transmission the continuous waves are modulated at audio frequency by using a 500-cycle current supply for the plate circuits of the tubes, by opening and closing the grid-leak circuit periodically, or by the use of a motor drum "chopper" (page 479) in the grid circuit. I.C.W. signals may be received either by ordinary detection or by the autodyne or the heterodyne methods. With ordinary detection the note is affected by the type of modulation, and with autodyne or heterodyne reception the receiving note is "mushy."

Transmitting Circuits.—The most common circuits used for vacuum-tube oscillators have been described on page 390. In the *Hartley circuit* the connections from the plate and grid of the tube are made to the ends of the coil, and the filament is connected to the middle of the coil. In this case the feed-back is due to inductive action. The tuning condenser is connected across part of the grid end of the coil and also part of the plate end of the coil. In the *Colpitts circuit* the connection from the filament of the tube is made to a point between two condensers, and the connections from the grid and plate are made to the other terminals of the condensers. In this case the feed-back is due to capacitive action. If the tuning condenser of a Hartley circuit is connected only across the plate end of the coil, the circuit is called a *tuned-plate circuit*. If the condenser is across only the grid end of the coil, the arrangement is a tuned-grid circuit. In the *Meissner circuit* the grid, plate, and antenna circuits are coupled magnetically. In the master-oscillator circuit a separate tube is used as an oscillator with the Hartley or the Colpitts circuit.

C.W. Telegraph Transmitter.—Many circuits have been developed in which vacuum tubes are applied to generate radio-frequency currents. The action of several of these has been described on page 390. The diagram which is shown in Fig. 17 is a modification of the Meissner circuit, designed for a range of wave lengths from 250 to 500 meters. In this arrangement L_1 is a coil having an inductance of 200 microhenrys which is common to both the plate circuit and the antenna circuit. The grid coil L_2, which is coupled to the coil L_1 and placed inside it, is used to feed back energy from the inductance coil L_1 in order to provide continuous oscillations in the antenna. The grid coil L_2 has an inductance of 50 microhenrys. The variable air condenser C_1 has a capacity of 0.000,70 microfarad and is connected across the grid coil L_2. The adjustment for the maximum antenna current is made by means of this condenser instead of by changing the number of turns in the grid coil, so that fewer turns of wire are required on the grid coil than would otherwise be needed.

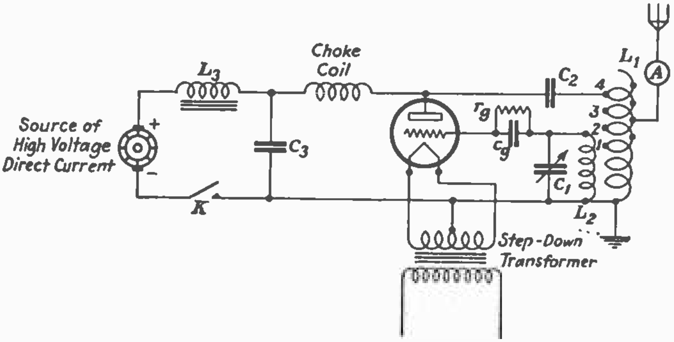


FIG. 17.—Modification of Meissner circuit for C. W. transmission.

Coupling to Antenna.—The three general methods of coupling by which radio-frequency energy is transferred from the closed circuit to the antenna circuit are designated as (1) direct, (2) inductive, and (3) capacity.

In *direct coupling* the antenna circuit is connected to the inductance of the closed circuit. This is equivalent to connecting a capacity across the part of the tuning inductance, and consequently the frequency of the circuit is affected. Direct coupling is seldom used in transmitters of the commercial type, because the operation of the circuit is affected by any weather conditions which change the capacity of the antenna.

In *inductive coupling* the inductance of the primary coil or tank circuit is placed in inductive relation to the inductance of the secondary coil or antenna circuit. An antenna loading coil, if necessary, is connected in series with the secondary coil.

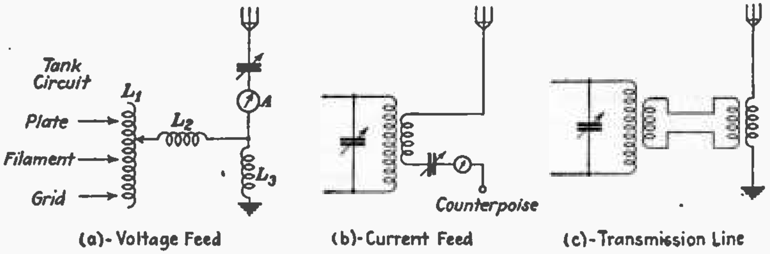
In *capacity coupling* the primary circuit and the antenna circuit are coupled by a condenser which is common to both. Any adjustment of this condenser affects the tuning of both circuits.

The coupling between circuits is said to be *close* or *tight* when a small change of current in one circuit produces an appreciable effect in the other circuit. With *loose coupling* one circuit has only a slight effect on the other. In a direct-coupled circuit the coupling is made tighter or looser by increasing or decreasing the amount of inductance common to both circuits. In an inductively coupled circuit, the coupling is made tighter or looser by moving the coils nearer to each other or farther apart and also by increasing or decreasing the inductance. In a capacity-coupled circuit the coupling is made tighter or looser by decreasing or increasing the capacity.

When the coupling between two circuits is loose, the circuits are *resonant* to one frequency. If the coupling is increased or tightened, both circuits are no longer resonant to the original frequency; each circuit now is resonant to *two* frequencies, one lower than the original and one higher. The value of coupling at which the circuits are resonant to but one frequency is *critical coupling*. If the coupling of a transmitter is loosened to less than the critical value, the current in the antenna circuit is reduced.

A rule sometimes used is that the coupling may be loosened, or the circuit may be detuned, until the reading of the antenna ammeter is about 75 per cent of its maximum value with any adjustment. For this condition there is a single sharp resonance peak as the antenna tuning condenser is varied.

Feed Line to Antenna.—If it is not convenient to locate the antenna near the transmitting set, the two units may be connected by a radio-frequency feed line as illustrated in Fig. 18. This method is also known as *voltage feed* in contrast to the method of *current feed* in inductive coupling. The series reactance represented by coil L_2 in the figure may be a condenser, but preferably a coil. The coil is not so convenient in operation as a condenser but it has the advantage of suppressing the radiation of harmonic frequencies.



(a)-Voltage Feed (b)-Current Feed (c)-Transmission Line

FIG. 18.—Methods of connecting antenna to transmitter.

In the application of such a feed line, the primary or tank circuit is tuned in the usual manner. Next, the feed line is connected, using all the turns of the coil or a low setting of the condenser. Then the antenna inductance and capacity are adjusted to obtain resonance in the antenna circuit as indicated by the ammeter A. After this, the series reactance is decreased by reducing the inductance of coil L_2 or increasing the setting of a condenser to a point at which the tube oscillates feebly. The same result may be obtained by shifting the feed-line connection on coil L_1 nearer to the filament connection. After these changes, it may be necessary to retune the primary and the antenna circuits. The last step is to check the state of resonance between the primary and the antenna circuits.

The *transmission line method*, shown at *c* of Fig. 18, has several advantages: (1) Its voltage is low, (2) it is not tuned to the frequency at which radiation takes places, (3) its high-frequency resistance is low, (4) the current flow is small, and (5) the power loss is low.

Grid Condenser and Grid Leak.—The grid condenser C_g (Fig. 17), which has a capacity of about 0.002 microfarad, is shunted by a high-resistance grid leak r_g of about 5,000 ohms. This resistance may be connected, however, directly from the grid to the filament. The purpose of this grid leak and the condenser is to allow the grid to have a certain definite voltage which is necessary for its most efficient operation.

Blocking Condenser.—The blocking condenser C_2 (0.002-microfarad capacity) is necessary to isolate the oscillating circuit from the high-voltage direct current of the plate circuit. This condenser passes the generated radio-frequency current to the oscillating circuit so that this current may flow in the antenna circuit.

Choke Coil.—A radio-frequency choke coil of 300 turns of the honeycomb type is used in the plate circuit of the tube to prevent the generated radio-frequency current from entering the power-supply circuit. The distributed capacity (page 86) of this coil must be low and its fundamental wave length should be equal to that at which the circuit is operated.

Filament Power Supply.—The filament of the vacuum tube may be lighted by either direct or alternating current. The use of alternating current is preferable because it produces a more uniform distribution of current throughout the filament than direct current. With direct current one end of the filament carries more current than the other (page 300) with a consequent reduction in its light intensity. The connection to the power circuit is made by means of a step-down transformer. The return wires from the grid and the plate circuits are connected to a center tap on the secondary winding of the transformer. The purpose of this connection is to maintain a voltage on the grid which is the same as that of the midpoint of the filament. This is done to prevent the generation in the transmitter of a modulation current or ripple having a frequency of 60 cycles.

The filaments of tubes in telegraph transmitters are usually heated with alternating current. In radio telephone transmitters the filaments are heated with direct current to avoid the alternating-current hum which accompanies the modulation. When the plate-circuit return wire is connected to one side of the filament, that side operates at a higher temperature than the other and will burn out more rapidly. To equalize this action, a *polarity reversing switch* may be used by means of which the plate current can be supplied to either side of the filament circuit.

Filters.—Several types of filters are used in the power circuits of the vacuum-tube type of transmitters to reduce the voltage fluctuations. The objection to fluctuations of voltage is that they modulate the radio-frequency current in the antenna circuit. Such fluctuations may be caused by poor commutation in the direct-current generator or by the imperfect rectifying action of vacuum tube or chemical rectifiers (page 256). A "low-pass" type of filter is used in the power circuit to prevent current fluctuations of high or medium frequencies from entering the plate circuit of the tube but to allow the passage of currents of *low* frequency. The low-pass filter used in such a circuit may consist of an iron-core choke coil L_3 which has an inductance of 10 henrys and the condenser C_3 with a capacity of 8.0 microfarads. This filter is designed to pass frequencies of 36 cycles per second or less and to attenuate higher frequencies.

Plate-voltage Supply.—A direct-current high-voltage supply is required for the plate circuit of the vacuum tube. This may be obtained from a direct-current generator or from an alternating-current source and some type of rectifier.

Series and Shunt Feed for Plate Circuit.—In the *series method* of supplying voltage to the plate of a tube the source of power is in series with the plate coil. One end of the coil and its condenser are at the high voltage of the direct-current supply and thus present a source of hazard to the operator.

In the *shunt method* the plate voltage is supplied to the circuit through a by-pass path by means of a blocking condenser and a choke coil. In this case the high voltage of the direct-current power supply is kept from the condenser.

In order that the plate coil may not be short-circuited with respect to radio-frequency currents, the reactance of the blocking condenser at the operating frequency must be low compared with the reactance of the choke coil. The radio-frequency current is prevented from entering the generator windings by the action of the choke coil; as an added precaution such choke coils may be inserted in both of the leads of the plate-supply circuit. Fuses are placed in the plate-supply leads to avoid damage from short-circuits, and an overload circuit breaker may be provided in the positive wire. In the *shunt-feed method*, the direct current and the radio-frequency current are separated before they reach the plate winding but unite again at the filament. In the *series-feed method*, the two currents separate after leaving the plate winding and unite again at the filament.

Keying Arrangements.—The operation of "keying" may be accomplished by causing the tube to stop oscillating, by breaking the antenna circuit, or by changing the frequency of oscillation.

A key placed in the primary winding of the main power transformer to the plate circuit in a self-rectifying system (page 480) will stop the supply of power. This method has the disadvantage that considerable time is required for a complete discharge of the condensers in the rectifier-and-filter unit of the power supply. The key is placed between the main filter and the set. In this case, the so-called "key thump" is avoided by using a small keying filter between the key and the set. Also, the filaments must be supplied from a separate transformer, or by another source of current.

A key placed in the grid leak or in the wire supplying the grid-bias voltage will cause oscillations to cease when it is opened. This occurs because the charge on the grid cannot leak away when the key is opened and consequently the voltage of the grid soon becomes so negative that the plate current falls below the value which sustains oscillations.

A key may be placed to open the negative high-voltage lead in a battery or a direct-current generator system. This may be accomplished directly with a hand key or indirectly with a relay and an auxiliary key. The parts which carry the full current must be designed so that they will not overheat or break down from the voltage.

A key placed in the filament circuit of a vacuum tube in a self-rectifying system is usually connected so that the break is made between the filament and the connection to the *B*-minus terminal which is also connected to the grid.

Various types of key filters have been developed to reduce the interference which is a result of the abrupt starting and stopping of the oscillations. In one arrangement the key is shunted by a high resistance which allows the continuation of weak oscillations when the key is opened. In another arrangement, the key is shunted by a circuit consisting of inductance, capacity, and resistance which is intended to delay the beginning of oscillations by the action of the inductance, and to avoid the sudden break in the power circuit by the action of the condenser.

Thus "keying" is accomplished by two general methods depending on whether the opening of the key *stops all oscillation in the antenna* or *changes the wave length of the oscillations.* In the first method the key or relay is placed in the grid circuit or in the plate circuit of an amplifier tube in the low-power stages. In the second method the key is connected in the oscillation-generator circuit in such a way that the closing of the key either short-circuits a portion of the inductance of the oscillation circuit or increases its capacity. This has the effect of changing the frequency of the oscillations. By the use of two keys in this manner, several messages may be transmitted at the same time, thus utilizing the full power of the transmitter with one antenna system and one oscillation generation (*Onde Electrique*, July, 1922).

Master-oscillator Power Amplifier.—A vacuum-tube transmitter in which the generating circuit is connected directly to the antenna circuit will radiate harmonics (page 72) in addition to the fundamental wave (page 188), which are a source of interference to receiving stations. The radiation of harmonics is eliminated in the master-oscillator power-amplifier circuit, in which an amplifier is connected by capacity or inductive coupling to the generating circuit. The function of an amplifier of this kind is to allow the maximum amplification of the output of the generating circuit with the minimum amplification of the harmonic frequencies (page 72). In order to accomplish this, the generating circuit must be "stiff"; that is, the ratio of inductance to capacity must be large; also, the output circuit (antenna) must be tuned to the fundamental frequency of the generating circuit. This arrangement allows the use of a crystal-controlled, stiff oscillator circuit which is not applicable to high-power tubes. Also, modulation may be effected at a low level of power, and consequently the music or speech does not have to be amplified to correspond with the final output of the transmitter.

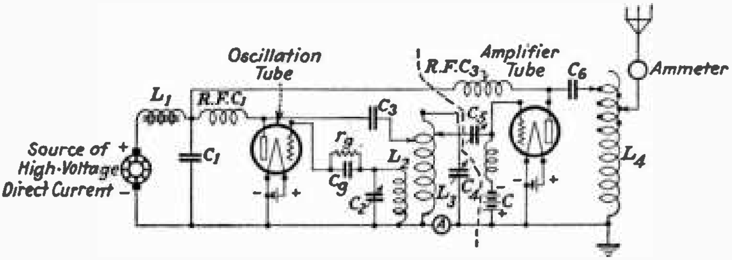


FIG. 19.—Power-amplifier circuit with master oscillator.

A wiring diagram of the *master-oscillator power-amplifier circuit* for a range of wave lengths between 300 to 500 meters is shown in Fig. 19. The apparatus on the left-hand side of the dotted line comprises the generating circuit and is similar to the Meissner circuit (page 468), except that the condenser C_4 is used instead of the antenna system. The coil L_3 has an inductance of 250 microhenrys. Consequently, in order to maintain a high ratio of inductance to capacity, the capacity of the condenser C_4 must be small, having a value of 0.003 microfarad. The other constants in this portion of diagram have the same values as in the previous circuit (Fig. 17). The amplifier circuit, which is shown on the right-hand side of the dotted line, is connected to the generating circuit by capacity coupling through the condenser C_5, which has a capacity of 0.000,30 microfarad. With capacity coupling the grid of the amplifier tube is supplied with a negative grid-bias voltage to the extent that the plate current is reduced to one-half of its rated value during periods when the oscillation generator does not provide any radio-frequency controlling voltage. Consequently, the efficiency of operation of the amplifier is increased considerably. If, however, the grid of the power amplifier puts a load of more than 20 per cent on the master oscillator, the advantages of the arrangement are lost. A radio-frequency choke coil RFC_2 similar to the one described previously is connected to the grid circuit in series with the grid battery C. This choke coil allows the passage of direct current but prevents the short-circuiting of radio-frequency current through the battery. The radio-frequency choke coil RFC_3 is similar to the other choke coils, and the radio-frequency by-pass condenser C_6 has a capacity of 0.002 microfarad. This condenser must be designed for the maximum voltages that may occur with the vacuum tubes that are used. The antenna coil L_4 has an inductance of 200 microhenrys. The power of the amplifier tube must be considerably greater than that of the oscillation tube.

In another arrangement of this kind a master oscillator excites the grids of an intermediate amplifier of one or more stages by means of a coupling condenser. The plate circuits of the stages in the intermediate amplifier are then coupled by means of a condenser to the grid circuits of the tubes in the main amplifier.

Feed-back through the electrode capacities of the amplifier tubes may be neutralized by the use of a neutralizing condenser (page 372) as in a receiving set. The neutralizing condenser is connected from a point on the coil L_3 to the plates of the amplifier tubes. No neutralization is needed if screen-grid power amplifier tubes (page 306) are used, because they have a very low grid-plate capacity.

The wave length of the master-oscillator is to be maintained at a fixed value and the purpose of the amplifier is to increase the power supplied to the antenna by amplifying the output of the master oscillator. Consequently, the wave length of the radiated wave is not affected by the swinging of the antenna. If the frequency of the radiated wave must be held to very close limits, the following quartz-crystal method of control may be utilized.

Crystal Control for Master Oscillator.—The frequency of a transmitter can be held within very narrow limits by utilizing the piezo-electric effect (page 125) of a quartz crystal to control the frequency of the master oscillator. A diagram of such an arrangement is shown in Fig. 20. The crystal is connected into the grid circuit of the oscillator tube. When the crystal is connected in this way it serves as the equivalent of the tuned grid coil in the tuned-grid tuned-plate circuit. The characteristic of crystal control is that for several degrees of change in the plate-tuning condenser, the frequency of the output is determined by the crystal. Consequently changes in voltages, and in the plate resistance of the tube, have but very little effect on the frequency of oscillation. The temperature of the crystal must be maintained at a constant value, as otherwise the frequency at which the crystal resonates will be affected. The radio-frequency choke coil RFC_1 which is in series with the grid-bias lead is useful in establishing oscillations and is necessary to prevent radio-frequency currents from entering the source of C voltage. The feed-back which is required to force the crystal to oscillate is controlled by the adjusting coil L_1 and the condenser C_1, while the condenser C_2 is connected to the coil L_1 near the plate lead from the oscillator tube. The voltage drop across this condenser is used to excite the grid of the amplifier tube.

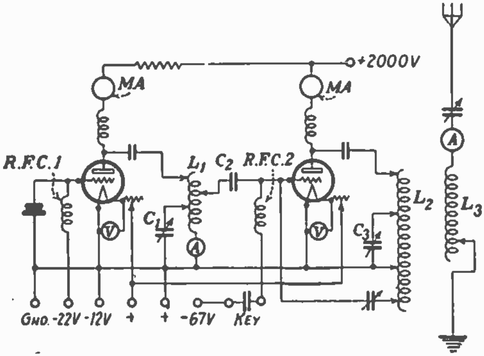


FIG. 20.—Crystal control for master oscillator.

The circuit of the amplifier tube is tuned to resonance with the frequency of the crystal by means of coil L_2 and the condenser C_3. The grid-bias voltage for the grid of the amplifier tube is obtained through the radio-frequency choke coil RFC_2. A neutralizing condenser may be connected from a point of coil L_1 to the plate of the amplifier tube to prevent a reaction on the crystal, and each stage should be shielded to avoid coupling effects. Adjustment of the antenna circuit for the maximum output is made by means of the tap on the inductance coil L_3.

Frequency-doubling Amplifier.—Frequency control with a crystal is not practical for high power or high frequency. At the ordinary broadcasting frequencies the crystal can take care of the output of a 5-watt tube. At lower frequencies the limit is about 50 watts. At frequencies as high as several thousand kilocycles per second the crystal must be very small and thin. If the crystal is overloaded, it may crack. This difficulty is avoided by using a large crystal as an oscillator at a frequency of, for example, $f \div 2$ where f is half of the frequency which is required for the antenna current. The tube is grid-biased to generate a second harmonic at a frequency f. This output excites the grid of the next tube which generates a second harmonic having a frequency of $2f$. This new output which now has the correct frequency is then amplified and radiated. This transmitter may be operated on direct current or on alternating current. A pure direct-current supply is required for broadcasting transmission, but a slight ripple may be desirable in the output for telegraph transmission.

Modulated-wave Transmitters.—In this type of transmitter the continuous waves are modulated by the voice at audio frequency, by the (1) *buzzer method* or (2) *chopper method.*

Several circuit arrangements have been devised to modulate the output of a *radio telephone transmitter.* Among these are the *grid-voltage variation method*, the *plate-voltage variation method*, sometimes called the *Heising method*, and the *antenna-current absorption method.* A circuit diagram of a transmitter for radio telephony using the plate-voltage variation method of modulation is shown in Fig. 21. The portion of the apparatus to the right of the dotted line comprises the oscillation circuit which supplies a continuous-wave output. The portion of the apparatus to the left of the dotted line is the modulating circuit. The apparatus required for the oscillating circuit is similar to that described previously for a C.W. telegraph transmitter (page 468). The apparatus required for the modulating circuit

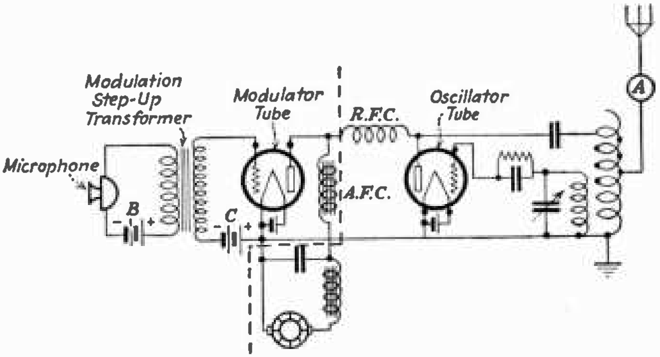


Fig. 21.—Circuit diagram of transmitter for radio telephony.

consists of a microphone (page 132), a step-up transformer, the modulator tube, the audio-frequency choke coil *AFC*, having an inductance of two henrys, and a grid battery *C*. In this circuit the modulator tube and the oscillator tube are identical in size and in characteristics. The audio-frequency choke coil is designed for maximum inductance with minimum resistance.

The power for the circuit which includes the microphone and the primary winding of the step-up transformer is supplied by a six-volt battery B. When the diaphragm of the microphone is actuated by a sound wave, it sets up in the microphone circuit a varying current which produces large voltage variations in the secondary circuit, that is, in the circuit connected to the secondary winding of the step-up transformer. These voltage variations are impressed on the grid of the modulator tube. The variations of voltage on the grid serve to control the voltages impressed on the plate of the modulator tube and the plate of the oscillator tube, because of the action of the audio-frequency choke coil. The grid battery *C* is required to maintain the voltage on the grid at the midpoint of the straight portion of the grid voltage-plate current curve (page 395) when the vacuum tube is not in operation. Under these conditions a voltage impressed on the grid produces undistorted currents in the plate circuit of the tube. The proper value of the grid-bias voltage to use with any tube depends on its type and should follow the recommendations of the manufacturer of the tube.

Speech-amplifier Circuit.—In a radio telephone transmitter used for broadcasting, the variations of voltage in the circuit containing the secondary winding of the modulation step-up transformer are not of sufficient amplitude properly to modulate the output of the oscillation circuit. The amplitude of the voltage variations depends on several factors which, in most cases, cannot be controlled, such as insensitive microphones, a low ratio of turns in the windings of the modulation transformer, or an insufficient "sound" input to the microphone. More amplification may be obtained by the use of a speech input amplifier.

A *speech-amplifier circuit* consisting of one stage is shown in Fig. 22. In this diagram the microphone circuit consists of the microphone, the 6-volt battery B, and the primary winding of the modulation transformer. The input circuit of the amplifier consists of the secondary winding of the modulation transformer. The input circuit of the amplifier consists of the secondary winding of the modulation transformer, the grid of the amplifier tube, and the grid battery C_A; the value of the grid-bias voltage depends on the type of tube that is used. The output circuit of the amplifier stage consists of the plate of the amplifier tube, the choke coil L_1, which may have an inductance of 4 henrys, and the plate B battery. A varying current flowing through the choke coil L_1 produces a varying voltage across it. This voltage, through the action of the coupling condenser C_1 (0.5 microfarad), is applied to the grid of the modulator tube T_M. A negative grid-bias voltage is placed on the grid of the modulator tube so that operation may take place at a point where the voice reproduction is most faithful. The purpose of the choke coil L_2 (10 to 50 henrys) is to allow the negative grid-bias voltage to reach the grid of the tube but to prevent the audio-frequency voltages from being short-circuited through the grid-bias battery C_M. The values of the inductance of coils L_1 and L_2, as well as the voltages of the plate, filament, and grid batteries, depend on the types of vacuum tubes used.

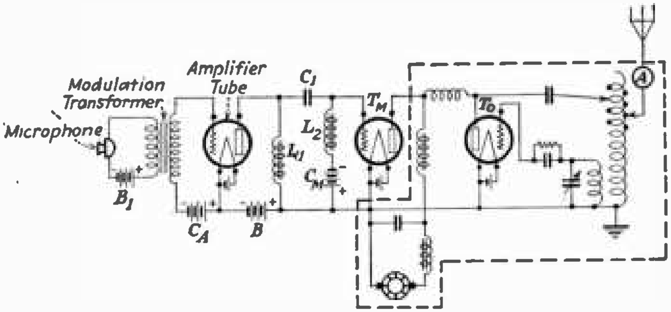


FIG. 22.—Speech-amplifier circuit.

Buzzer and Chopper Modulation.—By the substitution of a buzzer and key for the microphone it is possible to produce variations of the current flowing in the primary winding of the modulation transformer.

In the *"chopper" method*, modulation is effected by the action of a make-and-break device inserted in the grid circuit of the generating tube. One such device consists of a brush in contact with the edge of a metal disk. The outer edge of the disk is slotted and the slots contain an insulating material. The disk is driven by a motor at the speed necessary for the required frequency of interruption, or the modulation. If the circuit is broken one thousand times a second, the radiated wave has a form which produces in a receiver a note which is similar to that from a quenched-spark transmitter operating at 500 cycles per second. The rate at which the antenna is charged is very high; that is, the increment of the wave is high, although its decrement is low. A transmitter of this type causes interference in antennas located nearby. Its greatest use is in the U. S. Navy for communication under emergency conditions.

Alternating-current Vacuum-tube Transmitter.—In another type of interrupted continuous-wave telegraph transmitter, the so-called alternating-current vacuum-tube transmitter, the power supply for the plate circuit is obtained from a 500-cycle unit. This arrangement is known also as a self-rectifying transmitter. The method was developed primarily to allow the use of the power equipment provided for transmitters of the spark type. The secondary winding of the transformer in the power-supply circuit generally is arranged to provide about 3,000 volts. The filament supply may be obtained from an additional winding on this transformer, or a separate transformer may be provided. One terminal of the filament of each tube is connected to a mid-tap on the secondary winding of the transformer. The vacuum tubes are connected as shown in Fig. 23 in order that both halves of the cycle of power may be utilized. The purpose of the choke coils in each plate circuit is to prevent currents of radio frequency from flowing into the windings of the transformer. The radio-frequency components of the currents from the two tubes are combined through the condensers C_1 and C_2. A transmitter of this type radiates a wave which, when received with a non-regenerative vacuum-tube receiver or a crystal detector, produces a note clearer than that of a spark transmitter operating on a frequency of 500 cycles per second. If the tubes are operated in excess of an efficiency

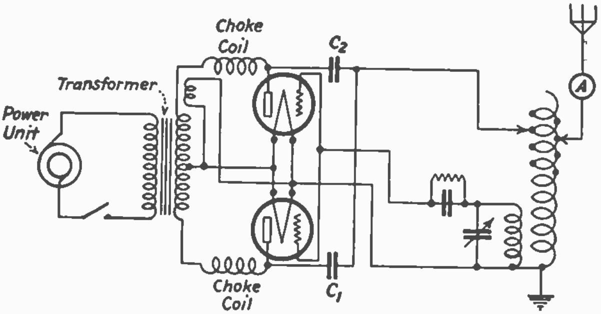


FIG. 23.—Arrangements of tubes in alternating-current transmitter.

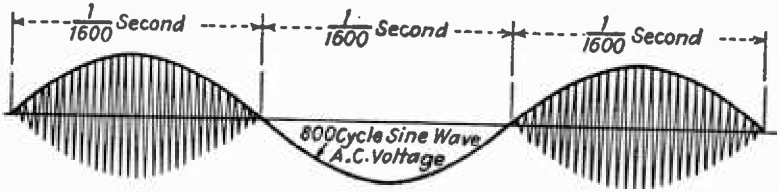


FIG. 24.—Form of wave from alternating-current transmitter.

of 50 per cent, the form of the wave is distorted, and filters or coupled circuits should be provided to prevent as much as possible the radiation of harmonic frequencies.

If only one-half of a cycle of power is utilized, the plate becomes positive 500 times a second, the tube oscillates 500 times a second, and the radiated wave has a varying amplitude and consists of groups of 500 per second. The vacuum tube does not operate during the negative portion of the cycle. When both halves of the cycle are utilized, the wave consists of groups of 1,000 per second. The radiated wave is completely modulated by the alternating-current supply; that is, the oscillations are reduced periodically to zero, as shown in Fig. 24.

Part 5

MODULATION IN RADIO TELEPHONY

In radio communication modulation is the process of producing variations of a required form in the amplitude of the wave which is radiated.

The antenna current of a continuous-wave generator can be modulated by three methods: (1) absorption modulation, (2) grid-bias modulation, and (3) plate modulation.

Absorption Modulation.—In the simplest application of this method a microphone is inserted in series with the antenna circuit. The antenna current flows through the microphone and its amplitude depends partly on the resistance of the microphone. The resistance of the microphone is changed by the effect of a sound wave and thus the antenna current is modulated as shown in Fig. 25. The form of the modulated current is alike or symmetrical on each side of the zero or reference line, because both halves

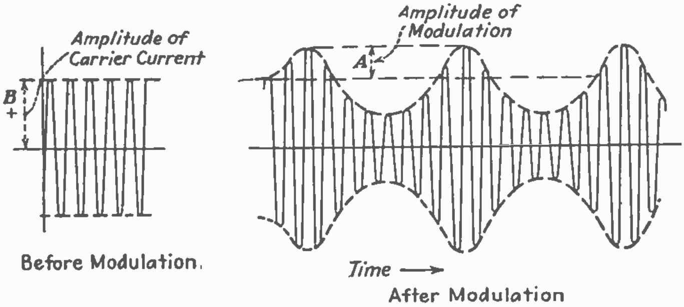


Fig. 25.—Form of modulated current.

of the cycle of current are affected by the microphone. This arrangement is called the *absorption method* because modulation is accomplished by absorbing power from the antenna. The amount of absorption varies with the intensity of the sound.

The microphone may be coupled directly across a few turns of the antenna inductance or it may be coupled inductively. With inductive coupling it is possible to match the resistance of the microphone to that of the antenna. The absorption method is used only with small outputs and the degree of modulation possible is low.

Percentage of Modulation.—The current before modulation is called the *carrier current* because it is the medium which transmits the variations of the sound wave in the form of current. The current after modulation is considered to consist of two parts: (1) the carrier current and (2) the modulating current. The ability of the carrier to transmit the modulation depends on the amplitude of the modulating current compared to that of the carrier current.

In Fig. 25, the modulation amplitude A is one-half of the carrier amplitude B, and the percentage of modulation is said to be 50 per cent. If A is equal to B, *100 per cent modulation* is obtained. The percentage of modulation is equal to the ratio of the modulating amplitude to the carrier amplitude, expressed in per cent. The carrier is utilized most efficiently at 100 per cent modulation. If the modulating amplitude exceeds the carrier amplitude, distortion occurs because the lower peaks of the modulating current are cut off, and the carrier is said to be overmodulated.

Carrier Frequency.—The frequency of the carrier wave should be at least three times that of the highest important speech frequency in telephony which may be taken as 5,000 cycles per second. Actually the carrier frequency usually is more than twenty times the highest modulating or sideband frequency.

Grid-bias Modulation.—This arrangement is simple in application but unstable in action and is used mostly in transmitters of low power. In the grid-modulation method the speech frequencies are introduced into the grid circuit of the vacuum tube through a modulation transformer which serves to isolate the high voltages and also to match the impedances of the circuits. This method depends on a variation of the grid-bias voltage of the oscillator tube in a self-excited system or the modulation of the output current of the exciter in a separately excited system.

One arrangement for grid-circuit modulation applied to a Hartley oscillator is shown in Fig. 26. When a sound wave strikes the microphone, the voltage induced in the secondary winding of the modulation transformer varies the grid voltage at an audio-frequency rate. This produces corresponding variations in the antenna current. The disadvantage of this method is that the output current is not affected to any considerable extent by changes in the grid voltage over the range in which stable operation takes place. If the grid voltage is reduced below this range, the tube stops oscillating and the antenna current drops to zero. A fair degree of modulation is possible by fine control of the grid leak and the load on the tube.

Plate-voltage Modulation.—This arrangement is used mostly in large transmitters, because more audio-frequency amplification is required than with the grid-voltage method. Modulation by the plate-voltage variation is possible because the value of the oscillating current is proportional to the plate voltage over a wide range. The method may be applied in any oscillator or amplifier having tuned-circuit coupling. In an amplifier it is necessary to provide sufficient excitation in the grid circuit.

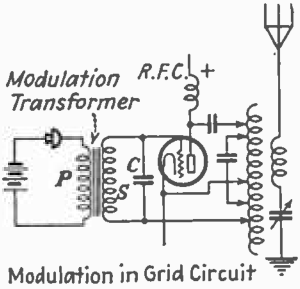


FIG. 26.—Grid-circuit modulation.

In the simplest form of plate modulation the microphone circuit is coupled through a modulation transformer to the plate circuit of an oscillator tube. The audio-frequency voltage induced in the secondary winding of the transformer varies the plate voltage, and consequently the antenna current also is varied. This arrangement, however, is applicable only to low-power circuits, because a microphone circuit is not designed to provide the power that must be supplied to the plate circuit of the tube. A complete fluctuation of the plate current from zero to double current requires an amount of power which is equal approximately to that supplied to the oscillator. The modulating device must either provide this power or control its supply. The microphone circuit is inadequate in this respect, hence its effect must be amplified by another tube called a *modulator tube*.

The action of the modulator tube may be regarded as (1) a speech-controlled amplifier or generator of speech-frequency power or (2) a speech-operated resistance which inserted in series with the plate source and the oscillator tube causes the voltage of the latter to vary. Usually these are classified as separate methods, the first being called *constant current* or the Heising system, and the second *constant voltage*. Another term sometimes used is that of *transformer* method.

Constant Current or Heising Modulation.—The constant-current circuit for plate modulation is shown in Fig. 27. In this arrangement the tube *O* is an oscillator with its associated circuit, *M* is a *modulator tube*, *B* is the common source of battery, or may be a generator, to provide power which is supplied to both tubes through a large choke coil L_2, and L_1 is a choke coil which is used to prevent radio-frequency currents from entering the modulator-tube circuit. The modulator tube does not supply any radio-frequency power to the oscillating circuit *LC*. The plate current of the modulator tube is controlled by means of the grid-bias voltage so that it has a value equal to the plate current of the oscillator tube when the latter is in oscillation.

If the negative grid-bias voltage of the modulator tube is increased, the plate current is reduced and there is a small decrease in the battery current.

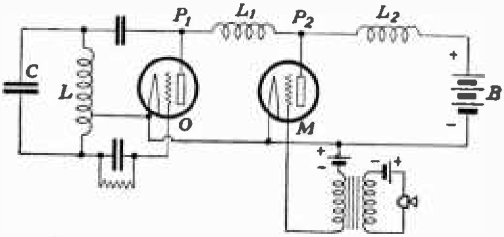


FIG. 27.—Circuit for Heising modulation.

When the current flowing in the choke coil L_2 is decreased, an induced voltage is set up which tends to maintain a constant flow of current. This induced voltage is in the same direction as the voltage of the battery. Consequently, there is an increase in the voltage on the plates of the two tubes and also an increase in the oscillating current in the circuit *LC*.

If the negative grid-bias voltage on the modulator tube is decreased, that is, if the grid-bias voltage becomes more positive, the plate current from the battery increases, and a voltage is induced in the choke coil L_2 in such a direction as to oppose the voltage of the battery. Consequently, the voltage on the plates of the two tubes is decreased, and the oscillating current is reduced. If the voltage variations applied to the grid of the modulator tube have a voice-frequency range (page 1), the variations in the amplitude of the oscillating current in the circuit *LC* will also be in the voice-frequency range.

One disadvantage of the constant-current circuit for modulation is that a number of modulator tubes operated in parallel are necessary to produce a high degree of modulation. The reason for this can be shown by an analysis of the relation between the modulated current and the unmodulated current. In order that the available power of the transmitting set may be utilized to the greatest extent, the arrangement for modulation must be capable of varying the amplitude of the radio-frequency current from zero to twice the unmodulated value. If this is accomplished, the plate current of the oscillator tube also should vary from zero to twice the unmodulated value. During modulation, the increase in the plate current of the oscillator tube is equal approximately to the decrease in the plate current of the modulator tube. The value of the modulation current I_m (amperes) delivered to the oscillator tube by the modulator is given by the expression

$$I_m = \frac{E_{p2}}{R_{po} + R_{pm}}$$

where E_{p2} is the change of voltage in volts on the plate of the modulator tube due to modulation, R_{po} is the resistance in ohms of the plate circuit of the oscillator tube, and R_{pm} is the resistance in ohms of the plate circuit of the modulator tube. The value of the unmodulated plate current I_o (amperes) of the oscillator tube is given by the expression

$$I_o = \frac{E_b}{R_{po}}$$

where E_b is the battery voltage in volts.

If it is assumed that E_{p2} is equal to E_b, then the ratio of the modulation current to the *unmodulated current* becomes

$$\frac{I_m}{I_o} = \frac{R_{po}}{R_{po} + R_{pm}}.$$

From this equation it is apparent that complete modulation cannot be secured by the constant-current circuit because the condition of $R_{pm} = 0$ cannot be attained.

The resistance R_{pm} may, however, be reduced by connecting several modulator tubes in parallel. The efficiency of a power-amplifier tube may be about 60 per cent or more; that is, about two-thirds of the power supplied is radiated, and one-third is dissipated as heat at the plate. Hence if one modulator and one amplifier are used, the modulator must dissipate three times as much power as the amplifier. Or, if the tubes are of the same size, three modulators should be provided to one amplifier. Because of the difference in efficiencies of the two types of tubes, the proportion of five modulators to three oscillators is commonly used. Another way to avoid this difficulty is to use a higher voltage on the plate of the modulator tube than on the oscillator tube. The voltage is impressed on the circuit by means of a coupling condenser. There are several ways of applying the higher voltage; for instance, a separate plate supply may be used in series with the plate lead to the modulator; two separate plate generators may be used for the modulator and the tube in which modulation is applied, with transformer coupling between stages. Or, with a common plate supply, a series resistance may be inserted in the plate circuit of the tube, which is modulated, in order to reduce the plate voltage by 15 to 20 per cent. Such a resistance is shunted by a condenser which passes the audio-frequency output of the modulator plate circuit to the amplifier plate. The reactance of the condenser must be low for audio frequencies.

Transformer Modulation.—The transformer circuit for modulation is shown in Fig. 28. In this arrangement the audio-frequency power from an amplifier is supplied to the plate circuit of the oscillator tube by means of the modulation transformer. The value of the modulation voltage is controlled by means of the voltage in the primary circuit of the transformer and by the transformer ratio. It is possible in this way to obtain complete modulation.

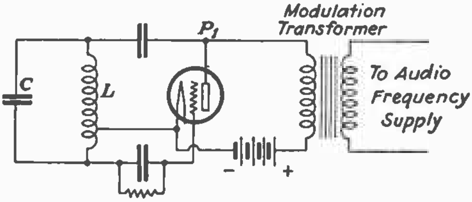


FIG. 28.—Circuit for transformer modulation.

Value of Modulation Current.—In the diagram of a modulated current, shown in Fig. 29, A is the amplitude of the carrier wave (page 34) and B is the amplitude of modulation. It may be shown that the modulated current, which appears to have constant frequency and a varying amplitude, consists of three currents, the amplitude of each being constant. The *first* is the original unmodulated current; the *second* is a current which has an amplitude equal to one-half the amplitude of modulation and a frequency which is equal to the sum of the frequency of modulation and the frequency of the carrier wave; the *third* is a current which has an amplitude equal to that of the second current, but its frequency is equal to the difference between the frequency of modulation and the frequency of the carrier wave. The frequencies of the two modulated currents are known as the *side frequencies*, or the upper and lower *side bands* when modulation is in the audio-frequency range.

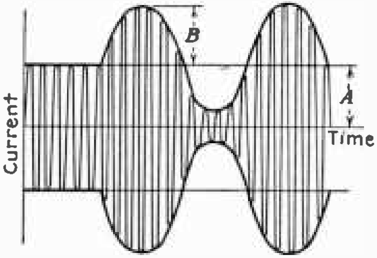


FIG. 29.—Typical diagram of modulated current.

The *effective value of a modulated current* is taken as the equivalent direct current which has the same *heating effect*. In terms of the amplitude A

of the unmodulated current, and the amplitude B of modulation, the effective value of a modulated current I_{me} (amperes) is given by the expression

$$I^2_{me} = \frac{A^2}{2} + \frac{B^2}{4}.$$

The first term of the right-hand side of this equation is equal to the square of the effective value of the carrier current (page 486).

The fraction of modulation k is equal to $B \div A$. If this value is substituted in the above equation, the expression becomes

$$I_{me} = I_o\sqrt{1 + \frac{k^2}{2}}.$$

This equation shows that the effective value of the current increases with the modulation, but the increase is not affected by either the carrier frequency or the frequency of modulation.

Expressed in percentage the modulation is $100\sqrt{2}\sqrt{\left(\frac{I_{me}}{I_o}\right)^2 - 1}$.

Modulated Oscillator with Amplifier.—If it is desired to obtain more power from the circuits which have been described, the size of the oscillator and of the modulator must be increased. An alternative is to amplify the output of a plate-modulated oscillator by the use of a radio-frequency amplifier.

Modulated Power Amplifier.—Instead of modulating the oscillator it is possible to apply plate modulation to the power amplifier of a master-oscillator, power-amplifier circuit. When modulation is applied to the tube that is coupled to the antenna, the arrangement is a *high-power modulation circuit;* when modulation is applied to any other tube, the arrangement is a *low-power modulation circuit.*

A comparison of the two schemes shows that (1) on the basis of the efficiency of power conversion there is no difference; (2) the low-power method has a larger factor of safety in the operation of the power amplifier; (3) in the high-power method, the plate voltage on the power-amplifier tubes increases to twice its normal value if 100 per cent modulation is obtained; (4) in low-power modulation, good transmission of a wide range of audio-frequencies is obtained; (5) the adjustments in a high-power modulated circuit are simpler. The application of these methods to transmitters is about equally divided.

Frequency Instability.—The modulation of a self-excited tube causes a shift in frequency, because any change in plate voltage also changes the plate impedance. Such frequency shifting results in a broad interfering wave. This difficulty is avoided by applying modulation to one of the radio-frequency power amplifier tubes, preferably not the first after the master oscillator, to prevent the reaction due to coupling between the adjacent stages. In order to minimize the interstage coupling, the oscillator is provided with its own source of power and is followed by one or two amplifier stages using screen-grid tubes.

Indicator for Volume Level at Speech Amplifier.—The operator of a broadcasting transmitter is usually provided with some form of visible indicator which shows the level of the volume at the output of the speech-amplifier circuit. The speech amplifier must be adjusted until the indicating device shows the proper level of volume. This portion of the control apparatus appears in several forms: (1) an alternating-current voltmeter which is connected to the modulator tubes by transformer coupling; (2) a device indicating directly in transmission units on a meter, the circuit being arranged for a radio-frequency pick-up of the output which after rectification actuates the meter; (3) a tube circuit which is coupled to the output of the speech amplifier and is provided with a galvanometer and level-measuring controls, as shown in Fig. 30.

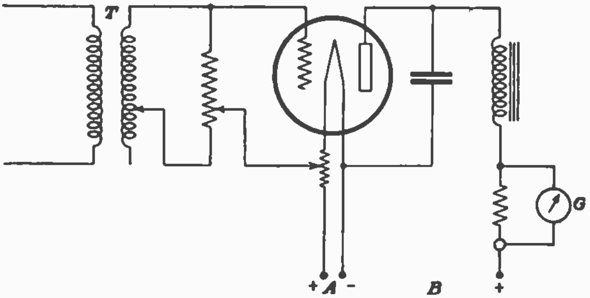


FIG. 30.—Tube circuit coupled to speech amplifier for indication of volume level.

The grid of this circuit is coupled by means of the input transformer *T* to the output of the speech amplifier. Adjustment of the grid-bias voltage is obtained with the potentiometer. A unit for measuring volume level in transmission units from zero volume is connected in the grid circuit. The deflection of a galvanometer *G* in the plate circuit and the proper adjustment of the level-measuring unit determine the level of volume of the output.

Part 6

TUBES FOR TRANSMITTERS

General Definitions.—The tube characteristics listed in the table of tubes (page 492) depend on the definitions of certain terms such as modulation factor, maximum undistorted power output, classes of amplifiers, rectifier-tube ratings, and certain symbols.

Modulation Factor.—The variation in amplitude of a modulated wave from its mean value expressed as a ratio to the mean value.

Oscillator Input Watts per Modulator Tube.—The value of input watts to the oscillator or power amplifier which can be modulated to a given value of modulation factor by each modulator tube operating under specified conditions.

Maximum Undistorted Power Output.—This is on the basis of an external non-reactive resistance in the plate circuit, having a value specified for the tube that is used. If the value of the resistance is not specified, then a resistance equal to twice the normal plate resistance of the type of vacuum tube being tested should be used. A sinusoidal alternating voltage and a grid-bias voltage which is equal to the maximum of the alternating voltage are impressed in the grid circuit and are increased together until the direct component of the plate current is 5 per cent higher than when the alternating voltage is removed. If, with this procedure, the plate current should exceed its normal safe value, then the alternating grid voltage and the grid-bias voltage should be adjusted to the values corresponding to this normal safe plate current; and the external plate resistance should be increased until the direct component (page 325) of the plate current is 5 per cent higher than when the alternating voltage is removed. The resultant alternating-current power in the external plate resistance is then taken as the maximum undistorted power output.

AMPLIFIER DEFINITIONS

CLASS A

Voltage or Power Amplifier or Modulator.—The Class-A amplifier operates so that the plate-output wave shapes are essentially the same as those of the exciting grid voltage. This is accomplished by operating with a negative grid-bias voltage of such a value that some plate current flows at all times, and also by applying such an alternating-current voltage to the grid that the dynamic operating characteristics (page 34) are essentially linear. Usually the grid must not become positive on the excitation peaks, and the plate current must not fall low enough at its minimum value to cause distortion due to curvature of the characteristic curve (page 288).

The amount of the second harmonic (page 72) which is present in the output wave but was not present in the input wave is generally taken as a *measure of distortion*, the usual limit being 5 per cent.

The characteristic conditions which are thus produced are low efficiency and output, with a large ratio of power amplification.

CLASS B

Radio-frequency Power Amplifier; Balanced or Push-pull Modulator.—The Class-B amplifier operates so that the power output is proportional to the square of the excitation grid voltage.

This is accomplished by operating with a negative grid-bias voltage of such a value that the plate current is practically zero with no excitation; and by applying an excitation grid voltage such that half sine waves of plate current are produced on the least negative half of a cycle of the grid voltage. The grid may usually become positive on excitation peaks, the harmonics being removed from the output current by suitable means.

The characteristics which are thus produced are medium efficiency and output, with a relatively low ratio of power amplification.

CLASS C

Radio-frequency Power Amplifier or Oscillator.—The Class-C amplifier is of the kind in which the output is the principal consideration. In this amplifier the output varies as the square of the plate voltage within limits.

This variation is accomplished by operating it with a negative grid-bias voltage of more than a sufficient value to reduce the plate current to zero with no excitation. An alternating-current grid excitation is applied so that large amplitudes of plate current are passed during a fraction of the least negative half cycle of the grid-excitation voltage. The grid voltage usually "swings" sufficiently positive to allow a saturation plate current to flow through the tube. Thus, the plate output waves are not free of harmonics (page 72), and suitable means are usually provided to remove harmonics from the output.

The characteristic qualities of this tube are high efficiency and output, with a relatively low ratio of power amplification.

RECTIFIER TUBE RATINGS

Because of the many forms of rectifier circuits which are now in common use employing vacuum tubes, it has been found desirable to standardize a new method of rating rectifier tubes. This method has been in use for some time on hot-cathode mercury-vapor tubes and is now being applied to the high-vacuum types. It reduces the ratings to the fundamental limitations of the tubes regardless of the circuit in which they are used. The maximum peak inverse voltage and the maximum peak plate current are the two fundamental limits.

Maximum peak inverse voltage is the highest peak voltage that a rectifier tube will safely stand in the direction opposite to that in which it is designed to pass current. It is a measure of the insulation of the tube when the plate is negative. Assuming a sine-wave shape, the peak inverse voltage on a given tube is approximately 1.4 times the root of mean-square (page 10) (r.m.s.) voltage supplied to the tube. In polyphase circuits, this voltage must be obtained vectorially (page 85).

Maximum peak plate current is the highest peak current that a rectifier tube will safely stand in the direction in which it is designed to pass current. In *hot-cathode tubes*, the safe value is a function of the electron emission available. In a given circuit, the value of peak plate current is largely determined by the filter constants (page 629). With a large choke coil located next to the tube, the peak plate current is not much greater than the load current; but with a large condenser next to the tube, it is often as great as four times the load current. In order to obtain peak current accurately, it is usually best to actually measure it with a peak form meter somewhat like an oscillograph (page 38).

SYMBOLS

E_b	Supply voltage in plate circuit in volts.
E_c	Supply voltage in grid circuit in volts.
E_{c1}	Supply voltage in inner grid circuit in volts (control or space charge).
E_{c2}	Supply voltage in outer grid circuit in volts (screen or control).
E_d	Supply voltage in screen-grid circuit in volts.
E_f	Heating voltage across the filament terminals in volts.
u	Amplification factor.
r_p	Internal output resistance in ohms.
g_m	Mutual conductance from grid to plate in micromhos.
R_p	Resistance in series with plate in ohms.
I_b	Direct current to plate in amperes.
r.m.s	Root mean square (page 10).
C_{gp}	Grid plate; C_{gf}—grid filament or cathode; C_{pf}—plate to filament or cathode. Direct interelectrode capacities in micromicrofarads. Input and output capacities for screen-grid tubes are direct interelectrode capacities of the grid to the filament and the screen, and also of the plate to the filament and the screen.
U.P.O.	Undistorted power output (page 489).

TABLE XXXIII.—DATA OF RADIO TRANSMITTING TUBES

Model of tube	Purpose	Base	Filament			C_{gp}, mmf.	C_{gf}, mmf.	C_{pf}, mmf.	Characteristic values							Length, inches	Diameter, inches	Type of cooling
			Type	Voltage, volts	Current, amperes				E_b, volts	E_c, volts	E_d, volts	u	r_p, ohms	g_m, milliamperes per volt	D.-c. plate current, ampers			
UV-203A...	R. F. amplifier oscillator	1839	XL tungsten	10.0	3.25	15.00	8	7.0	1,000	0	...	25	5,000	5	0.147	7⅞	2 5/16	Air
UV-204A...	R. F. amplifier oscillator	502 1904	XL tungsten	11.0	3.85	17.00	18	3.0	2,000	0	...	25	5,000	5	0.275	14⅜	4 1/16	Air
UV-206.....	R. F. amplifier oscillator	3502 1904	Tungsten	11.0	14.75	11.00	10	1.0	10,000	0	...	350	300,000	1.17	0.023	15½	5 1/16	Air
UV-207.....	R. F. amplifier oscillator	3906	Tungsten	22.0	52.00	27.00	18	2.0	10,000	−310	...	20	3,500	5.7	0.75	20¼	4 5/32	Water
UX- 210...	General purpose	3302	XL tungsten	7.5	1.25	8.00	5	4.0	425	−39	...	8	5,000	1.6	0.018	5⅝	2 3/16	Air
UV-211.....	General purpose	1839	XL tungsten	10.0	3.25	15.00	8	7.0	1,000	−55	...	12	3,400	3.53	0.072	7⅞	2 5/16	Air
UX-841[1]....	Voltage amplifier	3302	XL tungsten	7.5	1.25	8.00	5	4.0	425	−8	...	30	21,500	1.4	0.0075	5⅝	2 3/16	Air
UX-842....	A. F. power amplifier	3302	XL tungsten	7.5	1.25	8.00	5	4.0	425	−100	...	3	2,500	1.2	0.028	5⅝	2 3/16	Air
UV-845.....	A. F. power amplifier	1839	XL tungsten	10.0	3.25	15.00	8	7.0	1,000	−147	...	5	1,800	3.0	0.075	7⅞	2 5/16	Air
UV-848.....	Plate modulation	3906	Tungsten	22.0	52.00	27.00	18	2.0	10,000	−1,000	...	8	2,400	3.3	0.75	20¼	4 5/32	Water
UV-849.....	General purpose	3503	XL tungsten	....	.....	.....	...	.....	2,000	−87	...	19	4,000	4.7	0.060			
		1904	....	11.0	5.00	35.00	20	4.0	3,000	−132	...	19	3,200	6.0	0.100	14⅜	4 1/16	Air
UV-851.....	General purpose	3504																
		1902	XL tungsten	11.0	15.50	55.00	30	7.0	2,000	−65	...	20	1,400	15.0	0.300	17⅝	6⅛	Air
UX-852....	R. F. amplifier oscillator	3303	XL tungsten	10.0	3.25	3.00	2	1.0	2,000	0	...	12	6,000	2.0	0.225	8¾	4 1/32	Air

UV-858.....	R. F. amplifier oscillator	....	Tungsten	22.0	52.00	18.00	17	2.0	18,000	— 155	...	42	8,700	4.8	0.75	24½	5⅛	Water
UX-860....	R. F. amplifier oscillator	3303	XL tungsten	10.0	3.25	0.05	8.5	9.0	2,000	0	500	200	150,000	1.35	0.085	8¾	4¼[2]	Air
UV-861.....	R. F. amplifier oscillator	3503 1902SP	XL tungsten	11.0	10.00	0.10	17	13.0	3,000	0	750	300	133,000	2.25	0.172	17 7/32	6⅝[2]	Air
UV-862.....	R. F. amplifier oscillator	3908	Tungsten	33.0	207.00	80.00	52	2.0	18,000	— 35	...	48	2,800	17.15	3.0	5'0⅜"	6⅛	Water
UV-863.....	R. F. amplifier oscillator	3906	Tungsten	22.0	52.00	27.00	18	2.0	10,000	— 20	...	50	7,200	7.0	0.75	20¼	4 5/32	Water
UX-865....	R. F. amplifier oscillator	3302 3901	XL tungsten	7.5	2.00	0.05	10	7.5	500	0	125	150	200,000	0.75	0.021	6¼	2 3/16	Air

In the notation used "R. F." is radio frequency; "A. F." is audio frequency. Grid voltage is measured from midpoint of filament except as noted.

[1] Grid voltage is measured from the negative end of the filament.

[2] Maximum overall radius.

TABLE XXXIV.—AUDIO-FREQUENCY POWER AMPLIFIER, CLASS A

Model	Maximum operating d.-c. plate voltage, volts	Maximum plate power dissipation, watts	Normal operation							
			E_b volts	E_c volts	E_f volts	Plate current, amperes	Plate power dissipation, watts	Grid peak swing, volts	Load impedance, ohms	Output, 5 per cent second harmonic, watts
UX-210	425	12	425	− 39.0	7.5	0.018	. . .	35.0	10,000	1.6
UV-211	1,250	75	1,000	− 55.0	10.0	0.072	. . .	50.0	6,000	10.0
UX-841[1]	425	12	1,000	− 9.0	7.5 d.-c.	0.0023	. . .	9.0	250,000	250.0[2]
			425	− 4.5	7.5 d.-c.	0.001	. . .	4.5	250,000	100.0[2]
UX-842	425	12	425	−100.0	7.5	0.028	. . .	96.0	8,000	3.0
UV-845	1,250	75	1,000	−147.0	10.0	0.075	. . .	142.0	7,500	23.0
UV-849	3,000	300	3,000	−132.0	11.0	0.100	300	127.0	17,500	100.0
UV-851	2,500	600	2,000	− 65.0	11.0	0.300	600	60.0	3,100	100.0

Grid voltage is measured from the midpoint of the filament.

[1] Grid voltage is measured from the negative end of the filament.

[2] Volts.

TABLE XXXV.—RADIO-FREQUENCY POWER AMPLIFIER,[1] CLASS B

Model	Maximum d.-c. plate current unmodulated, amperes	Normal operation							
		E_b	E_c	E_d	E_f	D.-c. plate unmodulated, amperes	Maximum plate power dissipation, watts	Peak power output, watts	Carrier power output, watts. Modulation factor of 1.
UV-203A	0.085	1,000	− 50	...	10.0	0.085	100	75.0	17.5
UV-204A	0.140	2,000	−100	...	11.0	0.140	250	250.0	62.5
UV-206	0.050	15,000	− 50	...	11.0	0.035	......	700.0	175.0
UV-207[2]	1.0	15,000	−800	...	22.0	1.0	10,000	20,000.0	5,000.0
UX-210	0.030	350	− 50	...	7.5	0.030	15	7.5	1.9
UV-211	0.085	1,000	−100	...	10.0	0.085	100	75.0	17.5
UV-849	0.350	2,000	−95	...	11.0	0.260	400	660.0	165.0
UV-851	1.0	2,000	−85	...	11.0	0.550	750	1,400.0	350.0
UX-852	0.100	2,000	−150	...	10.0	0.050	100	75.0	17.5
UV-858	1.0	18,000	−450	...	22.0	1.0	......	24,000.0	6,000.0
UX-860	0.050	2,000	− 75	300	10.0	0.050	100	75.0	17.5
UV-861	0.175	3,000	−100	500	11.0	0.175	400	500.0	125.0
UV-862	5.0	18,000	−380	...	33.0	4.2	......	100,000.0	25,000.0
UV-863	1.0	15,000	−340	...	22.0	1.0	10,000	20,000.0	5,000.0
UX-865	0.030	500	− 40	125	7.5	0.030	15	7.5	1.9

Grid voltage is measured from the midpoint of the filament.

[1] For other maximum figures, see Class C.

[2] UV-863 is recommended for this purpose.

TABLE XXXVI.—OSCILLATOR OR RADIO-FREQUENCY POWER AMPLIFIER, CLASS C

Model	Maximum operating plate voltage			Maximum plate power dissipation, watts	Maximum screen power dissipation, watts	Normal output, watts	Maximum d.-c. plate current, amperes	Normal screen grid voltage, volts	Maximum radio-frequency grid current, amperes
	Modulated d.-c.	Unmodulated d.-c.	Alternating current, r.m.s.						
UV-203A	1,000	1,250	1,500	100	..	75.0	0.175	...	7.5
UV-204A	2,000	2,500	3,500	250	..	250.0	0.275	...	10.0
UV-206	12,000	15,000	15,000	350	..	1,000.0	0.100	...	10.0
UV-207	12,000	15,000	15,000	10,000	..	20,000.0	2.0	...	30.0
UX-210	350	450	450	15	..	7.5	0.060	...	5.0
UV-211	1,000	1,250	1,500	100	..	75.0	0.175	...	7.5
UX-842[1]	350	450	450	15	..	7.5	0.060	...	5.0
UV-845[2]	1,000	1,250	1,500	100	..	75.0	0.175	...	7.5
UV-848	12,000	15,000	15,000	10,000	..	20,000.0	2.0	...	30.0
UV-849	2,000	2.500	2,500	400	..	350.0	0.350	...	10.0
UV-851	2,000	2,500	2,500	750	..	1,000.0	1.0	...	10.0
UX-852	2,000	3,000	3,000	100	..	75.0	0.100	...	10.0
UV-858	20,000[3]	......	....	20,000	..	24,000.0	2.0	...	60.0
UX-860	2,000	3,000	3,000	100	10	75.0	0.100	300	10.0
UV-861	3,000	4,000	4,000	400	35	500.0	0.350	500	10.0
UV-862	......	20,000	100,000	......	..	100,000.0	10.0	...	60.0
UV-863	12,000	15,000	15,000	10,000	..	20,000.0	2.0	...	30.0
UX-865	500	500	500	15	3	7.5	0.060	125	5.0

Grid voltage is measured from the midpoint of the filament. In this notation "d.c." is direct current, a.c. is alternating current, "r.m.s." is root-mean-square value (see page 10).

[1] Data for reference only. Other tubes are recommended for this purpose.

[2] Data for reference only. UV-211 recommended for this purpose.

[3] This value is for direct current.

TABLE XXXVII.—MODULATOR TUBES

Model	Maximum operating direct-current plate voltage, volts	Maximum plate power dissipation, watts	Normal operation						
			E_b	E_c	Modulation factor	Direct-current plate currents, amperes	Grid peak swing, volts	Plate power dissipation, watts	Oscillator input per modulator tube, watts
UV-207[1]	12,000	7,500	10,000	−420	0.7	0.260	420	......	3,000
UV-210	425	12	350	−35	0.6	0.005	31	1.75	4
UV-211	1,250	75	1,000	−70	0.6	0.020	65	......	45
UX-842	425	12	350	−88	0.6	0.014	84	......	8
UX-845	1,250	75	1,000	−147	0.6	0.075	142	75	122
UV-848	12,000	7,500	10,000	−1,000	0.7	0.75	985	......	8,600
UV-849	3,000	300	2,000	−87	0.7	0.060	82	120.0	110
			3,000	−132	0.7	0.100	127	300.0	350
UV-851	2,500	600	2,000	−80	0.6	0.105	75	210.0	400

Grid voltage is measured from the midpoint of the filament.

[1] UV-848 is recommended for this purpose.

TABLE XXXVIII.—HALF-WAVE RECTIFIER TUBES

Model	Filament			Maximum peak inverse voltage, volts	Maxinum peak plate current, amperes	Length, inches	Diameter, inches	Base number	Socket type	Type of cooling
	Type	Voltage, volts	Current, amperes							
UV-214..........	Tungsten	22	52.0	50,000	7.5	20¼	$4\frac{5}{32}$	3906	Water jacket	Water
UV-217A..........	Thoriated tungsten	10	3.25	1,500[1]	0.20[2]	7⅞	$2\frac{5}{16}$	1839	UT-541	Air
UV-217C..........	XL tungsten	10	3.25	3,000[1]	0.15[2]	8½	$2\frac{5}{16}$	1839 and 3903	UT-541 and clip	Air
UV-218..........	Tungsten	11	14.75	50,000	0.75	15½	$5\frac{1}{16}$	3502 and 1904	UT-501 and UT-502	Air
UV-219..........	Tungsten	22	24.5	50,000	2.5	$22\frac{9}{16}$	6⅛	3502 and cap 3902	Special	Air
UV-1651[3].........	Tungsten	11	14.75	4,000[1]	0.25[2]	14⅜	$4\frac{1}{16}$	3502 and 1904	UT-501 and UT-502	Air

[1] This rating is the maximum alternating-current supply voltage (root-mean-square).

[2] This rating is the maximum direct-current load current.

[3] Supersedes UV-1651A.

TABLE XXXIX.—HOT-CATHODE MERCURY-VAPOR RECTIFIER TUBES

Model	Filament			Maximum peak inverse voltage, volts	Maximum peak plate current, amperes	Length, inches	Diameter, inches	Base number	Socket type	Type of cooling	Tube "voltage drop," volts
	Type	Voltage. volts	Current, amperes								
UV-857............	Coated	5.0	60	20,000	20.0	19⅞	7⅛	1904 and 3906	Special	Air	15
UV-866............	Coated	2.5	5	5,000	0.6	6⅝	$2\frac{7}{16}$	3302 and 3903	Standard UX and clip	Air	15
UV-869............	Coated	5.0	20	20,000	5.0	14⅜	$5\frac{1}{16}$	3502 and cap 3905	UT-501 and UT-502	Air	15
UV-872............	Coated	5.0	10	5,000	2.5	8½	$2\frac{5}{16}$	1839 and cap 3903	UT-541 and clip	Air	15

SECTION X

BROADCASTING TRANSMITTERS

Part 1

R.C.A., TYPE 100-W (100 WATTS)

The salient features of the R.C.A. 100-W broadcasting equipment are (1) low-power complete modulation, (2) precision crystal control, (3) substantially flat frequency response over the entire musical range, (4) linear amplification, (5) shield-grid tubes for radio-frequency buffer amplifiers, (6) mercury-vapor rectifier tubes of hot-cathode type, (7) non-microphonic tubes in speech-input equipment, (8) condenser microphone, (9) percentage modulation indicator, (10) monitor operating from rectified radio-frequency output, (11) automatic protection of operator against high voltages, and (12) low cost of operation and tube replacement. A simplified circuit diagram is shown in Fig. 1.

Modulation.—The transmitter is designed so that the carrier power can be completely modulated. The term "complete" or "100 per cent modulation" means that the current in the antenna is raised to twice the normal value and decreased to absolute zero, alternately, at the frequency of modulation. Raising the current to twice the normal value produced by the unmodulated carrier requires an instantaneous output of *four times the normal power* for the "peaks" of modulation. The final power amplifier is capable of handling the required 400 watts of power necessary for 100 per cent modulation, without introducing distortion.

By allowing for complete modulation an effective means is introduced for increasing the range and signal-to-noise ratio of the equipment without correspondingly increasing beat-note interference with other stations assigned to the same broadcasting channel.

Crystal Control.—The crystal-control unit consists of an oscillator and two stages of amplification, all enclosed in a completely shielded, replaceable box. The oscillator which has a UX-210 tube is operated by a quartz crystal. The crystal is enclosed in a chamber which excludes moisture and dust. The temperature of the crystal is kept constant by means of a vacuum-tube controlled heater. This insures practically perfect frequency stability.

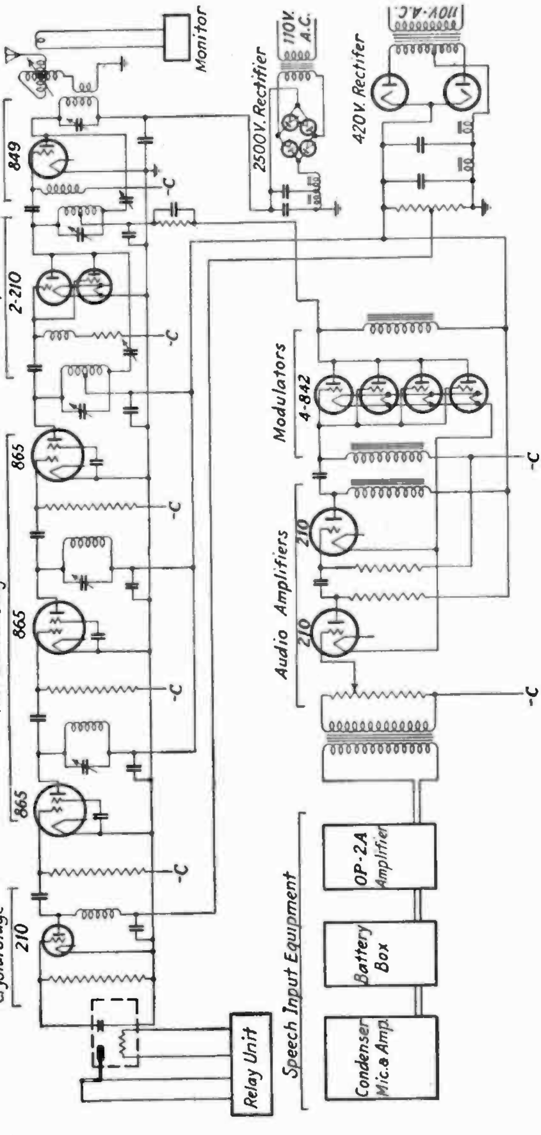


FIG. 1.—Circuit diagram of R.C.A. broadcasting transmitter (type 100-W).

The equipment is designed to maintain the carrier frequency constant within the limits required by the Federal Radio Commission. The oscillator tube is allowed to oscillate feebly and only a small amount of energy is taken from its output to drive the two self-neutralized stages of amplification which follow. This complete unit is removable and can be replaced with the spare unit which is supplied.

Condenser Microphone.—The condenser microphone, type 4AP, because of its compactness and long leads, can be used everywhere the carbon microphone is used. The desirable qualities of a microphone are good frequency characteristics, low noise level, freedom from blasting, and compactness.

A good frequency characteristic is necessary to reproduce faithfully all of the frequencies of the musical scale.

The low noise level in the microphone makes possible a low input level. This is a decided advantage, since it does away with the practice of placing the microphones close to the artists in order to override the microphone noises. The condenser microphone inherently has a low output level. This disadvantage is overcome by a very compact amplifier close to the microphone. The microphone equipment consists of three parts: (1) condenser microphone, (2) three-stage amplifier, and (3) microphone stand.

Microphone Amplifier.—A condenser microphone supplies a three-stage amplifier, having UX-864 non-microphonic tubes. The first two stages of the microphone amplifier are resistance coupled, and the output is transformer coupled to match a 200- or 500-ohm line. The amplifier unit, composed of catacomb, tube sockets, and terminals, is supported on sponge rubber and is enclosed in an aluminum case. A shielded cable is connected to this "floating" (rubber-supported) unit by flexible leads.

Speech-input Equipment.—The speech-input equipment is an R.C.A. OP-2A-type broadcast amplifier. The amplifier consists of four stages of amplification using dry-cell tubes. Power supply is obtained from cell batteries. Terminals are provided so that the output of the three condenser microphones or three carbon microphones can be controlled. Provision is made to supply current to the carbon microphones when these are used. The input system provides for the control of three microphones. The input impedance of the microphone transformer is 200 ohms, which is correct for the output of either the condenser or the carbon microphone. A reactance coil and a coupling condenser are used to keep the direct-current plate supply out of the output transformer. The output system includes a pad designed to supply a 500-ohm telephone line. This pad keeps the load on the output transformer nearly constant. For monitoring purposes, head phones may be plugged into a jack connected across the output terminals of the pad. A 2,000-ohm resistance is connected in series with the jack to prevent an accidental short-circuit of the line. A small push button is provided to short circuit the output while changing tubes or making adjustments. The amplifier is designed to give an overall amplification of not less than 45. The frequency is substantially flat over the entire musical range. The microphone volume control has been designed to give logarithmic control of volume; thus eliminating a master-control device. Provision is made for connecting an external microphone control so that additional microphones may be added.

The amplifier consists of four stages of amplification using three UX-864 non-microphonic tubes in the first three stages and one UX-120 in the last stage. The filaments of the UX-864 tubes are connected in series and all three are connected in parallel with the UX-120 tube. Resistance coupling is used between stages, and the last stage is connected to the output system through an impedance-matching transformer.

Speech Amplifier.—The speech amplifier consists of two stages of amplification with UX-210 tubes and is housed in the main transmitter unit. The input transformer for the speech amplifier is designed for 500-ohms primary impedance and is balanced to the ground. A relay is provided for connecting or disconnecting the primary coil of the input transformer. This relay is controlled by the announcer in the studio. The relay also lights a red light in the studio and on the transmitter to show when the studio is "on the air."

Modulator.—This unit utilizes four UX-842 tubes so connected to the intermediate stage of the power amplifier that complete modulation is obtained.

Buffer Amplifiers.—There are three buffer stages between the oscillator tubes and the modulated stage, two of which are included in the crystal unit itself. These stages, which utilize the UX-865 neutralizing tubes, prevent the modulation from reacting back on the crystal and causing a frequency shift or frequency modulation. All the amplifier stages are self-neutralized either by the four-element tubes or by a neutralizing scheme. Neutralization also prevents the amplifier stage from oscillating independently of the crystal. Further to guard against this condition, the stages are individually shielded.

Intermediate-power Amplifier.—This stage consists of two UX-210 tubes, and it might be termed the "modulated amplifier," since the modulation takes place here. The circuit is so arranged that the power in the plate circuit of this stage can be completely modulated.

Linear-power Amplifier.—The linear-power amplifier stage consists of one UV-849 tube and receives its excitation from the two UX-210 tubes of the intermediate-power amplifier. This stage will deliver 100 watts continuously to a suitable antenna and will supply 400 watts or more at "peak" power. This is necessary for high modulation, since the power increase on peaks is four times the carrier power when there is complete or

100 per cent modulation. The antenna is coupled inductively to this stage.

Power-supply Equipment.—The power supply is obtained from a 110-volt, single phase, 60-cycle power line. Equipment, however, may be secured for using a 110-volt direct-current power line. The total power required for operation is approximately 2.5 kilovolt-amperes (page 10). The plate power supply to the transmitter and speech amplifier is furnished by two rectifiers, one using four UX-866 tubes and furnishing power for the UV-849 power amplifier, and the other using two UX-866 tubes and furnishing power for the other tubes in the transmitter and for the speech amplifier. The filament power supply for the radio-frequency stages and modulators and grid-bias voltage for all stages are furnished by a motor-generator set; and for the speech amplifier, the OP-2A amplifier, and the 4A-condenser microphone amplifier the filament power supply is furnished by two storage batteries, one of which can be charged while the other is in use.

Equipment.—The transmitter proper is mounted so that all the controls for starting and stopping the transmitter are available from the front of the mounting panel. Shielding is used to prevent interaction between the various stages. All doors in the front panel are interlocked with the high voltage power supply.

The complete equipment includes a 4AP-type condenser microphone, an amplifier with program stand, a battery box for power supply to three condenser microphones, an OP-2A-type portable broadcast amplifier, an 100-W-type transmitter unit, a three-unit motor-generator set, an automatic starter for the motor-generator set, a tungar battery charger and charging panel, two 80-ampere-hour, 8-volt storage batteries, an 100-A-type monitoring loud-speaker; a studio signal light, a spare crystal unit, two complete sets of tubes, each set consisting of six UX-864 type, three UX-865 type, seven UX-210 type, one UX-120 type, four UX-842 type, six UX-868 type, and one UV-849 type.

Magnetic Pick-up Equipment.—The magnetic pick-up equipment is for use in broadcasting phonograph records for test purposes. This equipment converts phonograph recordings into electric pulsations which may be used for modulation of the broadcast carrier wave. A 12-inch turntable is driven by an electric motor of the induction disk type operating from a 50- or 60-cycle, 110-volt line and is provided with a speed regulator. A switch lever which projects beyond the turntable may be set to stop the motor automatically when a selection has been completed. The output of this device is designed to operate into the regular speech-input equipment of the transmitter. It is supplied with a low-impedance volume control which may be used in conjunction with the microphone *mixing controls*.

Part 2

WESTERN ELECTRIC, TYPE 105-C (5,000 WATTS)

Method of Modulation.—The low-level system of modulation employed in the 105-C-type transmitter has overcome the limitation to substantially complete modulation without added expense for operation or equipment and without the use of an added number of modulator tubes or of large modulator tubes. When the high-level modulation system is used, a considerable number of large and expensive tubes are required to obtain comparable results. The new arrangement is therefore not only a better engineering solution but is also a contribution toward decreased cost of operation. A simplified circuit diagram is shown in Fig. 2.

The increased modulation attained has two advantages: (1) The signal content of the wave is doubled; and (2) the increased modulation results in a two-to-one improvement in the signal-to-noise radio. The effectiveness of the equipment, therefore, in covering a given area through static and interference is quadrupled. In other words, results obtained are comparable with those to be had with what has been known to date as a 20-kilowatt set. Increased modulation is particularly advantageous under present-day broadcasting conditions, since it affords a means of almost doubling the range of a given station without a corresponding increase in the beat-note interference. The difference in operating expense between a 5- and a 20-kilowatt set is obvious.

Tubes.—The oscillator unit has one D-86737 tube (50 watts), two 211-D tubes (50 watts), and two 102-E tubes. Those in the amplifier unit are four 212-D tubes (250 watts) and one 211-D tube (50 watts). The power-amplifier unit has two 220-B tubes (10 kilowatts), the rectifier unit has three 222-A tubes (rectifier tubes), and the tuning unit has one 211-D tube (50 watts (for monitoring rectifier). The experience of many station operators over a period of years, indicates that such tubes will have a service life of about 2,000 to 2,500 hours. Long service life of tubes is important because the cost of tubes is one of the largest single items in the operating expenses of a broadcasting station.

Crystal Control of Frequency.—A piezo crystal consisting of a small quartz plate about one inch square is used. Its faces are accurately paralleled and ground to a thickness associated with the frequency of the mechanical vibration required. To assure the utmost degree of reliability of a second crystal, an exact duplicate of the first, and complete with container, thermostat, and control, is provided. Thermostatically controlled insulated containers keep the crystals at a constant temperature to assure stability of frequency.

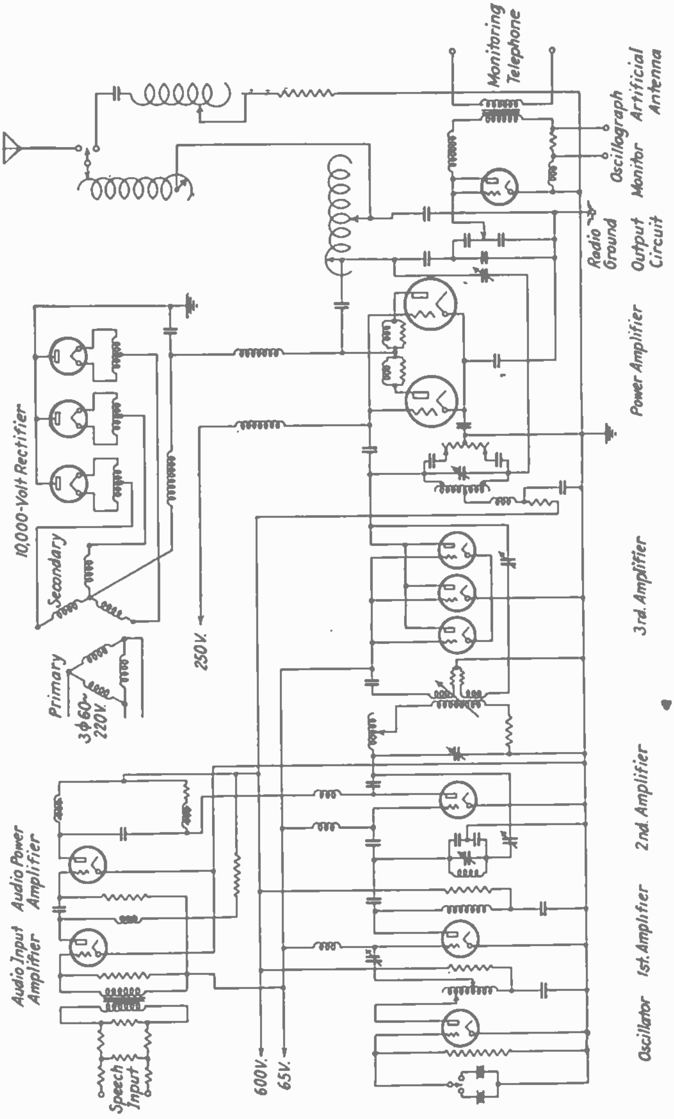


FIG. 2.—Circuit diagram of Western Electric broadcasting transmitter (type 105-C).

With ordinary supervision on the part of the operating force no difficulty will be experienced in maintaining the carrier frequency well within 100 cycles per second of the assigned frequency. Since the carrier frequency may be as high as 1,500,000 cycles per second, a control of frequency within 100 cycles per second is satisfactory. The importance of such precision is apparent, because many stations are faced with loss of licenses unless close adherence to their assigned frequencies is maintained. The use of crystal control and an isolating stage between the oscillator and the modulating amplifier prevents frequency modulation and distortion in transmission.

Harmonic Suppression.—The adequate suppression of harmonics becomes a problem of increasing difficulty as the output power of a transmitter is increased. In the design of the 105-C equipment a special double-tuned circuit and capacity coupling are employed between the last power-amplifier stage and the antenna, which prevents the effective transfer of harmonic power to the latter.

Protective Equipment and Safety Features.—Protective devices are provided to give adequate protection against circuit overloads, partial or complete failure of the cooling system, failure of the grid-bias voltage, and various other possible causes of interruption of service.

Safety for the operating personnel is essential in a radio transmitter. It is especially important that the danger in the use of relatively high voltages be eliminated. Thorough consideration has been given to precautionary measures in this equipment. The design affords assurance that injury to the operating personnel through accidental contact with high voltages is practically impossible. The panels are all "dead front." There is no danger of injury from contact with them or with the instruments mounted on them.

Several of the panels are provided with a plate-glass window behind which tubes are located for visibility. Should it be necessary to open a window, the act of opening will automatically shut off the current. The windows make all parts located at these points easily accessible for repairs and replacements, while the automatic opening of the circuit eliminates all personal danger from high voltage.

The equipment behind the panels is entirely enclosed by wire-mesh fencing. It is impossible to enter the enclosure except through a door made of the same wire mesh. When the door is opened the circuit is broken and high voltage in the whole system is automatically stopped. An additional safety factor is provided by two manual switches just inside the door which should be opened by the person entering. These switches when opened prevent the high voltages from being applied through error. The set cannot be started while either of these switches is open, nor is it possible to start the set without first closing all of the windows and the door in the fencing.

Pushing a single master-control button sets the transmitter in operation. As soon as the contact is made by means of this starting button, a control system is energized, which in turn, by means of time-delay relays, automatically applies the voltages in their proper sequence. This method of procedure is much more rapid and less subject to error than a manual system involving a number of switches. It also guards against damage to equipment should any failure of the cooling system develop. Neither can the operator through negligence or ignorance fail to apply the power in the proper sequence.

Cooling System.—Damage to the vacuum tubes of the power amplifier is prevented by the control of the water-cooling system. Should the water-cooling system fail for any reason, a relay operated by the flow of water will immediately stop the set.

Speech-input Equipment.—Good broadcasting practice and government regulation have caused the separation of studios and transmitting stations. Two speech-input equipments are therefore required, one at the studio and another at the transmitting point. The 8-A or the 8-B is used at the studio and the 5-B at the station. These equipments are mounted on relay racks to save floor space, to provide easy access, and to permit the addition of more apparatus.

Provisions are made for connecting the input of the radio broadcasting system either to the studio transmitter or to circuits from outside pick-up points. The control of this switching is made available to the announcer and also to the control-room operator. Suitable provision is made for preventing interference with the control or unauthorized changes in the connections.

Interphone signaling facilities are provided. Arrangement is made also for disconnecting the speech-input equipment from the transmitter and utilizing it as a studio announcing system.

Facilities are provided for connecting by means of patching cords any one of six outside program circuits through artificial lines and relays to either one of two switching circuits. Thus either the control-room operator or an announcer in the studio can control the connection of either of two outside programs. Provision is made for order lines for use with each program circuit. These order lines are interchangeable with the program circuits by means of patching cords.

Monitoring Equipment.—Loud-speakers of the No. 560 type are used in the 8-A and 8-B speech-input equipments for monitoring. The monitor amplifier is arranged to operate one or two loud-speakers and is connected so that it can be switched from the output of the common line amplifier to the output of a radio receiver. In this way a direct comparison of the input and output of the radio transmitter can be made.

Carbon- or Condenser-type Transmitter.—Five 387-W carbon-type transmitters are furnished with the 8-A speech-input equipment. One of these is a spare. Four transmitter mountings are provided, two for floor and two for table use.

The 8-B speech-input equipment is offered as an alternative when the condenser-type transmitter is desired. With 8-B equipment four 394-W transmitters with their associated amplifiers are furnished. These are of the single-stage type, which amplify the small voltages developed by the condenser transmitter and at the same time act as an impedance-translating device between the high-impedance condenser transmitter and the low-impedance input circuit to the common amplifier circuit.

Filament-current Supply.—Filament current is provided by heavy-duty batteries of the glass-jar type, supplied in duplicate, together with charging equipment. These facilities provide for 18 hours continuous service out of each 24. If greater capacity is required, only a new set of plates is needed.

The 5-B speech-input equipment for stations is of the same design and construction as the 8-A and 8-B studio equipments. This equipment includes the necessary program and monitoring features, a line amplifier, and an emergency announcing microphone. A rectifier for plate voltages and a storage battery of adequate capacity for filament voltages form the power supply.

Power-panel Unit.—This unit, which is served by a 200-volt, three-phase, 60-cycle power supply, imparts energy to the motor generators, the rectifier transformers, the pump and blowers for the cooling system, the heater circuit for the crystal enclosing chambers, and to other components requiring power from this source.

Rectifier Unit.—The rectifier, which supplies 10,000 volts for the water-cooled tubes in the power amplifier unit, is of the three-phase type and employs three 222-A water-cooled vacuum tubes as rectifying elements. Their filaments are heated by alternating current at a potential of 21 volts which is stepped down by three single-phase transformers from the 220-volt supply. The transformers also provide suitable insulation between the filaments of the rectifier tubes and the power-supply system.

The three-phase transformer increases the voltage of the 220-volt three-phase supply to a voltage of approximately 10,000 volts (to neutral). The rectified 10,000-volt direct-current supply is filtered by means of a choke coil and condenser to smooth out the ripples.

Oscillator Unit.—This is the unit in which the crystals are located. In this transmitter modulation is effected at an early stage. The first and second amplifiers, which are 50-watt vacuum tubes, are mounted in this unit. The first amplifier is tuned and feeds the grid of the second amplifier. The tuned-plate circuit of the second amplifier is connected by a modification of the Heising modulation system to the plate circuit of the 250-watt modulator tube mounted in the amplifier unit. Coupling between the modulating or second amplifier is made by means of a movable coupling coil operated from the panel, permitting a continuously variable adjustment of the power output. The oscillator unit also contains the direct-current apparatus and the system for obtaining from a 250-volt generator the several negative grid voltages required in operating the set.

Amplifier Unit.—There are four 250-watt tubes included in this unit, three of which are used in parallel to make up the third radio-frequency amplifier. The other 250-watt tube is used as the modulator, having its plate circuit connected to the plate circuit of the second amplifier in the oscillator unit by means of the special arrangement of the *Heising modulation* system.

Power-amplifier Unit.—This is the last step of amplification. The output of the amplifier unit is received by this unit and amplified to the 5,000-watt "level" by two tungsten filament water-cooled tubes operated in parallel. Plate voltage for these tubes is supplied by the rectifier unit at 10,000 volts. Water for cooling them is conducted to the tube jacket by means of a rubber hose. A pressure gage shows whether the water-circulating system is operating properly.

Tuning Unit.—The tuning unit housing a closed tuned circuit and a coupling condenser of large capacity provides the means by which the output of the power-amplifier unit is transmitted to the antenna. The coupling circuits constitute a filter which minimizes the radiation of all radio-frequency harmonics. Provision has been made for all necessary adjustments, the tuning coil being shielded. The arrangement of tuning and coupling condensers makes it possible to operate the transmitter in connection with antennas whose resistances fall within the range of 15 to 600 ohms. Three meters behind the plate-glass window in this unit assure precise adjustment of the output circuits, especially in connection with tuning high-impedance antennas.

Loud-speakers.—Loud-speakers of the No. 560 type are supplied as part of the monitoring equipment so that the operators may, by the use of the monitoring rectifier in the tuning unit, compare the quality of the output of the transmitter with its input. These speakers operate from an amplifier in the speech-input equipment. One is located in the radio room, and the other in the control room. In this way, the operating staff are constantly aware of the effectiveness of the programs as broadcast.

Power Equipment.—The power eqiupment requires for its operation a power supply of 30 kilovolt-amperes (page 10) of three-phase, 220-volt, 60-cycle power. To supply the 16 volts for the filaments and 1,600 volts for the plates of the air-cooled vacuum tubes used in the oscillator and amplifier units, a three-unit motor-generator set is used. For energizing the tube filaments in the power-amplifier unit, a 22-volt motor-generator set is used. A 250-volt motor-generator set supplies all grid voltages. The transformer rectifier system mentioned in describing the rectifier panel supplies the 10,000 volts necessary for the plates of the water-cooled tubes.

A complete water-cooling system is furnished for the vacuum tubes of the *rectifier* and *power-amplifier* units. It consists of a circulating pump, expansion tank, radiators, blowers, and rubber and metal conductors for the water. Water is pumped through the leads to the jackets of the tubes and then conducted back to radiators which are cooled by forced air draft from the blowers.

Part 3

R.C.A., TYPE 1050-B (50,000 WATTS)

In the design of the R.C.A. broadcast transmitter, type 1050-B, due consideration has been given to recent developments in vacuum tubes, such as the hot-cathode mercury-vapor rectifier type and the high-power type. The mercury-vapor rectifier tube is more efficient and has a lower first and maintenance cost than the ordinary type of rectifier tube of the same rating. The use of a 100-kilowatt tube simplifies the transmitter by making it unnecessary to operate a large number of small tubes in parallel to obtain the desired output. A picture of this tube is shown in Fig. 3.

Power Supply.—The equipment is designed to operate from a 2,300-volt, 50-cycle, three-phase, three-wire power supply, having a regulation (page 219) of not more than plus or minus 5 per cent. A total power input of approximately 220 kilowatts is required.

Frequency Range and Rating.—The frequency range of the transmitting equipment is 550 to 1,500 kilocycles per second. The rating of this transmitter as 50 kilowatts is conventional and means that the transmitter will deliver *unmodulated* power of this amount to a suitable antenna. This equipment is designed, however, for a nominal capacity of 200 kilowatts, since this output is required when the carrier wave is completely (100 per cent) modulated.

A 50-kilowatt transmitter when its output is modulated 50 per cent will have an average output of 56.2 kilowatts, whereas, the same transmitter when modulated 100 per cent will have an average output of 75 kilowatts.

The signal received at a distant station will be approximately twice as strong for the 100 as for the 50 per cent modulated transmitter. The additional power secured by 100 per cent modulation over the power secured by the "percentage" modulation permits a station to serve satisfactorily a much greater area and gives better quality of reception and more effective transmission. The ratio of signal to static strength is, moreover, increased, thus reducing the interference from atmospheric static and other electrical disturbances.

The audio-frequency characteristic of the transmitting equipment is substantially flat, between the frequencies of 30 and 10,000 cycles per second, meaning that the response of the equipment is uniform within one transmission unit (page 596) between 100 and 5,000 cycles per second and within two transmission units between 30 and 10,000 cycles per second. The transmitter is, therefore, adequate for sound reproduction at all ordinary frequencies.

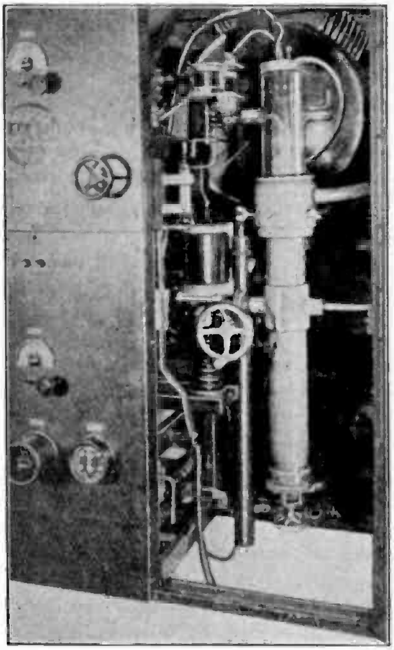


Fig. 3.—Super power radiotron.

Frequency Stability.—The frequency of this transmitter is controlled by a quartz crystal used in such a manner that every possible precaution has been taken to stabilize the frequency. A square-plate quartz crystal cut with proper orientation, and ground to a thickness determined by the desired frequency, controls the oscillator circuit. The crystal is mounted in a special compartment in which the temperature is held substantially constant by means of a heating element and a thermostat. The crystal unit is adjusted to operate at the specified frequency when at a temperature of 45°C. Duplicate crystal units are supplied. The frequency of the crystal-controlled oscillator is constant within plus or minus 50 cycles, of a given frequency.

Radio-frequency Amplifier.—The crystal-controlled oscillator utilizes a UX-210 tube. The output of the crystal oscillator passes through two stages of four-element vacuum-tube (UX-865) amplification. The tube immediately following the crystal-oscillator stage acts as a *buffer stage*, protecting the crystal stage from reaction that may occur in the succeeding amplifiers. The four-element tubes do not require neutralizing. The output of the second (UX-865) four-element tube passes into a third four-element tube (UX-860) amplifier and then into the modulating amplifier, where it is "plate modulated" by the audio-frequency currents coming from the speech-amplifier equipment. The modulated radio-frequency current is amplified in two successive push-pull stages, bringing it to full power.

Modulation.—The method of low-level modulation used here does not require that the audio-frequency currents be amplified to a high-power level, as in the usual high-level modulation method. Thus, a saving is effected in the number of high-power, water-cooled vacuum tubes required, and the apparatus is simplified in design and is reduced in size. The two water-cooled tubes used in the 50-kilowatt power amplifier provide the necessary reserve power to supply the maximum of 200 kilowatts of power to the antenna required during periods of 100 per cent modulation.

The tubes used in the power amplifier operate into a balanced circuit, enabling power to be supplied to the "tank" circuit during each half of the radio-frequency cycle. This type of circuit permits the use of relatively low-circulating kilovolt-ampere power in the tank circuit and thus increases the efficiency of the radio-frequency equipment.

Individual grid- and plate-current ammeters make it possible accurately to balance the tubes relative to each other. The small number of vacuum tubes used in the power amplifier indicates simplicity and stability of operation, high efficiency, and comparative freedom from parasitic oscillations. Filament and grid-bias voltage supplies are obtained from motor generators. The plate power supply is obtained from the main rectifier.

Safety System.—All high-voltage equipment is protected by grounded metal panels and metal screening. All doors are interlocked so that it is impossible for the operator to touch high-voltage apparatus before disconnecting all high-voltage circuits, with the exception of the 2,300-volt power-supply leads connected to the control panel.

Water flow and grid-bias voltage interlock and contact-making thermometers protect the tubes against possible damage due to interruption of circulating water or grid-bias voltage.

Tuning Equipment.—A transmission-line power-supply system is used between the transmitter and the antenna. An advantage of this type of power supply is that the antenna may be located at a considerable distance from the transmitter. The transmission line is a relatively high-impedance circuit, and, therefore, the line losses are low and the transfer of energy from the transmitter to the antenna is affected at high efficiency.

This equipment was designed to suppress the radiation of harmonic-frequency energy from all parts of the circuits. A special coupling arrangement is employed between the transmission-line terminating circuit and the antenna, which prevents an effective transfer of harmonic energy from the transmission line to the antenna. The transmission line is balanced with respect to the ground and is properly terminated to prevent reflection, thus causing the radiation from the transmission line to be a minimum value. The ratio of radiated fundamental-frequency energy to the harmonic-frequency energy is at least 40,000:1.

The method used of terminating the transmission line is advantageous in that after the initial adjustment, further adjustment is unnecessary so long as operation is maintained at the initial operating frequency. The antenna tuning equipment consists of a variable-inductance coil and a series condenser consisting of air condensers which may be connected into combination to give the correct value of capacity properly to tune the antenna to an operating wave length of 0.75 of the fundamental wave length of the antenna. A choke coil for preventing the accumulation of a static charge on the antenna and an antenna ammeter complete the antenna coupling and tuning equipment. The best type of antenna to be used depends upon local conditions and the operating frequency.

Cooling System.—A closed-circuit cooling system is supplied, consisting of a circulating pump, a radiator, and a blower. The use of distilled water is recommended, since water of high mineral content causes a scale formation on the anodes of the tubes. If the water supply available is of low-mineral content (5 grains per gallon or less), it will be satisfactory for use in the system. The water-cooling system requires approximately 300 gallons of water.

Rectifier.—The rectifier utilizes six UV-857, 20-ampere, 20,000-volt, hot-cathode-type, mercury-vapor rectifier tubes, connected in a three-phase, full-wave rectifier circuit. Starting mechanisms for plate transformers include time-delay devices to provide for safe operation.

Power Supply.—The rectifier operates from a 2,300 volt, three-phase, three-wire, 50-cycle power supply. A voltage regulator controls the input voltage to the plate transformers so that the output direct-current voltage of the rectifier may be varied from 10,000 to 20,000 volts. In case the plate power is not available, the regulator automatically returns to the minimum direct-current voltage position; and when the power is again applied, the plate voltage returns to a predetermined value which may be adjusted by means of the contact-making voltmeter.

Control Panel.—Mounted on the control panel are overload relays in the input and output circuits of the rectifier, a device for controlling the field of the filament and the grid-bias voltage of the motor generator, a "start-stop" switch for the rectifier, and meters for all circuits desirable to meter. On this panel are also the 2,300-volt power-supply controls.

The line voltmeter and ammeter are equipped with transfer switches so that either phase of the supply may be metered. Red and green indicator lights are supplied to indicate the condition of all major power circuits. Graphic recording instruments are supplied to record the input voltage of the supply line, the output current from the main rectifier, the rectifier filament voltage, and the power-amplifier filament voltage.

Speech Amplifier.—Speech equipment for this set consists of two stages of resistance- and impedance-coupled amplification using UV-203A tubes. This amplifier will produce 100 per cent modulation of the transmitter. Usually, the studio line is equalized and amplified by the line equipment before reaching the main speech-amplifier unit. This amplifier may be operated directly from a line, however, if the proper level is obtainable.

Motor-generator Sets and Power-supply Equipment.—The power supplies for this transmitter consist of the following units: (1) A filament motor generator which is designed to deliver 600 amperes at 35 volts, equipped with an automatic starter and automatic voltage regulator. Two motor generators are supplied with switches for change-over. (2) The motor-generator set supplying the grid-bias voltage consists of two separate generators in one frame, a motor and an exciter on one bedplate. One generator is used to supply the grid-bias voltage for the UV-860-stage tube, for the UV-849 modulated amplifier, and for the intermediate balanced amplifier stage. The first generator has connected across it a potentiometer arrangement for varying the grid-bias voltage of the UV-860-type tube, the UV-849 amplifiers, and the water-cooled intermediate amplifiers. The generators have sufficient power rating so that they have a low resistance. The grid-bias voltage is adjusted by means of generator field rheostats. The grid-bias voltage motor generators are furnished. (3) Two single-phase, full-wave rectifiers, supplying 600 volts, each using two 0.6-ampere, 5,000-volt, hot-cathode, mercury-vapor rectifier tubes, furnish plate and grid-bias voltage for the two crystal frequency-control units. (4) A 3,000-volt, three-phase rectifier supplies plate power for the (UV-849) modulated amplifier tubes, the modulators, the UX-860 tube and the speech amplifier. This rectifier uses six 0.6-ampere, 5,000-volt, hot-cathode mercury-vapor rectifier tubes. (5) A 20,000-volt, three-phase, full-wave rectifier, which consists of six 20-ampere, 20,000-volt, hot-cathode mercury-vapor rectifier tubes. This rectifier supplies the plate power for the intermediate balanced amplifier and the power amplifier.

Control.—For automatic control, the "start" push button starts the cooling apparatus. When water is at the correct pressure and rate of flow, the water-supply protective devices allow the filament motor generator to start. The increase of filament voltage is automatically controlled so that the current is kept at a safe value, while the filament is heating. During normal operation, the filament voltages are closely regulated at the proper value by an automatic regulator. The grid-bias voltage for all circuits is applied after the filaments are heated. Following the closing of the protective interlocks of the grid-bias voltage, the plate rectifiers for the crystal-control unit, the speech amplifier, and the low-power amplifier and modulator stages are applied in succession. After a short time delay, the main power rectifier is started at 50 per cent of its normal voltage, which is applied to the intermediate and main power-amplifier stages. The plate voltage is then automatically increased to its full operating value. In case of improper operation or overload, the other protective devices respond immediately and positively, removing all dangerous power in the correct sequence. The time required to put the station in full operation is about one and one-half minutes. The entire station equipment is shut down by pressing the "stop" button, which breaks the power circuits in sequence and allows the cooling system to run several minutes after the power is shut off and until the vacuum-tube elements are thoroughly cool. The cooling system then closes automatically.

The complete equipment is supplied for checking percentage modulation and monitoring the output of the transmitter. An operator's control unit is supplied for use on the operator's table. This unit contains buttons for the control of the transmitter. There are two major controls, one of which controls the entire transmitter by means of the automatic controls and the time delay relays. The second control serves to shut down the high-voltage rectifier for short stand-by periods.

Tubes.—The following vacuum tubes are required for the operation of this transmitter: two UX-210 type; four UX-865 type; one UV-860 type; three UV-849 type; two UV-863 type; two UV-862 type (100-kilowatt power tube); six 20-ampere, 20,000-volt mercury-vapor rectifiers (UV-857); ten 0.6-ampere, 5,000-volt, mercury-vapor rectifiers (UX-866); two UV-203-A-type; and one UX-280 type.

SECTION XI

MARINE COMMERCIAL TRANSMITTERS

Part 1

QUENCHED- AND ROTARY-SPARK RADIO TELEGRAPH TRANSMITTER, TYPE P-4

(Wave Lengths 300, 450, and 600 Meters)

General Description.—The quenched- and rotary-spark radio telegraph equipment consists essentially of a complete two-kilowatt, 500-cycle transmitting apparatus and a complete receiving set, together with the necessary control switches.

The transmitter consists of a transmitting panel on which are mounted the measuring instruments, a variable inductance, a fixed inductance, a movable inductance, a spark gap, and various switches and rheostats for controlling the wave lengths and the power emitted.

Two spark gaps are provided with this set. The quenched gap is mounted on a panel, and the rotary spark gap is mounted on the end of the motor generator. A switch is provided so that either gap can be used at will.

An automatic starter mechanism, an overload relay, and their appliances are mounted on a panel together with a switch for the direct-current line, a generator-field switch, and a switch for the alternating-current line.

Motor Generator.—The motor generator consists of a 100-volt direct-current motor directly connected to a 500-cycle alternating-current generator. A field rheostat is mounted on the transmitter panel for regulating the motor speed.

The generator is of the rotating armature type and has a normal open-circuit voltage of approximately 350 volts and a working or load voltage of 140 volts. This voltage can be varied by the field rheostat which is in series with the generator field. The field is excited from the direct-current line.

Protective Condensers.—Six condensers are provided for the purpose of protecting the motor and generator from excessive voltages caused by the operation of the transmitting apparatus. Each of these condensers has one of its terminals connected to the frame of the machine, the frame being connected to the ground. The other terminal of each condenser is connected to a terminal of the motor generator. The motor generator is connected to the control panel by means of lead-covered wires in two groups: (1) the motor group and (2) the generator group. The lead coverings of these wires are connected together and grounded to the machine and to the panel frame.

Transformer.—The transformer is of the closed-core type and is immersed in non-liquid oil. The primary winding is connected to the control panel by means of lead-covered wires which have their covering grounded to the transformer case and to the panel frame. The secondary winding of the transformer is brought out through two insulators, on which the terminals are mounted. A protective spark gap is provided which permits a discharge when the voltage becomes excessive. The terminals of the secondary winding of this transformer are connected to the terminals of the high-potential condenser of the transmitting circuit. The casing of the transformer must be grounded.

The transmitting circuits consist essentially of a closed oscillating circuit and an open or radiating circuit known as the *antenna* circuit. These two circuits are inductively coupled and the coupling can be varied by means of a handle (marked "coupling") on the panel.

Wave-length Range.—Three different wave lengths can be transmitted: 300, 450, and 600 meters. The closed circuit consists of a high-potential condenser with a total capacity of 0.012 microfarad, so constructed that either half or all of its capacity can be put into the circuit. The change of wave length is made by varying the amount of inductance in the closed oscillating circuit and also the amount of capacity. The switch handle marked "wave length" performs the function of varying the wave length of the closed circuit and at the same time indicates the wave length.

When the switch is set at 300 meters, half the capacity is inserted in the circuit together with the proper amount of inductance. At 450 meters, all the capacity together with the proper inductance is inserted in the circuit. When the switch is set at 600 meters, all the capacity and the proper amount of inductance is inserted in the circuit.

Variable coupling is provided between the inductance of this circuit (called the *primary*) and the inductance in the open or aerial circuit.

When operating on the 300-meter wave length it is necessary to reduce the power to one kilowatt, as only half the capacity is used. A series reactance is provided with a short-circulating switch which is operated automatically from the wave-length switch. When this switch is set at 300 meters the reactance is connected in series with the primary winding of the transformer. When set at any other wave length it is short-circuited.

Antenna Circuit.—The open or antenna circuit consists of an inductance which is fixed in position with respect to the panel. This is called the *secondary* and is connected in series with two other inductances, one of which may be varied by means of the handle marked "antenna inductance" and the other (called *loading* inductance) may be varied in any desired amount by means of contact clips. The outer end of the secondary inductance is connected to the ground through the thermo-element of the radiation meter. Taps are taken off this inductance at the necessary points, which, in turn, are connected to a switch, controlled by the handle which varies the wave length. This switch is for the purpose of varying the wave length of the antenna circuit and is called the *wave-length switch*. Another set of contacts is provided which connects with points on the loading coil of the antenna inductance. The inner terminal of this inductance is connected to the movable arm of the variable inductance. The outer terminal of the variable inductance is connected to the antenna circuit through the antenna switch. The object of having these connections and the wave-length a switch is to provide a means for varying the amount of inductance in the antenna circuit and at the same time, to maintain the necessary coupling between the two inductances, thus permitting a change of the wave length by moving a single switch. This matter will be treated in detail later on under the heading "*Tuning the Transmitter*."

Change-over Switch.—A change-over switch is provided in the closed-oscillating or primary circuit, which permits either the quenched gap or the rotary gap to be used at will. When the switch is in position for using the rotary gap, it is necessary to short-circuit the quenched gap, this being done by means of suitable clips.

The circuits in the apparatus are shown in Fig. 1. A type-C key, provided for the purpose of telegraphing, is connected in series with the primary winding of the transformer.

Series Condenser.—A condenser is provided which is inserted in series with the antenna circuit between the antenna and the antenna switch to shorten the wave length of the antenna for operation on the 300-meter wage length. If the natural period of the antenna is below 250 meters, this condenser is not needed. It is intended to be short-circuited on the 450- and 600-meter wave lengths.

A group of wires marked "antenna switch group" connect the antenna switch to the control panel. These should be lead-covered wires with their covering grounded.

Meters.—The antenna-current radiation meter is of the "thermo" type. A wattmeter is provided which indicates the power consumed in the transformer circuit. The current coil of this instrument is connected in series with the primary winding of the transformer and the potential coil is connected across the terminals of this winding of the transformer. This meter, therefore, indicates the power consumed in the primary winding of the transformer.

To meet the government requirements, provision is made for transmitting at a low power. This is accomplished by opening the switch marked "low power," which throws a fixed resistance in series with the field coils to reduce the potential of the generator. For operation under these conditions only one gap of the quenched gap is used. This low-power condition cannot be obtained with the rotary gap.

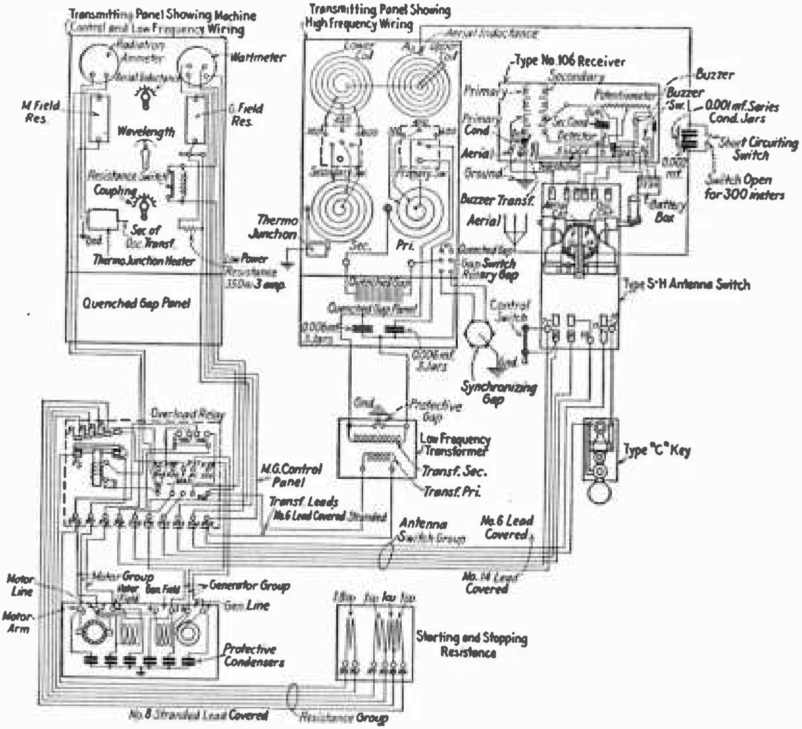


FIG. 1.—Circuit diagram of marine commercial transmitter.

Rotary Gap.—The gap should not be set at less than 0.005 inch. After it has been set to the proper distance the set should be started and the gap adjusted to bring the spark points to the proper angular position to discharge when the voltage rises to a maximum. If the gap does not have the proper angular position, the sparking distance will be too great to allow a discharge or will cause an irregular discharge.

Automatic Starter.—Figure 2 is a front view of the starting panel showing the essential parts of the automatic starter and overload relay. When all the starting resistance is taken out, the field of the generator becomes energized. In other words, the generator field remains open until the starting resistance is disconnected. This arrangement prevents operating the transmitter before the motor generator has attained its rated speed.

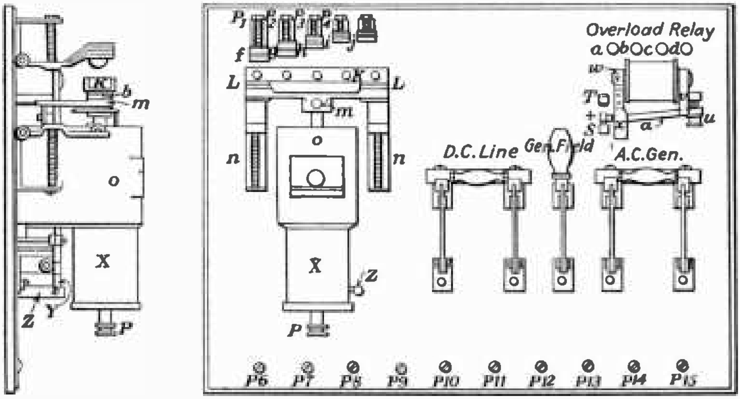


Fig. 2.—Starting panel.

Overload Relay.—The action of an overload relay is described on page 223. As soon as the control switch is opened the armature of the relay drops and closes the circuit through the solenoid, but as this circuit is still open at the control switch, it is necessary to close the control switch again to start the motor generator. The normal working position of this relay is 40 amperes. When a short circuit or overload occurs and this relay is operated, all that is necessary again to start the machine is to open and close the control switch, unless there is a permanent short-circuit in the line, in which case the relay will again open the circuit. The short-circuit should then be removed.

The line should be connected to the starter so that the contact *f* is positive (+); otherwise there will be excessive arcing between these contacts.

Receiver.—The receiver used with this apparatus is of the No. 106 type, which is similar to the commercial receiver described on page 438. A handle marked "potentiometer" is provided to vary the current through the crystal detector. A switch marked "battery" is included so that the crystal can be used either with or without a battery. A buzzer, which is mounted on the panel, is operated by a switch marked "test." A wiring diagram of the type-106 receiver is shown in Fig. 3.

If a *carborundum crystal* is used, the battery is needed properly to adjust the potentiometer. These adjustments are determined by a maximum response to a given signal. If a *cerusite crystal* is used, it is preferable to omit the battery, as this crystal operates best without it. *The potentiometer should be set at* 0. The sensitiveness of this crystal can be determined by the test buzzer.

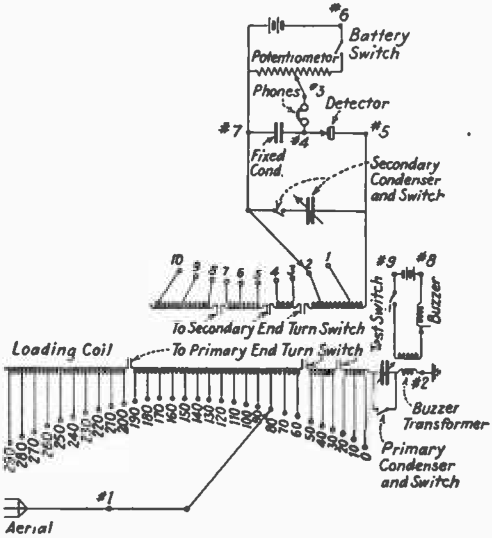


FIG. 3.—Wiring diagram of type-106 marine commercial receiver.

As the transmitter operates at approximately the wave length to which the secondary circuit of the receiver is adjusted, it produces strong signals which may impair the sensitive condition of the crystal. To obviate this, connections are made with the antenna switch so that when this switch is in the transmitting position, the terminals of the detector and the secondary condenser are short-circuited.

Quenched Gap.—The quenched gap used in this transmitter is similar to the one described on page 92. This gap consists of a number of copper disks or plates having parallel "sparking" surfaces, which are separated from each other by means of paper rings, especially treated with an insulating material. These plates are set in a trough in such a manner that they can be clamped together so as to make the enclosed space between the disks air-tight. In setting up this gap care should be taken that the sparking surfaces are clean and smooth. The paper disks or rings should also be clean. There are 15 plates which make 14 spark gaps. The two end plates have only one sparking surface.

If the gap is not air-tight, the note produced will be irregular. This gap is cooled by means of an air blast brought in from the back of the panel through a duct which connects with the rotary spark gap and blower. The number of gaps may be adjusted by changing the positions of the clips. If the surfaces of the gap are black or dark colored, it is an indication that the gap is not properly "seasoned." If the plates are rough, it is an indication that the gap is not air-tight. It requires a continuous running of from one to two hours properly to season the plates for this gap. The note will not be clear until the gap is seasoned.

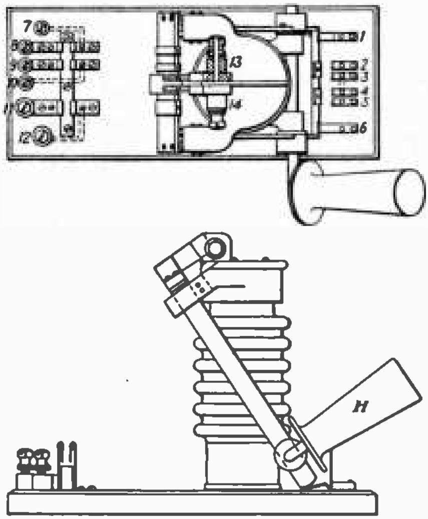


Fig. 4.—Antenna switch.

Antenna Switch.—The top and side views of the type-"S.H." antenna switch are shown in Fig. 4. The terminals have the same marking as in

Fig. 1. The antenna is connected to the terminal 13, and the terminal 14 is connected to the antenna inductance through the series condenser. Contact 1 is connected to 1 of the receiver, 3 and 4 to the top of the detector, 2 to 4 of the receiver, and 5 to 7 of the receiver. When the switch is in the sending position, contacts 2, 3, 4, and 5 are still short-circuited. A three-pole single-throw switch may be inserted between contacts 2, 3, 4, and 5 of the antenna switch and the corresponding receiver terminals, so that the receiver will remain in operative condition while the transmitter is in use. This enables the operator to use the receiver to test the note of the transmitter and to make the required adjustments for obtaining the proper note. Contacts 7 and 8 open and close the motor-control circuit, which in turn starts and stops the motor generator. Contacts 9 and 10 open and close the generator field circuit. Contacts 11 and 12 open and close the primary

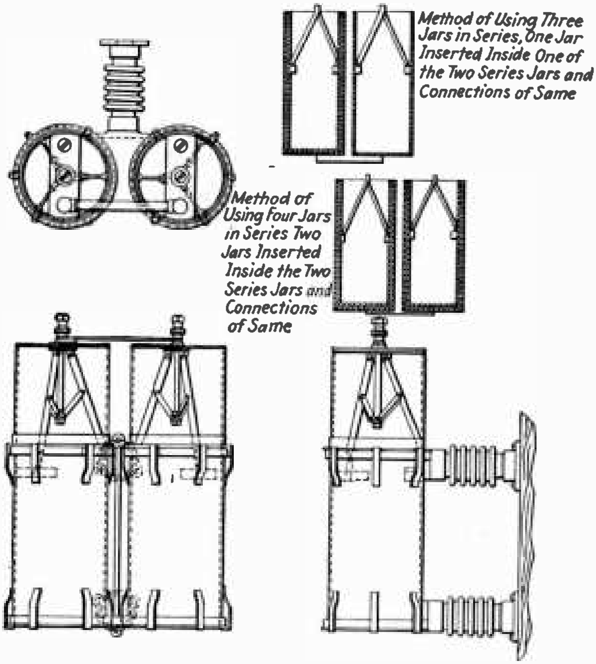


FIG. 5.—Series condenser.

circuit of the transformer. When the antenna switch is in its sending position these contacts are closed, and when in its receiving position they are open. The switch is operated by the handle *H*. The wires connecting contacts 2, 3, 4, and 5 to the receiver must be insulated and separated about ¼ inch to reduce their self-induction.

A single-pole flush switch called the *control switch* is provided which, when closed, keeps the motor generator running continuously. This switch can be kept closed when the noise from the motor generator does not interfere with the reception of signals. When this switch is open the motor generator will start and stop as the antenna switch is thrown from the receiving to the transmitting position, and *vice versa.*

Series Condenser.—Front, side, and top views of the series condenser are shown in Fig. 5. This figure shows also the method of using three or four leyden jars in series. The object of this series condenser is to reduce the natural period of the antenna to a value less than 250 meters, so that the proper amount of inductance to obtain the necessary coupling may be used in the antenna circuit. The exact size of this condenser cannot be predetermined. With two leyden jars in series the capacity is 0.001 microfarad; with three leyden jars in series, it is 0.00066 microfarad; with four leyden jars in series, it is 0.0005 microfarad. If the capacity of the antenna has an approximate value of 0.001 microfarad, then two leyden jars in series will be sufficient. If the antenna capacity is larger, then it will be necessary to use more leyden jars in series. A short-circuiting switch is provided by which the condenser can be short-circuited, when the longer wave length is used.

Tuning the Transmitter.—In this set no wave meter is required to do the work, as the primary or closed oscillation circuit is set for the required wave lengths.

Before starting to tune the set, the motor rheostat should be set at about half its rated value. The motor generator should then be started and brought to speed, care being taken that the automatic starter and all other appliances are carefully adjusted. The field rheostat of the generator should then be inserted to the full amount, so as to reduce the voltage of the generator. Six plates should be used in the quenched gap when starting. The normal operating position of the coupling indicator is at two turns, which is indicated by a red line on the scale. This coupling should be opened until approximately eight turns are visible. The wave-changing switch should be set for 600 meters. The closed oscillating circuit will then generate oscillations having a frequency corresponding to 600 meters. It is next necessary to make an approximate setting of the 600-meter contact on the secondary circuit and also of the loading coil. The antenna inductance should be set so that three turns can be seen. These circuits together with the coils are shown in Fig. 6. The approximate settings of the contacts are indicated by points 4, 5, 6, 7, 8, and 9. The figure shows the antenna, series condenser with its short-circuiting switch, antenna inductance, loading inductance, wave-length switch, secondary coil, and antenna ammeter. The primary circuit consists of a primary winding, wave-length switch, condenser, and spark gap. The wave-changing switch is connected permanently to the spiral at points 1, 2, and 3. In setting this apparatus for any wave length it is necessary to have a definite amount of inductance in the antenna circuit for a given wave length and also to have the proper coupling between the closed circuit and the antenna circuit.

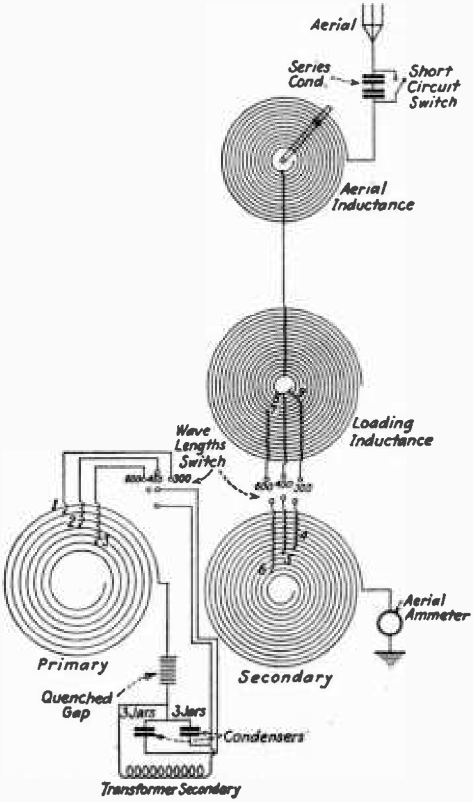


Fig. 6.—Coils of marine commercial transmitter.

This coupling can be changed by varying the amount of inductance included in the secondary circuit, which, in turn, varies the mutual inductance between the primary and the secondary circuits. If the distance between the primary and the secondary circuits is fixed, then it is possible to secure the proper coupling by getting the proper amount of inductance in the secondary circuit and adjusting the loading coil until the antenna circuit, as a whole, is adjusted to the required wave length. This last adjustment will be determined by the maximum flow of current in the antenna circuit as indicated by the antenna ammeter. In making the first approximation, the coupling can be "loosened" by increasing the distance between the primary and the secondary circuits and varying the antenna ammeter. This is the reason why three turns should be normally used in the antenna inductance. After this condition has been obtained, the coupling should be varied until a maximum current flows in the antenna circuit, as indicated by the antenna ammeter. If this indication of the maximum current occurs before the coupling is brought into the normal position as indicated by the red line on the scale, there is too much inductance in the secondary circuit and not enough in the loading coil. It will now be necessary to make a test for resonance between the antenna circuit and the secondary as before. Adjustments can be made for small variations and changes in the antenna circuit by means of the antenna inductance.

It is found in marine practice that if the transmitter is tuned and adjusted near a steel pier or other conducting body, slight changes will be required when the ship in which the apparatus is installed moves away from such objects. With the quenched gap the antenna circuit and the primary circuit must be in tune and must have the proper amount of coupling. After the set has been tuned in this manner, it can be brought to full power by inserting 12 gaps in the closed circuit and decreasing the resistance of the motor-generator field until the necessary power for operating the set is obtained. It is always well to do the preliminary tuning on small power. The wave-length switch should now be set to 450 meters and the process of tuning repeated for this wave length. In tuning for the 300-meter wave length the same method should be used after the wave length has been set for 300 meters; and in most cases it will be necessary to insert the series condenser. If it is found that there is not enough inductance in the secondary circuit to obtain the necessary coupling when the coupling indicator is set at its normal position, the capacity of the series condenser should be reduced until the necessary amount of inductance is obtained.

After these sets have been properly tuned for the different wave lengths all that is necessary in order to change the transmitted wave length is to throw the wave-length switch to the desired position, except on the 300-meter wave length, when it will be necessary to open the short-circuiting switch of the series condenser. If no wave meter or other form of detector is available, the receiving set can be used to determine the quality of the note. To do this it is necessary to eliminate the short circuits from the antenna switch by temporarily removing the wire on that switch. The field rheostat of the generator should be adjusted until the required note is obtained in the receiver.

Part 2

ARC RADIO TRANSMITTERS

General Description.—The designs of the arc radio transmitters made by the Federal Telegraph Company are based on the method of obtaining undamped radio-frequency oscillations by means of an electric arc. The arc is enclosed in a chamber with an atmosphere of hydrogen or other gas or suitable vapor, and the electrodes are placed between the poles of a powerful electromagnet, which produces a strong transverse magnetic field tending to blow out the arc. Carbon or graphite is used for the negative electrode, while the positive is made of copper and is water cooled.

A two-kilowatt Federal arc transmitter consists of the following main units: (1) a source of direct current of suitable voltage, (2) an arc converter, (3) an antenna loading inductor, (4) an antenna and ground system, (5) a signaling device, and (6) auxiliary and control apparatus. The essential features of such a transmitter and the main circuits are shown in Fig. 7. The arc converts the power supplied by the direct-current generator into radio-frequency energy with undamped current in the antenna circuit. The antenna circuit includes the antenna, the loading inductor, the electrodes of the arc, and the ground system. A choke coil prevents the flow of radio-frequency current from the arc into the power machinery and serves to sustain the steady operation of the arc. The frequency of the undamped current in the antenna circuit depends on the inductance and capacity of the circuit. The frequency, and therefore, the wave length may be altered by changing the value of either the inductance or the capacity, or both.

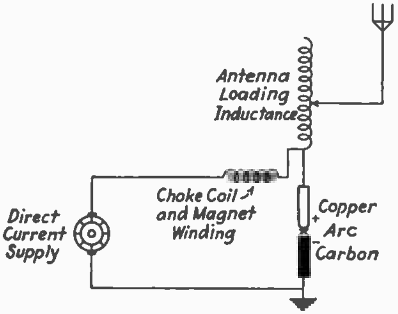


Fig. 7.—Arc transmitter.

Since the capacity is furnished by the antenna and is, therefore, fixed, the inductance of the circuit is varied by changing the connections to the antenna loading inductance.

Arc converters are used to convert direct current into alternating current of very high frequency,—for example, 60,000 cycles or more. All parts of an arc converter are stationary except the carbon electrode, which is rotated very slowly in order that it may burn evenly, and which is made so that it may be screwed in and out in order to strike and adjust the arc. In operation, the length of the arc flame is adjusted to secure maximum antenna current and this is the only adjustment or attention required. The carbon does not burn away as an ordinary arc, but, on the other hand, the arc usually builds up slowly, depending on the chemical composition of the gas in the chamber.

The hydrogen gas in the arc chamber is obtained by the decomposition of alcohol, which is vaporized by the intense heat of the arc. Kerosene vapor may also be used and it gives very good operation, especially on short waves, but has the disadvantage of causing an excessively large amount of soot in the chamber. Illuminating gas may be used in the arc chamber when available.

Signaling.—While the arc is in operation there will be a continuous flow of undamped current in the antenna circuit unless the radiated energy is broken up into dots and dashes. Signals may be transmitted by any of the three following methods: (1) back-shunt signaling, (2) coupled-compensation signaling, (3) a chopper (page 543) used with either of the above methods.

The transmitters are equipped with the *back-shunt method* as the principal means of signaling. A coupled-compensation system is supplied as an auxiliary. The sets are also equipped with a *chopper* for use on short waves when transmitting to a receiver which is using a detector of the crystal type, or the non-regenerative vacuum-tube type.

Back-shunt Method of Signaling.—The circuits employed for the back-shunt method of signaling are shown in Fig. 8. When the movable contact of the back-shunt relay key touches the stationary contact which is connected to the bottom of the antenna loading inductance, the radio-frequency current flows in the antenna circuit. When the movable contact touches the other stationary contact, the radio-frequency current flows in the back-shunt circuit and there is no current in the antenna, because it is then disconnected from the arc. The relay key is adjusted so that the movable contact makes connection with one stationary contact before it loses its connection with the other. This permits the arc to remain in constant operation while the transfer is being made from the antenna circuit to the back-shunt circuit.

The back-shunt circuit consists of a resistance, an inductance, and a condenser, all being connected in series. The resistance is made variable in order that the radio-frequency current may be the same whether the arc is operating on the antenna circuit or the back-shunt circuit.

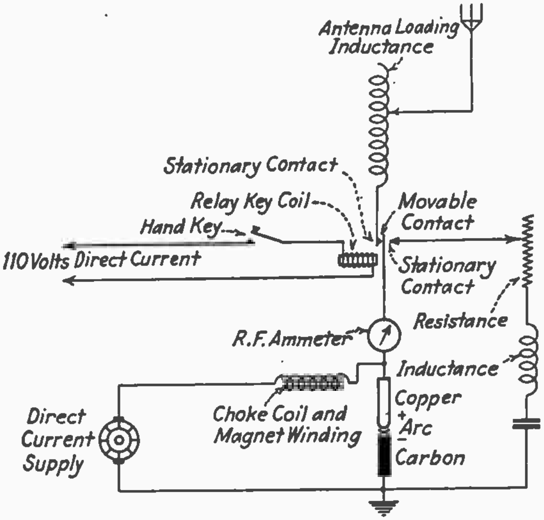


FIG. 8.—Back-shunt method of signaling.

The back-shunt relay key is operated by an electromagnet controlled by a small Morse hand key. When the hand key is pressed down, the electromagnet is energized and the movable contact connects the arc with the antenna circuit. When the hand key is released, a spring causes the movable contact to connect the arc with the back-shunt circuit.

Coupled-compensation Method of Signaling.—The circuits used when signaling by the coupled-compensation method are shown in Fig. 9. The coupled-compensation loop is a single turn of wire which is placed around the lower end of the antenna loading inductance. By means of the auxiliary hand key, the loop may be short-circuited at the will of the operator. With the arc in operation and the auxiliary hand key open, radio-frequency energy is radiated at a certain wave length. When the key is depressed, energy is radiated at a shorter wave length than before. This change in wave length is due to the transformer action and the mutual inductance between the main coil and the short-circuited loop. The receiving station may be tuned to hear only the shorter wave, since this is the one used to transmit signals by depressing the hand key.

Signaling with Chopper.—The chopper, which consists of a commutator wheel driven by a small motor, is necessary to break up the radiated energy into wave trains of an audible frequency. Referring to Fig. 10, the chopper commutator wheel, when rotated, opens and short-circuits the coupled-compensation loop at a speed which gives a musical note in the receiver. The radio-frequency energy is thus emitted at two wave lengths as when using the auxiliary hand key, but in this case the wave length rapidly alternates between the maximum and minimum value. A continuous musical note is thus produced which may be heard by receivers using detectors of the crystal type or the non-regenerative vacuum-tube type.

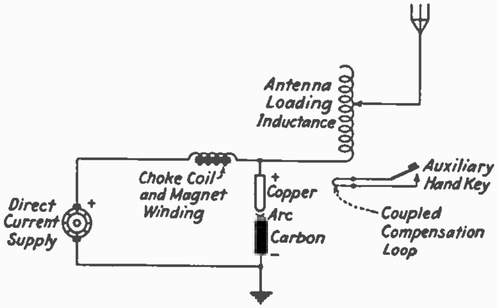


Fig. 9.—Coupled-compensation method of signaling.

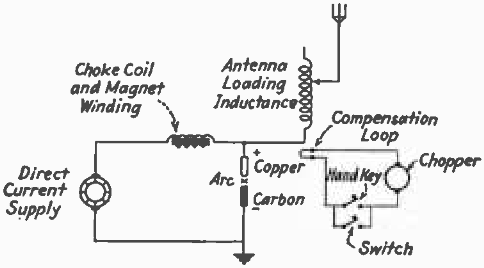


Fig. 10.—Chopper.

Signals may be transmitted either by means of the auxiliary hand key connected in series with the circuit between the loop and the chopper or by means of the back-shunt method of signaling. When the auxiliary

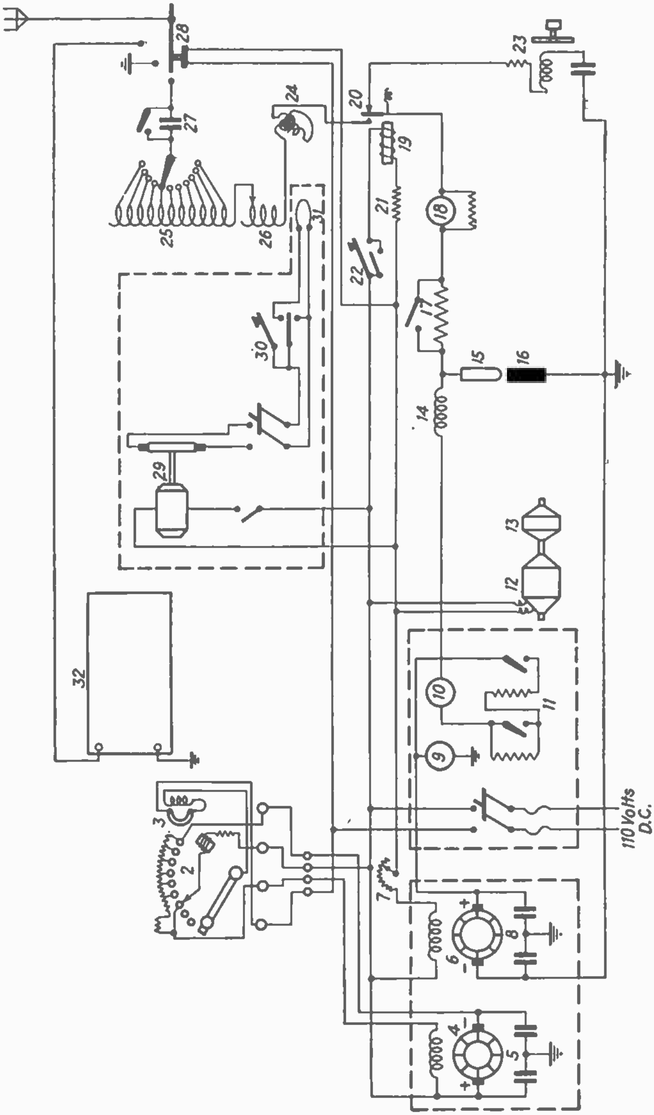


FIG. 11.—Complete wiring diagram of arc transmitter

hand key is used, the radiated wave is broken into wave trains of audible frequency only when the key is closed. The receiver, therefore, produces no signal when the key is open. When the chopper is used with the back-shunt method of signaling, the auxiliary key is short-circuited by a small switch. The chopper is effective whenever current is flowing in the antenna circuit, and signaling is accomplished by varying the current in the antenna in accordance with dots and dashes as described for the back-shunt methods of signaling.

Reception of Signals from Arc Radio Transmitters.—All signals produced by the arc without the use of the chopper are of continuous *undamped* radio-frequency energy, while those transmitted by using the chopper are of *undamped* radio-frequency energy broken into wave trains. Transmitted signals of undamped radio-frequency energy occur at such high frequencies that they are not audible in the telephone receivers of a receiving set using a detector of the crystal type or the non-regenerative vacuum-tube type. Two principal methods are used to receive signals of undamped radio-frequency energy: (1) the heterodyne method (page 36) and (2) the tikker method.

The heterodyne method makes possible the reception of signals of undamped radio-frequency energy by the use of the principle of beats (page 408). A local undamped current of which the frequency is either slightly greater or less than that of the incoming wave is produced in the receiving set. This local current combines with the incoming current to produce a resultant current which has a much lower frequency than that of either the incoming current or the local current. It is this current, known as the "beat" current, which is audible in the telephone receivers. In the case of *tikker reception*, the incoming undamped current is locally broken into a current which is audible in the telephone receivers.

Wiring and Diagram.—A complete wiring diagram of the Federal two-kilowatt arc transmitters, models K and Q, using the back-shunt method of signaling, is shown in Fig. 11. The parts of the complete assembly and their numbers as shown in the drawing are listed in the following table:

1. Main-line switch.
2. Hand starter.
3. Circuit breaker.
4. Direct-current motor armature field.
5. Protective condensers.
6. Direct-current generator armature field.
7. Direct-current generator field rheostat.
8. Protective condensers.
9. Direct-current voltmeter.
10. Direct-current ammeter.
11. Arc switch with overload release coil and starting resistance.

12. Direct-current motor for carbon drive and water pump.
13. Centrifugal water pump.
14. Magnet coils.
15. Copper (anode).
16. Carbon (cathode).
17. Antenna resistance.
18. Antenna ammeter and protective coil.
19. Relay key.
20. Fixed contact.
21. Relay-key resistance.
22. Morse hand (back-shunt) key.
23. Back-shunt unit.
24. Note-varying variometer.
25. Coarse-tuning loading inductance.
26. Fine-tuning inductance.
27. Antenna series condenser and short-circuiting switch.
28. Send-receive-ground switch.
29. Motor-driven chopper.
30. Auxiliary hand key.
31. Compensation loop.
32. Receiver.
33. Chopper switch.

Two-kilowatt Arc Transmitters, Models K and Q.—The model-K arc radio transmitter is for use in naval vessels, and the model Q is for merchant ships. The sets are identical except for the range of wave lengths employed. With the model-K sets, the chopper is used on waves below 952 meters. On 952 meters and above, the set is operated as an undamped-wave transmitter. In the case of the model-Q sets for merchant ships the chopper is used on all waves up to and including 1,000 meters. For the waves of 1,000 meters and over, it is operated as an undamped-wave transmitter. In general, the 2-kilowatt arc radio set may be operated as an undamped-wave transmitter on wave lengths of 950 meters and above; but below 950 meters the chopper is used.

Motor Generator.—The arc of a 2-kilowatt transmitter requires direct-current power supplied at from 250 to 400 volts. This is furnished by a two-bearing motor generator which consists of a direct-current motor to operate at from 100 to 120 volts. The motor is directly connected to a shunt-wound, separately excited 2-kilowatt, direct-current generator to operate at 400 volts. The generator will deliver 2 kilowatts at from 250 to 400 volts and is wound for separate excitation from a 120-volt direct-current supply. Terminals for the motor and generator are located on an enclosed terminal board.

Protective Devices.—Two protective devices for the motor and generator are mounted in the terminal box on top of the unit and are connected in the circuit at all times. These are small condensers which absorb any stray radio-frequency currents which may leak into the circuits of the motor and the generator.

Motor Starter.—The motor generator is started by means of a hand-operated motor-starting panel. This is equipped with an overload circuit breaker which opens the motor-supply circuit in case the current becomes excessive. The motor starter should be mounted vertically to permit the circuit breaker to operate properly.

Generator Field Rheostat.—The power output of the arc converter is regulated by adjusting the voltage of the direct-current generator by means of the field rheostat of the generator, which is of the single-plate type. The rheostat should be easily accessible and located where there is sufficient air circulation to prevent overheating.

Arc-control Panel.—The arc-control panel is the switchboard through which connections are made between the arc converter and the direct-current generator. It also carries a switch through which the entire transmitter is supplied with 110–120 volt direct current. On the panel as shown in Fig. 12 are mounted: (1) supply switch and fuses; (2) arc main-line switch, with an overload trip coil; (3) arc starting resistance and short-circuiting switch; (4) direct-current ammeter for the arc circuit; (5) direct-current voltmeter for the arc circuit.

The arc main-line switch is a special quick-break switch which connects the arc converter to the direct-current generator. It is provided with a trip coil which opens the switch in case of overload. The arc starting resistance is connected in series between the arc converter and the direct-current generator and serves to protect the generator from sudden overloads when the arc is established. It may be short-circuited by the starting-resistance switch after the arc has been started. The direct-current ammeter and voltmeter indicate the power input to the arc. The negative terminal of the direct-current voltmeter is supplied through the ground connection of the panel.

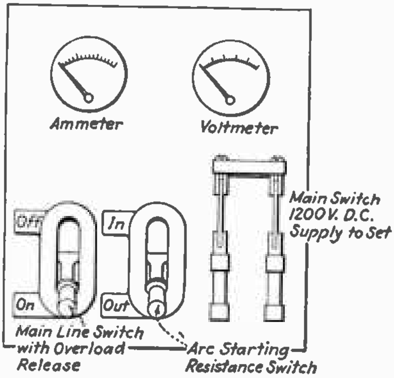


FIG. 12.—Arc-control panel.

When the handle of the arc main-line switch is pushed down until it locks, the arc is connected to the generator through the ammeter and the arc starting resistance. To open the switch, the operating handle should be raised until the switch trips. The arc starting-resistance switch is operated in the same manner. It should be closed only after the arc has been started and is in operation. These two switches are interlocked so that both are opened whenever the arc main-line switch is opened, but they may be operated separately. The arc starting resistance is thus automatically placed in series, between the arc converter and the generator whenever the main switch is opened to extinguish the arc.

When the operation of the transmitter is to be stopped the switches should be opened in the following order: (1) arc main-line switch and starting-resistance switch and (2) supply switch of the set.

Arc-converter Rating.—The arc converter has a nominal rating of 2 kilowatts. The series field coils are designed to carry 8 amperes (direct current) for 5 hours. The maximum direct-current rating is 10 amperes for 2 hours.

The arc converter is designed for operation at from 250 to 400 volts (direct current). The voltage necessary to obtain a given antenna current on any wave length depends on the resistance of the antenna circuit at that wave length.

The magnetic circuit is of the closed type. The pole tips project into the top and bottom of the arc chamber. The steel outer shell of the arc converter forms a return path for the magnetic flux.

Series-field Coils.—The field winding is divided into four coils. Three of these are placed below the arc chamber and one is placed above. The coils are connected in series and serve both as a magnetizing winding and as choke coils to prevent the flow of radio-frequency current back into the direct-current generator.

When a field coil is to be replaced the new coil must be inserted so that current flows through all the coils in the same direction. The magnetic field must blow the arc flame toward the exhaust opening at the back of the arc chamber. The reversal of polarity of one coil would be sufficient to impair the arc seriously.

Arc Chamber.—The arc chamber is a gas- and water-tight compartment within which the arc burns. The chamber is enclosed at the top and bottom by water-cooled bronzed plates and is divided horizontally into two parts by a hinged joint. The gasket between the two chamber surfaces must be kept free from dirt. Failure to do this will result in air leaks, causing a noisy, unsteady arc and a reduction of antenna current. All water connections must be tight, as any water in the arc chamber will cause a decrease in antenna current and rapid wearing away of the carbon electrode.

The arc chamber should never be opened until at least one minute after the arc has been extinguished; otherwise, the red-hot carbon will ignite the explosive mixture which is made when air combines with the chamber gases.

Anode Tip.—The anode, or positive electrode, consists of a water-cooled copper tip supported by a holder which is insulated from the arc chamber. The copper tip is renewable when it becomes worn. There must be a supply of water circulating through the anode to keep it cool. The anode holder should be kept clean; otherwise, deposits of soot will ultimately form a conducting path from the anode to the arc chamber, and a flash-over may occur which will result in burning the parts.

The anode tip must be aligned exactly midway between the magnet poles and must always be connected through the arc series-field winding to the *positive* terminal of the direct-current generator. If connected to the negative terminal, it will melt very quickly when the arc is started.

Carbon.—The negative electrode of the arc is the cathode. It consists of a carbon rod which is one-half inch in diameter and seven inches long. It is held in a removable holder which is, in turn, supported within a mechanism which is slowly rotated by means of worm gears. The proper position of the carbon is secured automatically by the use of a special wrench and gage.

Alcohol Supply.—The hydrogen gas which is necessary for the operation of the arc converter is supplied by the decomposition of either grain or denatured alcohol. An alcohol cup mounted on the arc converter is provided with a valve and a sight-feed glass by means of which the flow may be adjusted and observed. The alcohol drips into the chamber through the upper magnet pole. When it reaches the arc flame it is decomposed and hydrogen is released.

Water-flow Indicator.—An indicator to show the flow of water consists of a small metal case with a glass front and back within which a colored marble is placed. When water flows through the indicator, the circulation is indicated by the motion and rattling of the marble.

Pressure Regulator.—As alcohol is supplied continuously to the arc converter during its operation, there will always be a certain amount of gas in the chamber. Excess gas is carried through a rubber hose to the pressure regulator, which consists of an aluminum receptacle divided into two compartments by a rubber diaphragm. This diaphragm serves to maintain the gases within the chamber at approximately atmospheric pressure. The pressure regulator is provided with an outlet through which the excess gases may escape to an outdoor vent.

Installation of Arc Converter.—The arc converter is clamped to a table and installed where the carbon knob for its adjustment is easily reached by the operator and where the alcohol sight-feed and water-flow indicator are visible. Clearance should be provided for lifting the top section and for removing the electrodes. The arc must be located where there is a place beneath it to mount the water pump and the shaft for the gears which turn the carbon cathode.

Care of Arc Converter.—The main points to be observed in caring for an arc converter are: (1) Arc chamber should be kept clean; (2) water leaks inside the arc chamber must be prevented; (3) arc chamber should be kept air-tight; (4) anode holder should be kept clean; (5) moving parts of the cathode should be cleaned and oiled occasionally.

Water Pump.—A centrifugal pump for circulating the water is mounted upon the floor under the arc converter. The pump is driven by a ¼-horsepower, 110-volt, direct-current motor. The same motor is used for driving both the water-pump and the carbon rotating mechanism. A pet cock on the pump casing provides a means for the air to escape from the pump and piping, thereby priming the pump when starting.

Water Tank.—A 15-gallon tank is provided for the arc cooling water. It is necessary to use fresh water for the arc converter in order that the anode may be insulated from the earth. Salt water would act as a relatively good conductor from the anode to the arc chamber, and the electrodes would be short-circuited. The tank may be mounted either vertically or horizontally above the level of the arc converter. Three test cocks are provided for determining the water level in the tank. The water should be renewed occasionally in order to prevent the accumulation of sediment and foreign material.

Antenna Loading Inductance.—A coil of radio-frequency cable wound on a bakelite frame is the antenna loading inductance. It is inserted in the antenna circuit between the arc converter and the series condenser, from which a connection is made to the antenna. Taps are brought out from the coil winding for the adjustment of wave length. When a large amount of this coil is connected in the antenna circuit, a relatively long wave length is secured; with a small amount of the coil in the circuit, the wave is relatively short.

A bare copper helix is built into the lower end of the antenna loading inductance coil to provide for very close adjustments. This copper helix is used in connection with the bottom layer of this coil. This bottom layer has four taps at equal intervals, and by making the proper connections between these taps and the bare helix, an exact adjustment for any wave length is obtained.

A *coupled-compensation loop*, consisting of a single turn of radio-frequency cable, is placed around the lower end of the antenna loading inductance. This loop couples the auxiliary key circuit and the chopper (page 543) to the antenna circuit.

When in operation the voltage on the upper end of the antenna loading inductance is relatively high (approximately 20,000 volts above earth, *i.e.*, ground potential). The coil should be located where the personnel of the operating room will not come in contact with it and should be placed as far as possible from other objects and especially from iron. If the coil is less than about 12 inches from a steel bulkhead or similar structure, a large loss of energy will occur because of the action of the high-frequency magnetic field of the coil upon the iron.

Adjustment of Wave Lengths.—Metal tags are provided for marking the positions of the connections for the wave lengths at which the set is to be operated. In the case of the model-K transmitter for naval vessels, these tags are stamped with the following wave lengths: 300, 476, 600, 756, 952, 1,200, 1,512, 1,905, 2,400. The model-Q sets for merchant shops have tags stamped with the following wave lengths: 300, 450, 600, 750, 1,000, 1,400, 1,800, 2,300.

Two flexible conductors are supplied for making connections to the terminals of the loading inductance. In order to make the necessary connections to obtain any given wave length the following general procedure should be followed:

1. Connect the clamp on one end of the cable to the lowest turn of the bare-copper helix, and connect the other end of the cable to which the clamp is attached to the bottom tap on the main terminal board of the loading inductance. This eliminates both the bare helix and the bottom layer of the loading-inductance coil from the antenna circuit.

2. By means of the longer of the two flexible cables, connect the antenna series condenser with one of the upper terminals of the antenna loading inductance. If the desired wave is relatively long, this connection should be made to one of the terminals near the top of the coil. If a relatively short wave is desired, the connection should be made so that only a small portion of the coil is included in the antenna circuit.

3. The arc may be started and the wave length observed by means of a wave meter.

4. In case the observed wave length is too short, more layers of the coil should be included in the antenna circuit. If the wave is too long, a portion of the coil should be taken out of the circuit by shifting the connection to a lower terminal.

5. When two such terminals have been found that one of them gives a wave slightly longer than is desired, and the other slightly shorter, connections may be made to obtain the exact wave length by using the terminal which gives the shorter wave and then including a portion of the bare copper helix in the circuit. This is done by shifting the clamp from the lowest to one of the upper turns of the bare-copper helix. In case this does not sufficiently increase the wave length, a portion of the bottom layer of the main loading inductance may be included in the circuit by shifting the connection to one of the four taps which are brought out from this layer.

6. After the proper positions for the various connections have been determined by trial, these positions should be permanently marked by using the stamped metal tags provided for this purpose. Three different kinds of

tags are provided: one for the main terminal board of the loading-inductance coil, one for the bare helix, and another for the four taps in the bottom layer of the loading-inductance coil.

Radio-frequency Ammeter Panel.—A radio-frequency ammeter with a ten-ampere scale is supplied for indicating the current in the antenna circuit. This is a "thermo" ammeter with a self-contained thermocouple. The meter is mounted on a bakelite panel to insulate it from the bulkhead. On the back of this panel, a coil of heavy copper wire is shunted across the terminals of the meter. This coil is called an *inductive protective shunt.* Due to the high reactance of the coil, radio-frequency current will take the more direct path through the ammeter, and the presence of the coil as a shunt around the meter will, therefore, not affect the reading of the instrument. If the antenna becomes grounded or if a direct-current short circuit occurs in the antenna circuit, the coil will take most of the direct current.

Relay Key.—The relay key provides a means of connecting the arc either to the antenna circuit or to the local back-shunt circuit. It consists of a movable contact controlled by an electromagnet and a spring. When the operator presses down on the Morse hand key, the electromagnet is energized and the movable contact connects the arc converter to the antenna circuit. When the Morse hand key is released, the spring causes the movable contact to connect the arc converter to the local back-shunt circuit.

A series resistance for the solenoids of the relay key is mounted on the base of the key. When this resistance and the two solenoids are in series, the proper current is obtained by supplying the key with direct current at 110–120 volts through the Morse hand key.

Back-shunt Circuit Unit.—A local, non-radiating oscillatory circuit is supplied in order that the arc converter may have a circuit on which to oscillate during the intervals between the dot-and-dash signals. This is called the back-shunt circuit because it is shunted around the arc when current is to be excluded from the antenna.

The back-shunt circuit unit consists of a bakelite panel on which are mounted an inductance coil, a condenser, and a resistance coil. The inductance coil is a small one of insulated copper wire. The condenser has a capacity of 0.004 microfarad and the resistance coil consists of two resistance tubes connected in parallel. A switch is provided to short-circuit this resistance when desired. An additional and variable resistance is obtained by placing a steel disk in front of the inductance coil. When radio-frequency current flows in the coil, eddy currents and hysteresis losses in the steel disk cause an increase in the resistance of the back-shunt circuit. These losses are greatest when the disk is near the coil. The resistance may be varied by turning a knob which moves the disk nearer to or away from the coil.

The back-shunt circuit unit may be mounted on the bulkhead of a ship. One connection is made to the relay key, and the other to the grounded side of the arc converter.

In operating the set the resistance of the back-shunt circuit should be adjusted so that the radio-frequency current delivered by the arc converter remains constant whether the arc is in the antenna circuit or in the back-shunt circuit. This adjustment of resistance is secured by screwing the steel disk in or out and by use of the switch which short-circuits the fixed-tube resistance.

Transfer Switch for Chopper and Auxiliary Hand Key.—A single-pole, double-throw transfer switch is provided to connect the coupled-compensation loop (page 540) around the bottom of the antenna loading inductance to the chopper, or to the auxiliary hand key, or to the two in series.

When this switch is turned one way, the coupled-compensation loop is connected directly with the auxiliary hand key, and signaling may then be accomplished by the coupled compensation method. When the switch is turned the other way, the chopper is connected directly to the coupled-compensation loop. Signaling with the chopper may then be accomplished by the use of the back-shunt relay key.

Chopper.—The chopper consists of a commutator wheel driven by a ¼ horsepower direct-current motor. Segments of the commutator wheel are connected to a central ring. There are two brushes on the chopper which are adjusted so that both make contact with the connected segments *at regular intervals* during the rotation of the wheel. The two brushes are connected through a switch to the coupled-compensation loop, which is placed around the bottom of the antenna loading inductance. The commutator wheel serves alternately to open the circuit of this coupled-compensation loop and short-circuit it. When the compensation loop is "open," energy is radiated at a given wave length. When the commutator wheel is in the position to short-circuit the compensation loop, energy is radiated at a slightly shorter wave length.

The chopper should be installed close to the antenna loading inductance. The connections between the chopper compensation loop, auxiliary hand key, and transfer switch should be as short as possible in order that the compensation loop may be effectively short-circuited by the chopper and auxiliary hand key. A single-pole snap switch is provided for starting and stopping the motor of the chopper.

Auxiliary Hand Key.—An auxiliary hand key is provided for signaling by the coupled-compensation method whenever desired, and in case of failure of the back-shunt method.

Note-varying Variometer.—The tuning with an arc radio transmitter is very sharp and in case an arc set is calling a station whose receiver is not tuned exactly, the call may not be heard. In order that the operator while calling, may be able slightly to vary the length of his wave, a note-varying variometer is supplied. When the movable coil of the variometer is turned in one direction, the wave is lengthened; and when it is turned in the opposite direction, the wave is shortened. Thus the operator is able slightly to vary the wave and thereby make his call heard by the receiver.

The variometer is connected directly in series in the antenna circuit between the antenna loading inductance and the relay key.

Antenna Low-power Resistance.—In order that the antenna current may be reduced when communicating with a nearby station, a resistance unit may be connected in series in the antenna circuit between the arc converter and the radio-frequency ammeter. A short-circuiting switch, mounted on this unit, is kept closed except when it is desired to operate at low-power conditions.

Send-receive-ground Switch.—This switch provides the means of connecting the antenna to (1) the transmitter, (2) the receiver, or (3) the ground. The high-voltage parts have brass shields which are made so that the radius of curvature prevents corona. The "ground" and "receive" positions are mounted within a protective hood which prevents a flash-over between the high-voltage parts and the clip connected to the receiver.

Interlock contacts are provided on the send-receive-ground switch for the 110-volt direct-current circuit which supplies the relay key and other auxiliaries.

Morse Hand Key.—By means of a Morse hand key a relay key is controlled, and signaling is accomplished by the back-shunt method. The hand key is provided with a short-circuiting switch in order that the relay key may be closed and the arc kept on the antenna circuit when desired.

Antenna Series Condenser.—This is a mica condenser which is connected in series with the antenna circuit on all wave lengths below 2,000 meters. It is placed in the circuit between the antenna loading inductance and the send-receive-ground switch. The capacity of the series condenser is 0.0006 microfarad and it considerably reduces, therefore, the effective capacity of the antenna circuit. This permits the use of more antenna loading inductance than could otherwise be used for any given wave length.

The increase of inductance and decrease of capacity insure steadier operation of the arc converter, especially when used as an undamped-wave transmitter on wave lengths between 950 and 2,000 meters. For waves over 2,000 meters, the series condenser is short-circuited from the circuit by means of a switch mounted on its terminals.

Testing K- and Q-Types of Transmitters.—Before starting the set for the first time, the various circuits should be tested to see that all electric connections have been made in the proper manner. Also, the alcohol cup should be full and feeding properly; the water tank should be three-fourths full of fresh water; the valves of the water tank should be open and the flow indicator should indicate a circulation of water when the pump is started; all moving parts should be properly lubricated.

Starting Set after Period of Rest.—When the K- and Q-types of transmitters have been out of service for a long time, the procedure in starting should be as follows: (1) Supply switch of the set is closed; (2) send-receive-ground switch is placed in the sending position, this switch starting the water-pump and the carbon rotating mechanism which are supplied through interlock contacts; (3) motor generator is started by closing the circuit breaker on the starting panel and bringing the motor gradually to full speed, the generator voltage being adjusted to about 250 volts by means of the field rheostat; (4) alcohol supply is started so that it drips rather rapidly; (5) carbon on the arc is adjusted so that there is about $\frac{1}{32}$ inch movement when the arc is struck; (6) arc main-line switch is closed and the arc is made. The arc should be drawn out as much as possible without causing it to break. In starting for the first time after a period of rest, it will be necessary to keep the arc rather short for a minute or two until sufficient alcohol has been decomposed to give a partial hydrogen atmosphere in the arc chamber. As soon as the arc starts oscillating, the radio-frequency ammeter will indicate a flow of current in the oscillatory circuit and the arc should then be adjusted to obtain a maximum reading of this meter. The switch for the arc starting resistance is then closed and the arc adjusted for a maximum reading of the radio-frequency ammeter. The alcohol flow should be reduced to a few drops per minute and the generator voltage adjusted to obtain the desired antenna current. After these adjustments have been made, the sending key may be pressed for service.

Transmitting Signals.—After the arc is operating, signals may be transmitted by sending with the Morse hand key. In case radio-frequency current through the back-shunt circuit differs materially from that in the antenna circuit, the resistance of the back-shunt circuit should be adjusted so that the output of the arc converter is the same for both circuits.

Arc Breaks.—If the arc breaks or goes out, it is necessary to open the switch of the arc starting resistance and form the arc again. In case the arc is formed without opening this switch, a short circuit results and a trip coil opens the arc main-line switch. It is then necessary to lift the handle of this switch to its upper position and then close it. After this procedure the arc will be formed and the switch of the starting resistance should be closed again.

Stopping Arc for Short Period.—The procedure is as follows: (1) Arc main-line switch is opened (automatically opening the switch of the arc starting resistance), and (2) send-receive-ground switch is set in its receiving position. The motor generator may be stopped by opening either the supply switch of the set or the circuit breaker on the motor-starting panel.

Starting Arc after Short Period of Rest.—The procedure is as follows: (1) Send-receive-ground switch is set in its sending position and the motor generator is started if it has been stopped; (2) arc main-line switch is closed and the arc is formed and adjusted; (3) switch of the arc starting resistance is closed.

Shutting Down Set for Long Period of Rest.—The procedure is as follows: (1) Arc main-line switch is opened; (2) supply switch of the set is opened (automatically releasing the arm of the motor-starting panel by means of the low-voltage release coil); (3) alcohol flow shut off; (4) send-receive-ground switch is put in the sending or the grounding position as desired.

Use of Chopper with Back-shunt Method of Signaling.—When it is desired to transmit signals on waves shorter than 950 meters by means of the chopper, the procedure is as follows: (1) The single-pole, double-throw transfer switch is moved to the left and closed. At the same time the double-pole switch mounted on the chopper is closed, thereby connecting the chopper to the coupled-compensation loop on the loading-inductance coil; (2) chopper motor is started by closing the snap switch; (3) motor generator and arc converter are started in the usual manner; (4) signals may then be transmitted by using the Morse hand key and the back-shunt circuit.

Use of the Chopper with the Auxiliary Hand Key.—The procedure is as follows: (1) Single-pole, double-throw transfer switch is opened and double-pole switch mounted on the chopper is closed; (2) chopper motor is started by the snap switch; (3) arc converter is connected to the antenna circuit by closing the short-circuiting switch on the Morse hand key; (3) motor generator and arc converter are started in the usual manner; (4) signals may then be transmitted with the chopper by using the auxiliary hand key.

Transmitting Undamped Wave Signals by Means of the Auxiliary Hand Key.—When signals are to be sent by using the auxiliary hand key without the chopper, the procedure is as follows: (1) Single-pole double-throw switch is turned so that the auxiliary hand key is connected directly to the coupled-compensation loop on the antenna loading inductance; (2) arc converter is connected to the antenna circuit by closing the short-circuiting switch on the Morse hand key; (3) motor generator and arc converter are started in the usual manner; (4) signals may then be transmitted by the coupled-compensation method with the auxiliary hand key.

Changing Wave Length.—The following procedure is carried out for changing the wave length: (1) Arc converter is stopped; (2) antenna connection on the loading inductance is changed to the terminal which is marked for the new wave length; (3) connections between the bare-copper helix and the taps in the lower layer of the loading inductance are changed to the positions which are marked for the new wave length.

Part 3

RADIO TELEGRAPH TRANSMITTER, C.W. AND I.C.W.

(Model ET-3626C)

General Description.—The model-ET-3626C transmitter is designed primarily as a medium-power transmitter for marine telegraph service. It can be tuned rapidly to any wave length in its range or shifted from any one predetermined wave length to another. The power delivered to the antenna is between 500 and 750 watts for C.W. (continuous-wave) transmission. The exact output depends on the kind of antenna and on the wave length.

The transmitter is designed to cover two wave-length bands, one from 600 to 800 meters and the other from 1,800 to 2,400 meters, when used with antennae having an electrostatic capacity of from 0.0006 to 0.0015 microfarad, a resistance of from 2 to 10 ohms, and a natural wave length (page 188) of from 300 to 450 meters. When using the larger antennas specified, it is necessary to have a series antenna condenser in order to tune the antenna circuit to the low wave lengths. In cases where the electrostatic capacity of the antenna is small, it is necessary to use an antenna condenser in parallel with the 1,800- to 2,400-meter antenna variometer.

The complete transmitter consists of the radio panel, a motor generator, a motor-generator high-frequency filter, and an operator's control unit.

Radio Panel.—An angle-iron frame is used as the support of the radio panel shown in Figs. 13, 14, and 15. It consists of the exciter, the audio-frequency oscillator, the power amplifier, the filament lighting transformer, the automatic motor starter, the keying relay, and the terminal board.

The circuit is of the exciter power-amplifier type and uses eight UV-211 vacuum tubes. The exciter and the audio-frequency oscillator have one tube each, and the remaining six tubes are used in the power amplifier.

"Keying" is uni-wave and is effected through the relay key, which controls the tube grid circuits, stopping oscillation and blocking the vacuum tubes by applying a negative grid bias of 250 volts to the grids of all the vacuum tubes. Additional contacts on the relay key connect the antenna to the receiver when the operator's key is open, thus allowing break-in operation. The "keying" grid bias is obtained from a 40,000-ohm potentiometer connected across the 1,000-volt, direct-current power supply. The ground tap is taken off this potentiometer at a point representing 10,000 ohms from the negative end, so that when the contacts of the relay key grid are open, the grids have a negative potential of 250 volts.

Two entirely separate exciter and power-amplifier tuning circuits are provided, one for the 600- to 800-meter range and the other for the 1,800- to 2,400-meter range. A transfer switch on the front panel makes the proper connections between the vacuum tubes and the circuits of the 600- to 800-meter range when closed one way and between the vacuum tubes and the circuits of the 1,800- to 2,400-meter range when closed the opposite way.

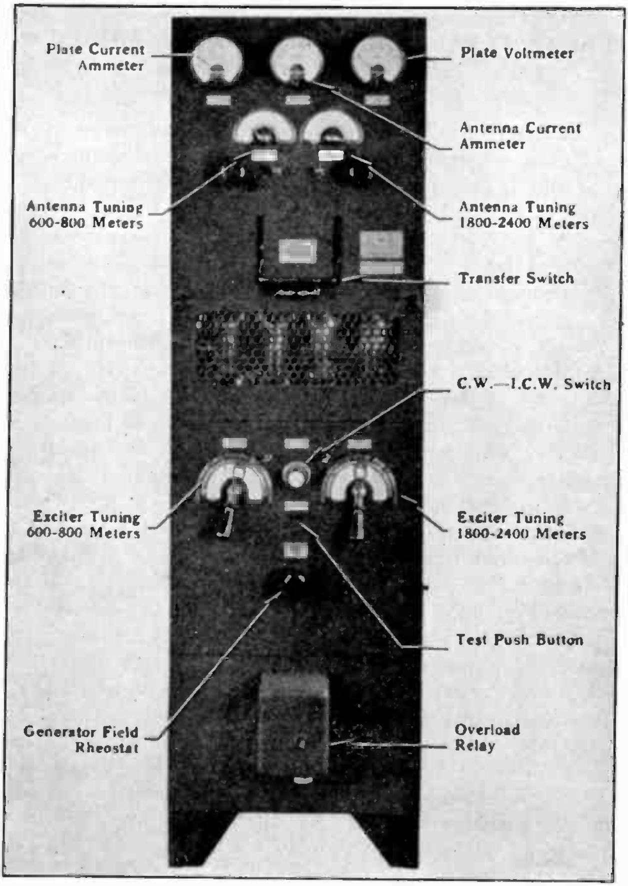


Fig. 13.—Front panel for telegraph-type transmitter.

The exciter circuits, each consisting of a variometer and an oscillating-circuit condenser, are mounted in the lower part of the frame. The variometer controls, wave-length scales, and locking devices are mounted on the

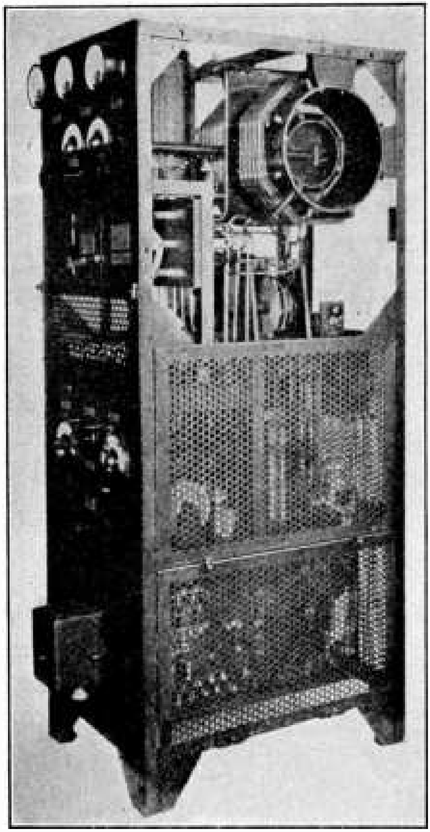


Fig. 14.—Left side of telegraph transmitter.

lower part of the front panel. The usual plate- and grid-coupling condensers and grid leak, are provided. The 600- to 800-meter exciter is located on one side of the radio panel, and the 1,800- to 2,400-meter exciter is mounted on the other.

The power-amplifier tuning variometers are located in the upper part of the radio panel. The variometer for the 600- to 800-meter range is on the left-hand side and the variometer for the 1,800- to 2,400-meter range is on the right. Each variometer is provided with a locking clamp and a large knob geared (five to one) to its shaft. Pointers and scales above the knobs show the position of the variometer rotors at all times.

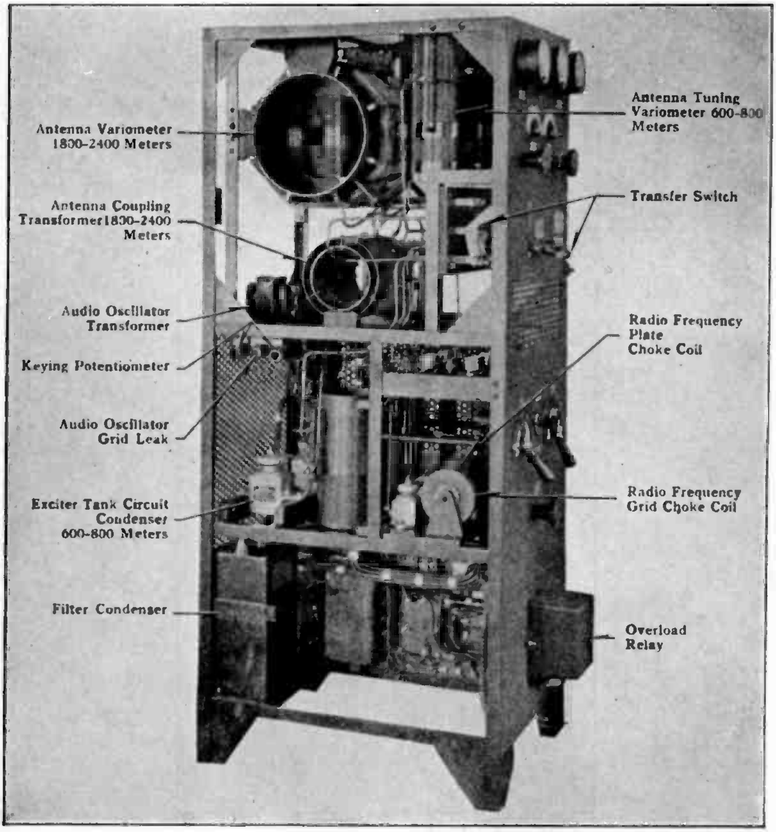


FIG. 15.—Right side of telegraph transmitter.

The power-amplifier tubes deliver their output to the antenna circuit through coupling transformers, so designed that when the antenna circuit is not in tune with the exciter, the power-amplifier tubes are not overloaded, the plate current, in fact, being considerably less than when in tune. The transformer for the 600- to 800-meter range is on the right-hand side of the radio panel and the transformer for the 1,800- to 2,400-meter range is on the left.

The audio-frequency oscillator is located in the rear of the radio panel. It is used only for I.C.W. (interrupted continuous-wave) operation and is controlled by the C.W.-I.C.W. signal switch which is mounted on the lower part of the front panel, and by the tone-frequency switch which is located in the rear of the radio panel. The tone-frequency switch selects any one of three frequencies, the approximate values of which are 500, 700, or 1,000 cycles per second.

An overload relay is mounted on the lower part of the front panel. It has its current coil in series with the negative high-voltage line and its contacts in series with the "stop" push button on the operator's control unit. If an overload should occur in the vacuum-tube circuit, this relay will operate and stop the motor generator. In order to start the motor generator again after stopping for this reason, it is necessary to push the "reset" button on the overload relay before the machine can be started.

Motor Generator.—The motor generator is a two-bearing unit consisting of a 110- or 220-volt, direct-current motor rated at 3 horsepower, and a 1,250 volt, direct-current generator. They are mounted on a common field frame. Both the 110- and the 220-volt motors are equipped with slip rings which provide alternating-current power for filament lighting. The generator is separately excited from the 110- or 220-volt power supply. The normal full-load direct-current taken from the supply line is about 25 amperes at 115 volts.

Motor-generator High-frequency Filter.—The high-frequency energy produced by sparking at the brushes of the high voltage direct-current generator will cause interference in the receiver when not transmitting, unless adequate filters are provided.

The amount of induction changes greatly with the generator, the condition of the brushes, and the installation. However good the installation may be, the induction can be severe if the grounding condition and the inductive and capacity couplings are such as to aggravate the induction. Under some conditions, the induction may be greatly reduced by adding ground connections, rearranging the leads, or connecting a condenser here or there in the circuit, but no one of these remedies is applicable to all installations. For this reason a filter unit is supplied which is placed on the side of the generator frame.

Operator's Control Unit.—This unit allows the operator to have his control buttons for starting and stopping the transmitter and for the operation of the filament rheostat and voltmeter near the operating table. It is a metal box containing the filament rheostat, the filament voltmeter, and the motor-generator start-and-stop push buttons. The push buttons are of the momentary-contact type.

Theory of Operation.—In Fig. 16 is shown the connections of the circuits involved in the generating of oscillations, amplification, and the transfer of energy to the antenna. The power-control and protective circuits are omitted, as they are not involved in the explanation, since the circuits for the two wave-length bands are the same. Figure 16 shows only one coil of the system.

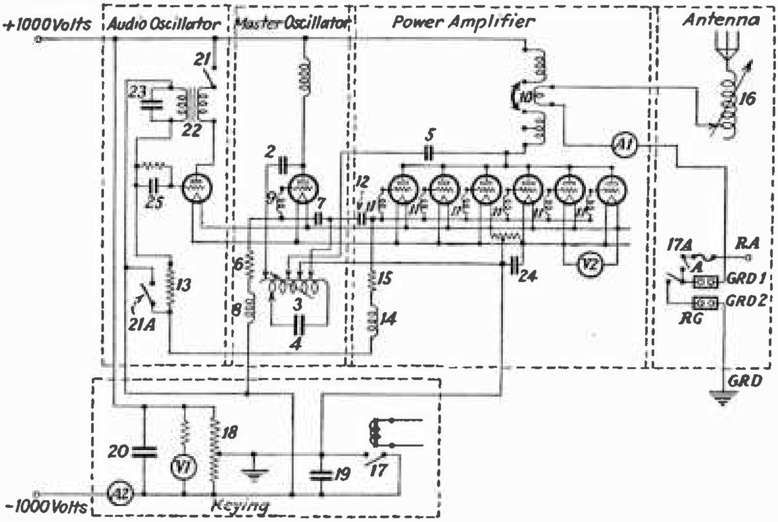


FIG. 16.—Circuit connections of telegraph transmitter.

The exciter consisting of one tube uses the *split-inductance* or *Hartley* method of feed-back (page 304) to produce oscillations. The high-voltage current is supplied to the plate of the tube through a choke coil 1. The blocking condenser 2 (page 33) separates the direct-current circuit from the oscillating circuit, which consists of the variable inductance 3 and the fixed condenser 4. The plate, grid and filament taps are set to give that ratio of plate-to-grid voltage which will give good efficiency and stable operation. It is not necessary to change these taps with a change of wave length, since the inductance is varied by the revolving coil in such a manner as to maintain a constant ratio of plate-to-grid voltage. The neutralizing condenser 5 prevents any reaction of the amplifier on the master oscillator due to the internal capacity of the amplifier tubes. The correct grid-bias voltage is maintained when oscillating through the resistance 6. The blocking condenser 7 separates the direct current of the grid from the oscillating circuit. The choke coil 8 separates the radio-frequency voltage of the grid from the "keying" circuit. The choke coil 9 is used to prevent oscillations of very short wave length from starting.

The power amplifier, consisting of six tubes, receives its energy through the plate winding of the air-core transformer 10 from the 1,000-volt, direct-current supply, thus eliminating the need for a plate choke coil and blocking condenser as is used for the exciter. The grids of the power amplifier have each a choke coil 11 which has the same function as 9 in the master-oscillator grid circuit. The grids receive their excitation from an adjustable point on the inductance of the exciter. The condenser 12 blocks the direct-current grid-bias voltage, and the inductance 14 separates the radio frequency of the grid from the "keying" circuit. The correct grid-bias voltage is maintained when oscillating by the resistance 15.

The antenna tuning is controlled by the variometer 16. The amount of power going into the antenna at a given plate voltage is varied by the ratio of turns in the windings of the transformer 10. Thus, with a given setting or number of turns in the primary winding or *plate* coil the power is increased by increasing the turns in the secondary winding or *antenna* coil. If, on the other hand, the turns of the antenna coil are not changed, the power can be increased by decreasing the turns in the primary coil.

The relay key 17 is controlled by the hand key, obtaining its current from the direct-current power supply. It has auxiliary contacts shown at 17*A* which close preceding the closing of the grid circuits and open after the opening of the grid-circuit contacts, thus providing "break-in" operation. The opening of the key contacts forces the plate current to pass through part of the resistance 18. The tapped point of this resistance is grounded and not the negative side of the 1,000-volt plate supply. Since the grid return is connected to the negative side of the 1,000-volt supply line and the filament and ground are connected to the tapped point on the resistance 18, any current flowing in the resistance 18 causes a grid-bias voltage on the grid. When, therefore, the key is opened, a large grid-bias voltage stops the oscillations due to the flow of the total plate current, and, subsequently, a "holding" grid-bias voltage exists due to the smaller current maintained through the resistance 18 by the generator. The condenser 19 prevents arcing at the contacts 17. The 6-microfarad condenser 20 is a radio-frequency by-pass around the generator which prevents excessive voltage surges when operating the set.

The audio-frequency oscillator used for modulating the output of the power amplifier for I.C.W. operation uses one tube which receives its energy from the primary winding of an iron-core transformer 22. The secondary winding of the transformer and the condenser 23 make up the circuit of the audio-frequency oscillator. The grid excitation for the audio-frequency oscillator tube is taken from one side of the secondary winding of the transformer, the other side being connected to the negative 1,000-volt end of the potentiometer 18. The audio-frequency oscillator is thus provided with a blocking grid-bias voltage in the same way as the exciter and the amplifier tubes. A negative "operating" grid-bias voltage is maintained on the audio-frequency oscillator tube by the condenser and grid leak shown at 25.

During C.W. operation of the transmitter the grid-leak circuit for the power amplifier is through the choke coil 14, the resistance coil 15, and the switch 21*A* to the negative 1,000-volt end of the potentiometer resistance 18. For I.C.W. operation the switch 21*A* is opened and the switch 21 is closed, thus putting power on the plate of the audio-frequency oscillator tube and removing the short circuit around the resistance coil 13 and the secondary winding of the transformer 22. When the switch 21*A* is opened it causes grid-leak current of the power amplifier to pass through the resistance coil 13 and the secondary winding of the transformer. The alternating-current voltage across the secondary of the transformer is thus impressed on the grids of the power-amplifier tubes, and the output of the amplifier tubes is modulated with the frequency of the audio-frequency oscillating circuit. The resistance 13 prevents overloading the audio-frequency oscillator and acts as an additional grid-leak resistance for the power amplifier when operating as an I.C.W. transmitter.

Condenser 24 is a radio-frequency by-pass around the filament balancing resistance. The following symbols are used to explain the instruments used in the circuit shown in the figure: *A*1 is the antenna-current ammeter; *A*2 is the plate-current ammeter; *V*1 is the plate voltmeter; *V*2 is the filament voltmeter.

Vacuum Tubes.—The transmitter uses eight vacuum tubes as follows: one UV-211 tube as an exciter, one UV-211 tube as an audio oscillator, and six UV-211 tubes operating in parallel as a power amplifier.

For normal C.W. operation only seven tubes are used, the eighth being used for only I.C.W. operation. In case of emergency it is possible to operate the transmitter at a reduced power output with a reduced plate voltage when using only the exciter tube and two or three power-amplifier tubes.

When one antenna is used for both transmitting and receiving, the links on the terminal board of the radio panel should connect the terminal marked "Grd-1" to the terminal marked "A" and the terminal marked "Grd-2" to the terminal marked "RG." When a separate antenna is used for receiving, the links should connect the terminal Grd-1 to the terminal Grd-2, and the terminal Grd-2 to the terminal RG. The separate receiving antenna should then be connected to the terminal marked "A." In either case the antenna and ground terminals on the receiver should be connected to the terminals "RA" and "RG," respectively, on the terminal board of the radio panel. The antenna and ground wires from the radio panel to the receiver should be of No. 14 rubber-covered wire and should be separated from each other by several inches. The antenna wire to the receiver should be kept away from all other wires which are at the ground potential. When possible, it should be carried on porcelain insulators. When the "break-in" system is used with only one antenna, the terminal marked "Grd-1" must not be grounded, as this would short-circuit the leads to the receiver.

In cases where the antenna is too long, a series antenna condenser will be required in order to tune the transmitter to low wave lengths. This condenser may be mounted on two porcelain insulators provided at the side of the transmitter. When a series antenna condenser is to be used, the copper-tube lead connecting the antenna terminal and the transfer switch is removed. Then the copper-tube leads are connected from the transfer switch to the lower side of the condenser, and from the upper side of the condenser to the antenna terminal.

In cases where the antenna capacity is too small to cover the 1,800- to 2,400-meter range when all the turns in the 1,800- to 2,400-meter antenna-tuning variometer are in use, a condenser must be connected in parallel with the variometer. The same condenser mounting may be used for this condenser as for the series antenna condenser. Copper-tube leads should connect the two sides of the condenser to the opposite ends of the 1,800- to 24,000-meter antenna variometer.

Adjustments after Installing.—After the two UV-211 vacuum tubes have been placed in the front and back sockets, the filament and generator field rheostats are turned to the minimum voltage position, and the C.W.-I.C.W. switch is moved to the C.W. position. The motor-generator set is then started and the filament potential adjusted to 10 volts by means of the rheostat on the operator's control unit. The plate ammeter should read zero until the key is pressed, when it should indicate roughly 0.1 ampere. The transfer switch should be in the position for its proper range. It must be remembered that the generator plate voltage is on the tube plates when the motor-generator set is running, even though the key is "up." The motor-generator set should not be running when the tubes are changed or adjustments are made.

The exciter-coil taps are adjusted for stable and efficient operation. An approximate list of settings is given in Table XL, to serve as the basis for adjustment in case the leads have come off in transit.

TABLE XL.—SETTINGS OF EXCITER-COIL TAPS

Tap marked	No. turns[1]	
	600- to 800-meter coil	1,800- to 2,400-meter coil
Grid	27	51
Ground	21	34
Neutral condition	18	27
W. L.	12	15
Plate (lowest turn)	0	0

[1] Turns counted from the bottom of the coil.

After the adjustments have been made as outlined, the motor generator should be stopped and the six UV-211 tubes are to be placed in the six remaining tube sockets. The transfer switch is turned into the position for the 600- to 800-meter range, and the exciter variometer is adjusted to approximately 700 meters. Then the motor-generator is started again, the filament voltage is adjusted to 10 volts, the plate voltage to 800 volts, and the test push button is closed, the plate ammeter indicating less than 1 ampere while the test button is closed. The 600- to 800-meter antenna variometer is adjusted until the antenna ammeter indicates a maximum current. If the plate temperature of the tube is not over that corresponding

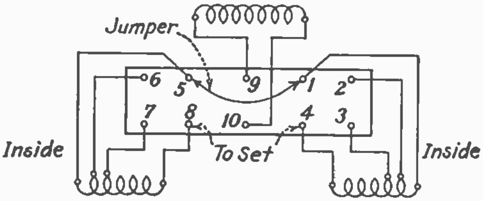


FIG. 17.—Taps for coil adjustments.

to a dull red heat, the plate voltage is increased to 1,000 volts. The meter in the plate circuit should then indicate from 1.2 to 1.75 amperes. If the plate current is low, fewer turns are needed in the primary winding of the coupling transformer, and if it is high, more turns are needed. Maximum turns of the primary winding are obtained on the 600- to 800-meter transformer by connecting the jumper between the binding posts 1 and 5 of the transformer. Minimum primary turns are obtained with the *jumper* connecting the binding posts 3 and 7, and an intermediate number of turns with the jumper connecting the binding posts 2 and 6, as marked in Fig. 17. A fine adjustment may be obtained by sliding the primary (outside) coils away from the antenna coil to obtain less plate current or toward it to obtain more plate current. The coils however, should be kept as close together as practicable. The number of turns in each primary coil need not be the same but should be as nearly the same as possible.

As the turns of the primary winding are decreased, the step-up ratio of the transformer is increased, and, therefore, the load is increased. In any tube circuit, if the load resistance is too large, the plate current will be high without an attendant increase in the antenna current. To determine the best adjustment it is always advisable to start with the maximum number of turns of the primary winding and gradually decrease them until the proper loading is obtained; but never to the point where an increase of plate current does not increase the antenna current.

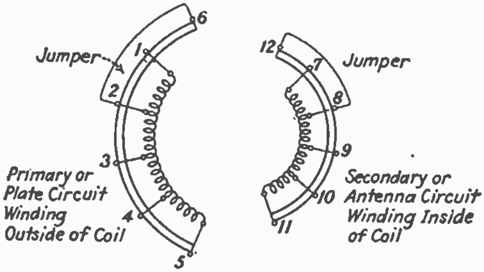


FIG. 18.—Coil adjustments of coupling transformers.

The transformer for the 1,800- to 2,400-meter band is provided with taps on both the primary and secondary windings and should be adjusted for operation at a wave length of approximately 2,000 meters. The same theory of operation applies here as for the short wave band. It is desirable to keep the primary inductance as high as possible to protect the tubes when the antenna is detuned. For this reason the set is adjusted first with all the primary turns in use and a minimum of the secondary turns. If the input and output are low, the number of turns in the secondary winding must be increased. If they are still low when all the turns of the secondary winding are used, the turns in the coil of the primary winding should be reduced to the next tap, and the secondary turns readjusted. This procedure is to be repeated until a satisfactory adjustment is obtained. The primary turns are adjusted as shown in Fig. 18 by connecting the jumper from the terminal 6 to one of the terminals 2, 3, 4, or 5. The turns of this winding have a maximum value when the jumper connects the terminals 6 to 5 and have a minimum value when the jumper connects the terminals 6 to 2. The secondary turns have their maximum value when the jumper connects the terminals 12 and 11 and their minimum value when the jumper connects the terminals 12 and 8.

After obtaining a satisfactory adjustment of the coupling transformers at one particular wave length in each band, the operation is checked by testing over the range.

The audio-frequency oscillator must also be tested for operation. Both the plate and the antenna currents will be somewhat lower than when C.W. transmission is used.

This set is adjusted in the factory for satisfactory operation on an antenna having a capacity of 0.001 microfarad and a resistance of 6 ohms. When the set is used with an antenna having similar characteristics, the output on the 600- to 800-meter range will be from 9.8 to 10.2 amperes, and on the 1,800- to 2,400-meter range from 9.6 to 10 amperes.

A relay key is provided for "break-in" operation. The keying contacts open and close the grid circuit while the "break-in" contacts open and close the loop to the receiver. It is desirable to have these contacts close, before the key contacts close, and also to have these contacts open, after the key contacts open. This operation is accomplished by the relay.

Operation of Transmitter.—The operation of the model-ET-3626C transmitter is simple, the set being tuned as follows:

1. The generator field and filament rheostats are turned to the lowest-voltage positions.
2. The line switch is closed (if open) and when the starting button on the operator's control unit is held down, the motor-generator should start and attain the rated speed immediately. The motor current may be limited to a lower value on the final step of the motor starter by holding down the starting button for a few seconds.
3. The filament voltage is adjusted to 10 volts by means of the filament rheostat and the voltmeter on the operator's control unit.
4. The plate voltage is adjusted to 1,000 volts by means of the field rheostat of the generator and the voltmeter on the radio panel.

5. The transfer switch is moved to the position for the proper range of wave lengths, the exciter being tuned to the wave length desired. The C.W.-I.C.W. switch should be in the C.W. position, and the proper antenna-tuning variometer adjusted for a maximum antenna current as indicated on the antenna ammeter, while the "test" push button is depressed. When the set is tuned, the telegraph key may be operated for the transmission of messages.

6. When the transmission is completed the "stop" button is depressed to stop the motor-generator and the transmitting set.

7. An audio-frequency oscillator is provided for I.C.W. transmission. To operate this type of transmission the C.W.-I.C.W. switch is turned to the I.C.W. position, and after the set is tuned as described in paragraph 5, the audio-frequency oscillator operates in conjunction with the master oscillator and the power amplifier, when the key is pressed. In addition to the C.W.-I.C.W. switch on the front panel, the audio-frequency oscillator is provided with a three-point dial switch, accessible from the right-hand side of the set, which adjusts the audio-frequency oscillator to three different tone frequencies, namely: 500, 700, or 1,000 cycles per second (approximately). When the set is tuned the C.W.-I.C.W. switch should be in the C.W. position. The operator should not touch the tone-frequency switch while he is using the key, because the high-voltage alternating current on the switch may cause severe burns.

Troubles and Causes.—The difficulties which are most likely to occur in the operation of this transmission unit are outlined in the following paragraphs:

1. *Pressing the Starting Button Does Not Start the Motor Generator.*—Main power switch on starter panel open; defective fuse; no line voltage; line voltage too low. The line voltage may be tested by operating the telegraph key which will cause the relay to work if the line voltage is available.

2. *Starting Button Causes Starting Contactor to Close, but Motor-generator Set Does Not Start.*—Burned-out starting resistance on back of starting panel; connection between starting panel and motor-generator set open; or bearing on motor generator "frozen" because of insufficient lubrication.

3. *Starter and Generator Satisfactory as Indicated by Plate Voltage on Radio Panel, but Tube Filaments Do Not Light.*—Defective filament fuse on terminal board (probably caused by tube having its filament short-circuited); loose connection on filament transformer on terminal board; defective brush on slip rings of motor.

4. *Plate and Filament Voltages and Tubes Satisfactory and Relay Operates, but Depressing Key or Test Button Causes No Antenna Current while Tubes Do Not Heat beyond Very Dull Red when Key Is Pressed.*—Antenna circuit

out of tune; adjust antenna variometer for maximum antenna current. If still no antenna current, shift transfer switch to other wave-length range. If this operates in same manner, trouble is probably in antenna circuit (outside the set) or with antenna ammeter. If other wave-length range works normally, trouble is in antenna variometer or coupling transformer of wave-length range that does not operate. Open or loose connections may be found.

5. *Set Operates Normally when Key is Pressed Down, but Tubes Heat Badly when Key Is Elevated.*—Tubes not blocking properly, due to low grid-bias voltage caused by a defective resistance in the key potentiometer. May also be due to an amplifier tube that is soft and partially short-circuits the grid-bias voltage. This tube will probably flash blue and indicate higher temperature than other tubes.

6. *Tubes Heat Badly as Soon as Key Is Pressed Down.*—Exciter tube defective or circuit not oscillating; change tubes and examine circuit for loose connections; remove all but front and back left-hand tubes from sockets; exciter tube still overheats when key is depressed, if tube or circuit is defective.

7. *Amplifier Tubes Heat Excessively when Key Is Pressed Down and Antenna Circuit Is in Tune.*—Defective coupling transformer; insufficient number of plate turns.

8. *Audio-frequency Oscillator Does Not Operate when Switch Is Turned to I.C.W. Position and Key Is Pressed Down.*—Poor connections to C.W.-I.C.W switch; connections defective to transformer and condensers and condenser tap switch; broken down condenser; defective vacuum tube.

9. *Audio-frequency Oscillator Operates when Key Is Pressed Down, but Plate Current Extremely High.*—3,000-ohm grid leak of amplifier short-circuited; grid leak of audio-frequency oscillator short-circuited.

The set may be operated with three or four amplifier tubes in place of six if all the tubes are not available. With a reduced number of amplifier tubes in use, the plate voltage should be reduced to prevent overheating the plates of the tubes. The exciter tube, however, must always be used, and the audio frequency oscillator must always be used for I.C.W. operation.

Emergency Measures for Apparatus Failure.—When there is a failure of some part of the apparatus, the following points of emergency procedure will be helpful:

1. *Insulation Break-down.*—If the insulation is charred and causes continued arcing and burning, the insulation should be cut away, if possible, or the winding should be cut and sufficient turns removed. Before the wire is cut, the ends of the remaining winding should be suitably fastened by tying them with a cord. A temporary jumper may be used to close the circuit. If the insulation is broken down at the terminal blocks and the arc-

over cannot be stopped by cutting away the insulation, the connections may be removed and the circuit completed by a temporary jumper.

2. *Burn-out of Exciter Plate Choke Coil.*—If the failure is inside the coil so that turns cannot be removed, this choke coil may be replaced by the grid choke coil. A jumper may be used in place of the removed grid choke coil. The exciter will operate under these conditions, but with somewhat reduced efficiency.

3. *Plate or Grid Blocking Condenser Short-circuited.*—The defective condenser may be replaced by the tank condenser which is in the other wave-length band. The connections may be lengthened to reach the substitute condenser as temporarily mounted.

4. *Filament Voltmeter Inoperative.*—The filament voltage should be reduced until the tubes begin to heat or the antenna current is reduced rapidly. Then the filament voltage should be increased until the tubes operate at their normal temperature and the antenna current is not rising rapidly.

5. *Plate Ammeter or Voltmeter Inoperative.*—The generator field rheostat is set at the normal position and the set is operated with the tubes at the normal temperature.

If the plate ammeter is not functioning and other adjustments are to be made, a 150-watt lamp may be inserted in place of the ammeter. For safe operation its light should not exceed full brilliancy.

6. *Antenna Ammeter Inoperative.*—In this case the set should be adjusted in accordance with the tuning record card, and the plate ammeter should be observed for the condition of final resonance.

7. *Filament Transformer or Filament Rheostat Burned Out.*—The filament transformer and rheostat should be disconnected and five cells of the lead-acid storage-battery type may be connected in series directly to the filament buses (page 34) with wires intended to carry 30 amperes. The voltage of the battery is practically correct for the tube filaments (without rheostat control).

8. *Grid Leak Open.*—The grid leak of the power amplifier may be replaced by a 40-watt, 110-volt tungsten lamp or, in the event this burns too brilliantly, a 60-watt lamp.

The grid leak of the exciter may be replaced by a resistance of from 4,000 to 10,000 ohms. A column of water, 12 inches long, in a rubber hose plugged at each end and having wire electrodes will be a satisfactory resistance of this kind. If the resistance seems to be too high, a little salt or washing soda may be added to the water.

9. *Tank Condenser Is Short-circuited or Overheats.*—The defective condenser may be replaced by a similar one taken from the circuit of the other tank.

Part 4

A.C.W. TUBE TRANSMITTER

(Model ET-3630 A.C.W.)

The model ET-3630 A.C.W. (alternating continuous wave) tube transmitter consists of a ½-kilowatt *spark* transmitter which has been converted for *tube* operation. A panel view and a side view of this transmitter are shown in Figs. 19 and 20.

All connections to the motor generator and automatic starter are the same as for the corresponding spark-transmitting sets. The method of "keying," by breaking the primary circuit of the power transformer, is exactly the same as that used with the spark set. Power is regulated by means of the field rheostats of the generator and the motor. The connections to the wattmeter and radiation ammeter are also the same as in the spark sets.

Changes Made in Converting for Tube Transmission.—The changes which have to be made in converting from spark to tube transmission are principally in the closed or primary circuits, with some minor changes in the open circuit. Closed-circuit changes consist of the complete removal of the quenched gap, the rotary gap, the condenser rack, and the condensers used with the spark set. In place of these, new parts have to be installed and connected, as shown in Fig. 21. The figures shown on the diagram indicate the location in the circuit of the various units, which are as follows: (1) ½-kilowatt power transformer with mid-tapped secondary, (2) plate choke coils, (3) plate blocking condensers, 0.001 microfarad, (4) UV-211 tubes, (5) plate-excitation condenser, 0.004 microfarad, (6) grid-excitation condenser, 0.02 microfarad, (7) "tank" (primary) inductance, (8) filament by-pass condenser, (9) filament transformer, (10) filament converter, (12) grid-leak choke coil (if used), (13) grid leak, (14) 10-microfarad condenser (if used) and (15) filament voltmeter.

A small rotary converter and transformer are provided to supply alternating current for heating the filament. The rotary converter operates directly from the 110-volt direct-current power line and supplies alternating current at about 70 volts to the primary of the filament transformer, which reduces this voltage to 10 volts for the tube filaments.

Two UV-211 tubes are used in a self-rectifying circuit. Two UV-203A tubes may, however, be used if the UV-211 tubes are not available.

Theory of Operation.—Figure 21 shows the power and radio-frequency circuits, and the antenna which is loosely coupled to the coil 7. The antenna circuit comprises the same apparatus that is used when it is excited

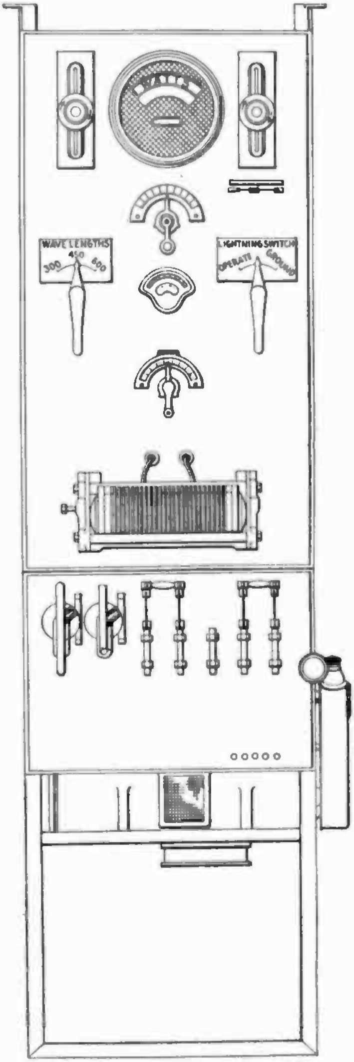


Fig. 19.—Panel of tube transmitter.

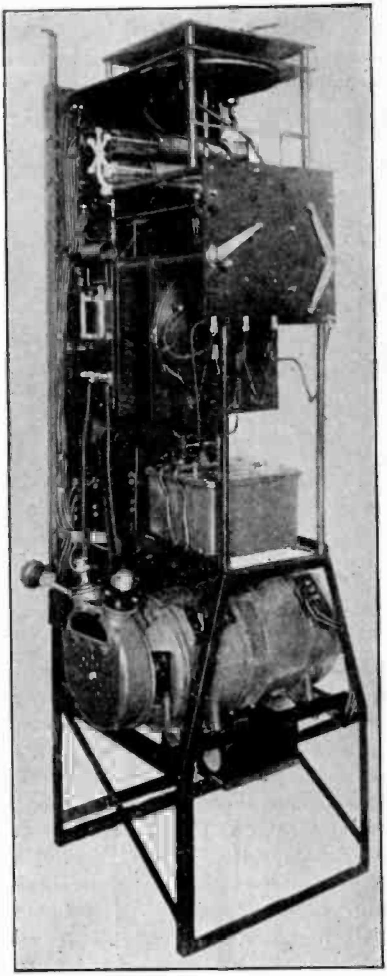


Fig. 20.—Side view of tube transmitter.

by the quenched gap, except that the secondary inductance has only one variable tap, the same value being used for all wave lengths.

Power is taken from the 500-cycle generator, and the "keying" is done as in a spark set by inserting the key in one side of the line from the generator to the primary winding of the transformer. The regular 500-cycle high-tension transformer 1, having its midpoint on the high-voltage side and the secondary sections connected in series-parallel, as shown in Fig. 21, supplies high voltage of the correct polarity alternatively to the two tubes 4. As each tube in turn receives power, it generates radio-frequency oscillations in the split-capacity or Colpitts circuit (page 391), consisting of the tank (primary) inductance 7, the plate-excitation condenser 5, and the grid-excitation condenser 6. Condensers 5 and 6 also comprise the tank capacity. Since condensers 5 and 6 are fixed, the relation of grid and plate voltage remains fixed at the proper value for all wave lengths or values of coil 7. The choke coils 2 prevent radio-frequency currents from backing into the power transformer. Condensers 3 prevent the 500-cycle power from backing into the tank circuit. The choke coil 12 and the resistance 13 provide a path for the direct current from the grid, which gives the proper negative grid-bias voltage on the grid for efficient operation.

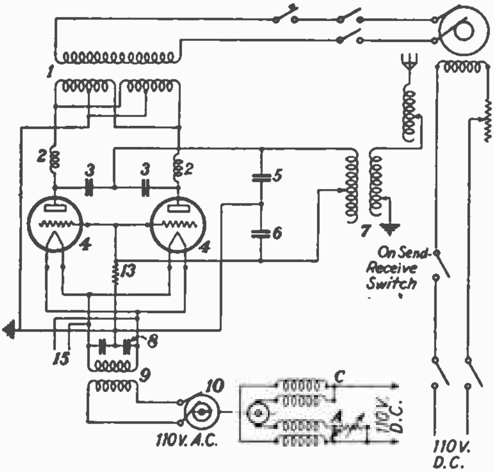


FIG. 21.—Circuit diagram of tube transmitter.

Operation.—The first step in the operation of the transmitter is to adjust the filament rheostat so that all the resistance is in its circuit before the filament rotary converter is started. At this time it should be noted whether the filament voltmeter is properly indicating the voltage and whether the filaments of the tubes are brightly lighted. The controls of the field rheostat should be set at their lowest points and then the ½-kilowatt motor generator may be started by the usual method. The filament voltage should be adjusted to 10 volts. The next step is to press down the key of the transmitter and adjust the power in the transmitting circuit to about 200 watts, as indicated by the wattmeter. Finally, the wave-change switch should be adjusted for the wave length to be used, and the open circuit resonated by means of the aerial inductance device until the maximum radiation is obtained. The resonance point is sharp, and the aerial inductance must be adjusted slowly and carefully, as otherwise, the resonance point may be passed over. After these adjustments have been made, the power should be increased to the amount necessary for efficient communication. This amount should not, however, exceed 500 watts. If sparking continues, the power must be decreased. All adjustments for resonance should be made with the smaller power. With the average antenna a radiation of about 5 amperes may be expected with an input of 500 watts.

The filaments should be operated at not more than 10 and not less than 9 volts. The use of excessive filament voltage will greatly decrease the life of the tubes. If, on the other hand, the filament voltage is too low, the tube plates will overheat when the key is depressed even though normal power is being used. With the transmitter in operation and all the adjustments properly made, the tube plates should not be heated beyond a cherry-red color.

Signals from a transmitter of this type may be received with a crystal- or non-oscillating-tube detector due to the modulation of the 500-cycle plate generator. A chopper (page 543) is not required. Greater distances may be covered, however, if the receiving station uses an oscillating-tube detector for beat reception. Signals from transmitters of this type should be always tuned in with an oscillating detector, to avoid interfering spark signals and permit reception of the C.W. beat note through heavy interference or static.

Troubles and Remedies.—The circuit used is very stable and can be relied on to operate satisfactorily under all conditions if the apparatus is not defective, with two exceptions:

1. The oscillations will not start when the key is closed if there is a poor connection in the tank circuit or an intermittent breaking down of the insulation of its circuit either to ground or in the condensers.

2. When the antenna coupling is too tight the maximum antenna current cannot be obtained, as the tank circuit will vary its frequency when approaching resonance of the antenna circuit.

When the antenna is small, or its resistance is very low, it will be found that the maximum output may not load the tubes to their full rating, and, under these circumstances, no attempt should be made to increase the loading by excessive voltage or by changes in the circuits, other than careful tuning and the use of the proper degree of coupling.

The coupling is varied by changing the number of turns in the secondary inductance instead of by varying the distance between the primary and the secondary coils.

Swinging Signals.—Signals from these transmitters may "swing" slightly in rough weather due to changes in the antenna capacity caused by the rolling of a ship. The antenna should be pulled taut to minimize this as much as possible. If excessive swinging is observed, the secondary circuit is probably too closely coupled to the primary. The coupling should be loosened by decreasing the number of turns used in the secondary coil of the oscillation transformer. Usually not more than two or three turns are required on this coil for proper coupling. Any change in the number of turns used in the secondary coil must be compensated by a corresponding change in the aerial inductance to bring the set back into resonance.

Burned-out Plate Choke Coils.—If no spare plate choke coil is available, temporary repairs may be made by using two 400-turn honeycomb coils connected in series, or any equivalent inductance, to replace a defective plate choke coil.

Set Fails to Oscillate or Tubes Heat Badly.—The first requirements are that all the connections in the tank and the open circuits are tight, that the wave-change switch arms make good contact, that the aerial sliding contact has good connections, and that the ground connections are tight and clean. The wiring should be checked with the diagrams to see that all connections are properly made. If trouble persists, the tubes should be changed.

Burned-out Filament Voltmeter.—The correct point of operation may be obtained by first reducing the filament voltage until the tube plates begin to overheat when using the normal amount of power in the plate circuit. Then the filament voltage may be increased slowly until the tubes operate at their normal temperature.

Burned-out Wattmeter.—After the circuits have been resonated, the power may be increased until satisfactory radiation is obtained.

Burned-out Filament Converter, Filament Transformer, or Filament Rheostat.—All of these units must be disconnected. Then the filament terminals are connected directly to a five-cell lead-acid storage battery which will supply approximately the right filament voltage. The leads formerly connected to the mid-tap of the filament transformer should be connected to the negative side of the storage battery. The regular filament rheostat cannot be used with a storage battery, as it will not carry the heavy current flowing directly in the filament circuit. The voltage of a five-cell storage battery, however, should be so close to the normal value that no regulation is required.

Burned-out Grid Leak.—The resistance of the grid leak used on this transmitter is 5,000 ohms. Should the grid leak be burned out with no spare unit available, a suitable resistance could be made up by using a piece of rubber hose about a foot long, filled with salt water and plugged at both ends with wires extending through the plugs and making contact with the salt water in the hose. Any suitable resistance having a value between 2,000 and 10,000 ohms may be used.

Filament Converter Fails to Start.—In some cases the filament converter may not start immediately when the circuit is closed if the maximum resistance of the filament rheostat is used. In such cases the armature of the converter should be turned over immediately by hand.

Trouble in One Side of Circuit Which Cannot Be Repaired at Sea Due to Lack of Material.—Spare tubes, a spare plate choke coil, a spare grid leak, and spare secondary sections of the transformer should be available at all times. If these spare parts are available and the set is properly maintained, it should be possible to keep the set always operating at its maximum efficiency. If necessary, however, this set may be operated at a reduced power with only one good tube, one plate choke coil, one good plate blocking condenser, or only one side of the secondary coil of the power transformer. Should there be available only one good tube, one plate choke coil, one good plate blocking condenser, or only one-half of the secondary coil of the plate transformer, the defective part should be removed from the circuit and the lead to the plate transformer on that side disconnected. The set may then be operated at a reduced power on one tube with about half the normal radiation. If only one tube is used, care should be taken to reduce the filament voltage to its normal value.

In the event of irreparable damage, making it impossible to use even one side of the circuit, a "plain aerial" spark transmitter for emergency use only may be made by removing all connections from the three secondary terminals of the plate transformer and connecting the antenna to one of the outside secondary terminals of this transformer and the ground to the other outside secondary terminal. The safety gaps on the secondary terminals will then serve as a spark gap. Necessary changes may be quickly made by disconnecting the flexible lead from the secondary coil of the oscillation transformer, lengthening this lead as much as necessary, and connecting it to one side of the power transformer. The other side of the power transformer should then be connected to the lead from the secondary coil of the oscillation transformer to the thermal unit of the radiation ammeter. This tunes the circuit and also permits the reading of the radiation on the radiation ammeter. It is very improbable that it will ever be necessary to resort to the use of the plain aerial circuit which should never be used unless the ship is in distress and the transmitter is damaged so that it cannot be made to function normally.

Porcelain, micalex, or glass antenna and deck insulators should be used throughout with this type of transmitter. If other forms of insulation are used, there is likely to be an excessive loss of radiation during wet weather.

Part 5

LOW-POWER RADIO TELEGRAPH TRANSMITTING EQUIPMENT

(Model ET-3650)

The model ET-3650 (RT-30A and RT-30B) radio telegraph transmitter and the associated equipment is designed primarily for installations on vessels where a *low-power* emergency transmitter is required.

Component Units.—Each transmitting equipment consists of the following component units:

1. For 12-volt power supply, one radio transmitter, model ET-3650 (RT-30A) and one motor-generator-set rated: motor—12 volts, 2,340 revolutions per minute, direct current; generator—350 cycles, 110 volts, 1.5 amperes.

2. For 110-volt power supply, one radio transmitter, model ET-3650 (RT-30B); resistance unit; one motor-generator set rated: motor—$^{95}/_{115}$ volts, direct current, 1.6 horsepower; generator—350 cycles, 110 volts, 1.5 amperes, 2,340 revolutions per minute.

Electrical Characteristics of the Transmitter.—The transmitter is designed to deliver 25 to 50 watts of 750-cycle modulated power into an antenna having the following characteristics: effective capacity, 0.0006 to 0.0014 microfarad; effective resistance, 4 to 10 ohms; fundamental wave length, 225 to 450 meters.

Wave-length Range.—The transmitter is designed to cover the wave band of 600 to 800 meters. Any one of four different wave lengths in this band is selected by means of a wave-change switch.

Method of Signaling.—The I.C.W. telegraph transmission is the only method of signaling that is provided.

Transmitter Construction and Installation.—The general construction of the transmitter may be understood by reference to the accompanying drawings. The panel is shown in Fig. 22, and the side and back views in Figs. 23 and 24. The various units are mounted either on the panel or on the framework. The sides, back, and top of the transmitter are provided with a detachable shield which makes the transmitter splash proof and also permits it to be installed close to a metal bulkhead without affecting its adjustments.

Four vacuum tubes UX-210 are used as power oscillators in the transmitter. These tubes are mounted on a "cradle" near the top of the set, while all meters, switches, and rheostats are mounted on the panel and are controlled from the front.

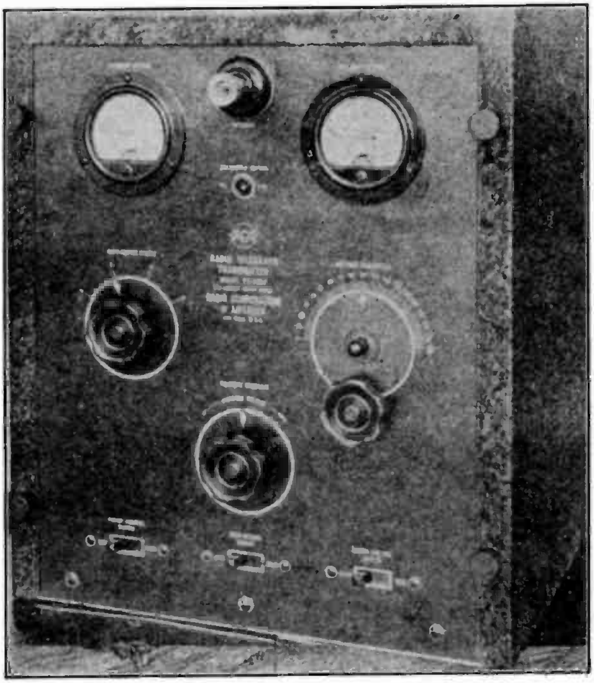


Fig. 22.—Panel of low-power telegraph transmitter.

The desired wave length is selected by means of a wave-change switch. This switch also selects the proper tap on the loading inductance coil of the antenna circuit. This circuit is resonated by means of the antenna variometer.

A diagram of connections both internal and external for the model ET-3650 (RT-30A) transmitter is shown in Fig. 25, while Fig. 26 shows the diagram of connections for the model ET-3650 (RT-30B) transmitter.

Theory of Operation.—Before considering in detail the procedure for adjusting the transmitter to any desired wave length within its range, it is well to understand the theory of operation of the various circuits involved. Reference will be made first to the diagram shown in Fig. 27 which is for the RT-30A transmitter. The same circuit is used in both the RT-30A and RT-30B transmitters. The additional equipment needed in the RT-30B transmitter is indicated in Fig. 28.

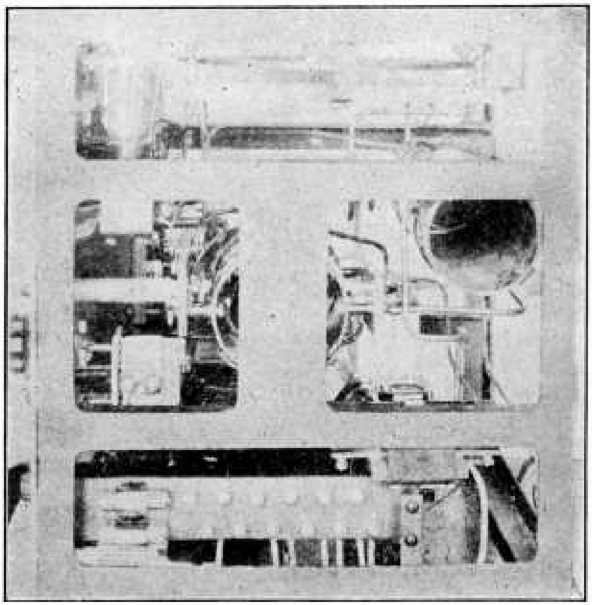


FIG. 23.—Side view of low-power telegraph transmitter.

The anodes of the vacuum tubes are supplied with power at 350 cycles by the transformer 22. The anodes are then coupled by means of the capacity 9 to the tank circuit, which is made up of capacities 21 and 23 and the inductances 5 and 2. The grid-leak circuit is made up of the inductance 7 and the resistance 6. The antenna system is inductively coupled to the tank circuit by means of the coupling inductance 3. The antenna system is resonated to the frequency of the tank circuit by means of the variometer 4. A particular tap is selected on this variometer by means of a wave-change switch which also selects the tank-circuit frequency. Resonance is indicated by means of the antenna ammeter 11. The filaments of the tubes are adjusted by means of the rheostat 13. The voltmeter 12 may be used to indicate either the filament or the line voltage. The set is operated by means of an external key connected in the primary circuit of the plate transformer.

Adjustment of Transmitter.—The following procedure is recommended for adjusting the transmitter to any frequency within the band of 600 to 800 meters. The shield over the top and sides of the transmitter is removed to make accessible the variable elements of the transmitter which are required in order to adjust the wave length to any definite value. A four-position wave-change switch is provided which permits the wave length of the transmitter to be rapidly changed from one definite value to another. For the purpose of simplicity the adjustment to only one definite frequency

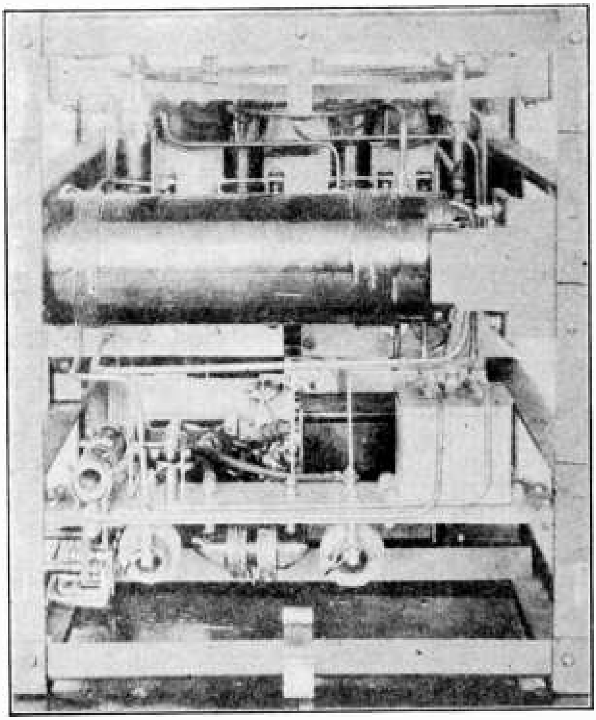


FIG. 24.—Back view of low-power telegraph transmitter.

will be explained, as the procedure for adjusting the transmitter to any other frequency will be the same.

First, the shortest wave length required for the operation of the transmitter is selected. Then the wave-change switch is placed in the position A. The tap on the spiral-wound coil that corresponds to the A position on the wave-change switch is selected and is clipped on the coil. Next, the link connection on the second tap of the coil is placed on the antenna coupling coil. Power can now be placed on the transmitter, and this is done in the following manner: With the power-control switch in the "low" position, the send-receive switch in the "send" position, and the voltmeter switch in the "filament" position, the starting switch of the motor is placed

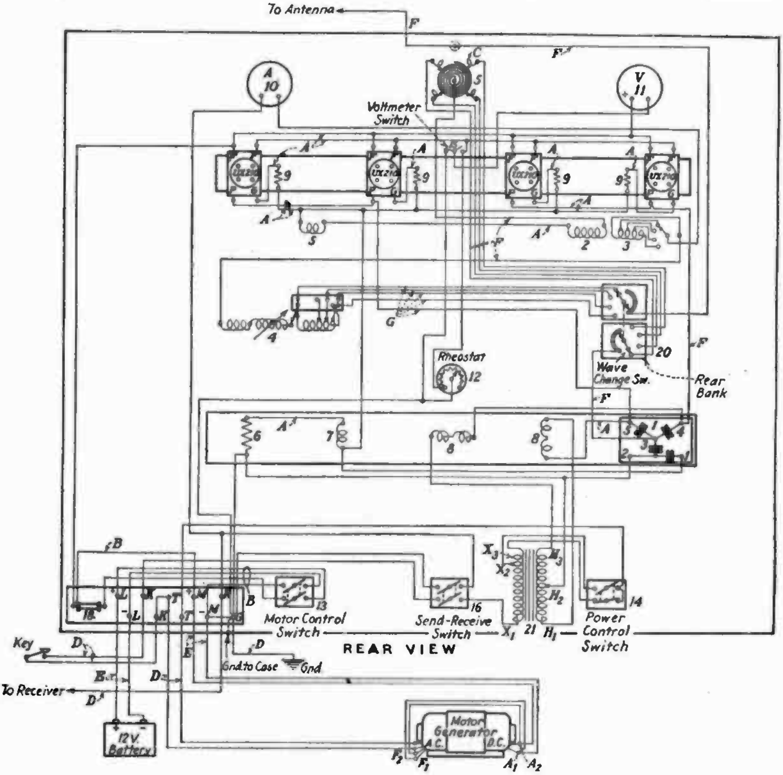


Fig. 25.—Diagram of connections for RT-30-A transmitter

in "run" position. The RT-30A set has only a single-step starting switch, while the RT-30B set has a two-step starting switch which should be advanced to the "run" position after a period of 10 or 15 seconds has elapsed. This switch lights the filaments of the tubes and starts the motor generator. Then the filament voltage is adjusted to 7.5 volts on the 12-volt set and to 30 volts on the 110-volt set by means of the filament rheostat. The wave length at which the transmitter is oscillating can now be measured with a wave meter (page 111) and if it is found to be too high or too low the transmitter should be stopped by placing the starting switch of the motor in the "off" position, after which the flexible connection on the spiral-wound coil can be moved, either increasing or diminishing the number of turns,

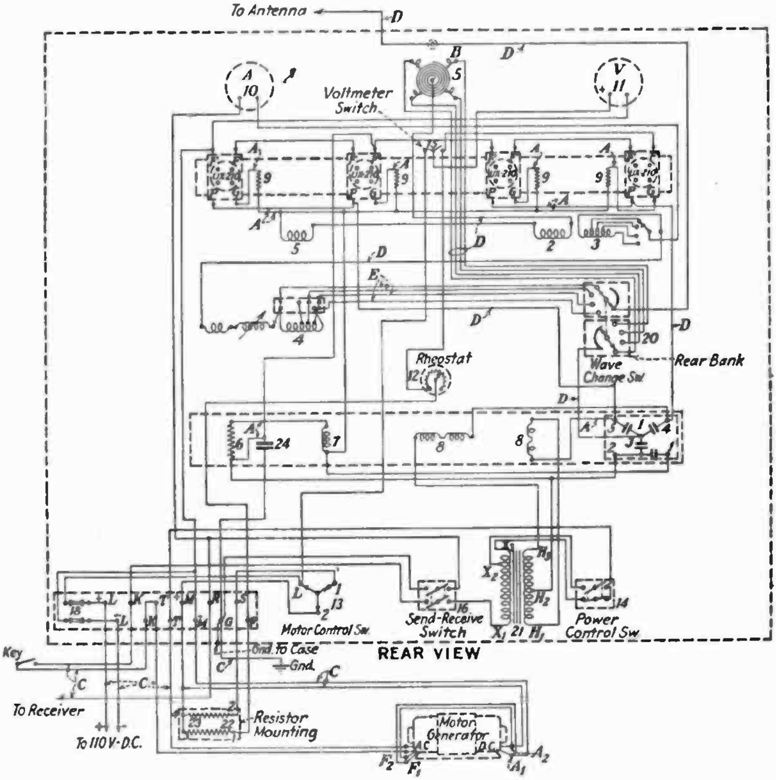


Fig. 26.—Diagram of connections for RT-30-B transmitter.

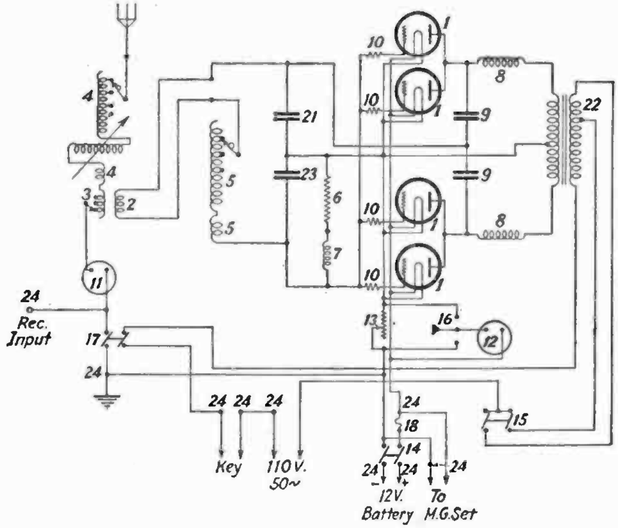


FIG. 27.—Circuit diagram of low-power telegraph transmitter (RT-30-A).

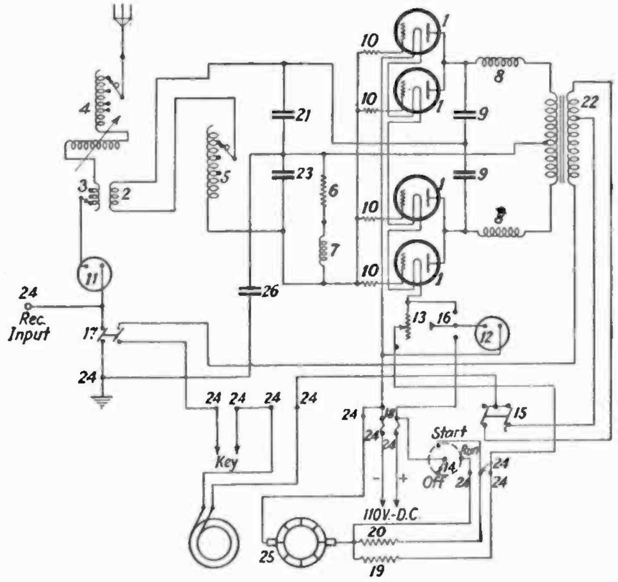


FIG. 28.—Circuit diagram of low-power telegraph transmitter (RT-30-B).

depending on whether the wave length is to be raised or lowered. The flexible connection on the wave-change switch, corresponding to the shortest wave length, is selected and is connected to one of the taps on the antenna variometer. The antenna is "resonated" (page 83) by rotating the antenna variometer and observing the reading of the antenna ammeter. One or two trials may be necessary before the proper tap on the antenna variometer is selected in order to resonate the antenna. The tap on the antenna coupling coil may now be changed, increasing the number of turns in the coil until a point is reached where the antenna current breaks sharply when the antenna variometer is swung through resonance, after which it should be dropped back one tap.

The shield is placed over the set and the wave length is again checked. If it is found to be too high or too low, the shield is removed and the number of turns on the spiral-wound coil is decreased or increased accordingly. The power-control switch may now be placed in the "high" position but it is not recommended that this position be used for general communication. The same procedure should be followed for adjusting the set to other wave lengths. The operator should stop the motor generator every time he makes an adjustment on the inside of the set.

Part 6

RADIO TELEGRAPH TRANSMITTING EQUIPMENT

R.C.A. Model ET-3655-B

The Transmitting Unit.—The circuit used in this transmitter is of the master-oscillator, power-amplifier type. The screen-grid tubes which are used prevent the oscillation in the power-amplifier circuit without neutralization. Provision has been made within the transmitter for its installation with either a Hertzian antenna or an antenna-ground system. I.C.W. operation is afforded by means of an audio-frequency vacuum-tube generator which modulates the carrier frequency of the transmitter.

The tubes required are one UX-860 tube as a master oscillator; two UX-860 tubes as power amplifiers; and one UX-860 tube as an audio-frequency oscillator.

The transmitter operates on five wave bands covering the entire range from 17.15 megacycles (17.5 meters) to 2,000 kilocycles (150 meters). These bands are as follows: 17.15 to 8.2 megacycles (17.5 to 36.6 meters); 12.8 to 6.15 megacycles (23.4 to 48.8 meters); 11.4 to 5.55 megacycles (26.3 to 54 meters); 6.0 to 3.335 megacycles (50 to 90 meters); and 3.335 to 2.0 megacycles (90 to 150 meters).

The first three of these bands are covered by a one-coil system and the last two by another coil system.

The Radio Unit.—The radio unit (Fig. 29) contains everything necessary for taking power from the high-voltage direct-current generator and delivering 200 watts of radio-frequency energy to the antenna. The unit as shown in Figs. 30 and 31 is divided into two sections vertically. All meters as well as the tuning and power controls are mounted on the front panel. In the lower left-hand compartment (Figs. 30 and 31) are located the audio-frequency oscillator circuit, the grid-bias potentiometer, the screen-grid resistances, the relay key resistance, and the field rheostat of the plate generator. The audio-frequency oscillator circuit consists of a transformer, tank and grid condensers, and a signal-selector switch, the transformer and

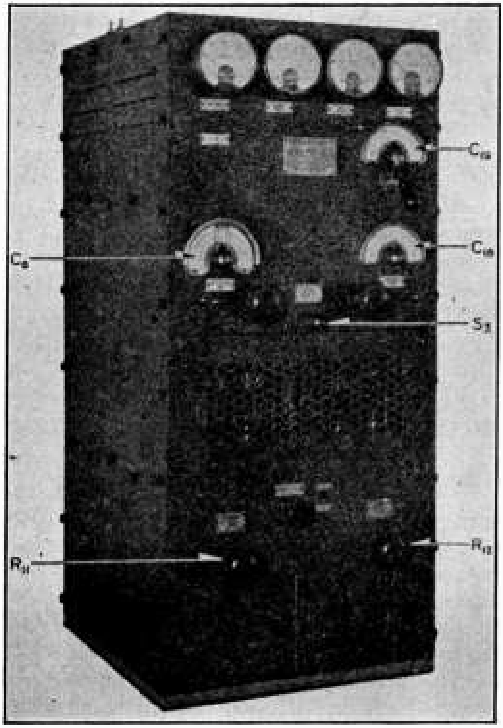


Fig. 29.—Panel of master-oscillator type of transmitter.

condensers making up the plate and grid circuits of the audio-frequency oscillator tube. The grid circuit is tuned to give approximately 700 cycles of oscillation per second. The signal-selector switch in the I.C.W. position closes the filament circuit, removes a short circuit from the tank circuit of the audio-frequency oscillator tube, and allows it to modulate the master oscillator. The plate potential is on the audio-frequency oscillator tube at all times.

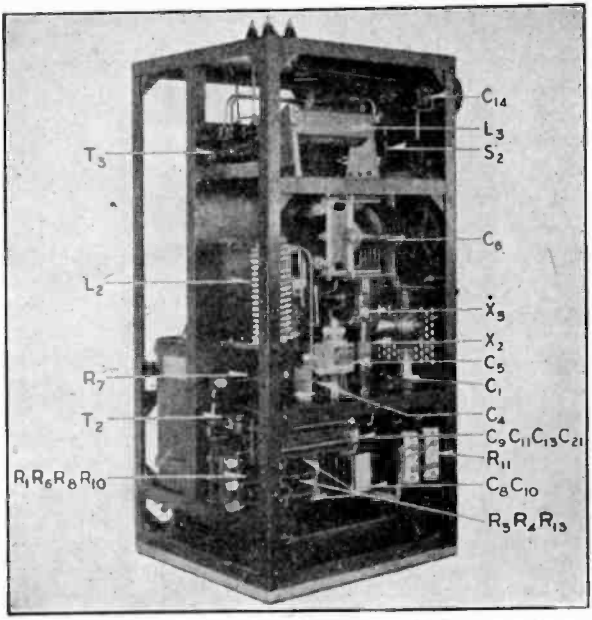


Fig. 30.—Right side and rear view of master-oscillator type of transmitter.

The master-oscillator circuit, including the two tubes just mentioned, is enclosed in the compartment immediately above the audio-frequency oscillator (Fig. 30). The tubes are mounted behind the door, and directly above them is mounted the tuning condenser of the master-oscillator tank circuit. Just back of the tubes and below the tank condenser are the plate choke coil, the grounding condenser, and the plate "stopping" condenser. To the rear is mounted the master-oscillator tank inductance with its associated link and switch mechanism for changing wave bands. The tank tuning condenser is controlled by a knob mounted on the front panel.

One UX-860 tube functions as the master oscillator in the conventional Hartley circuit (page 390) with "parallel power feed." All leads are as rigid as possible to eliminate frequency variation. The master-oscillator tank inductance for use on the higher-frequency bands is wound with ¼-inch copper tubing on insulators. It is mounted rigidly and wound with heavy tubing to insure minimum frequency drift due to heating by heavy circulating currents.

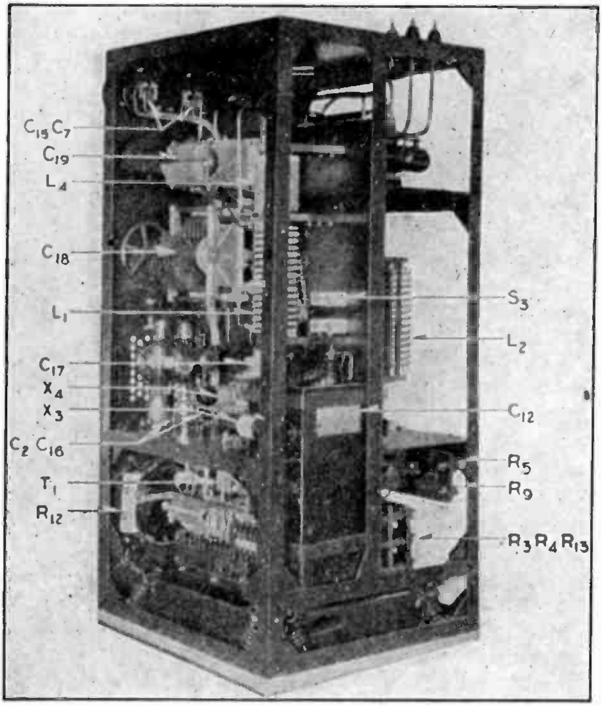


FIG. 31.—Left side and rear view of master-oscillator type of transmitter.

The power-amplifier circuit, antenna coupling coil, and antenna-tuning condenser are mounted in the upper compartment as shown in Fig. 31. The two UX-860 tubes used in the power-amplifier circuit are mounted as on the oscillator side and are connected in parallel to operate on the fundamental frequency of the master oscillator. There is no neutralizing (page 371) of the power-amplifier tubes because of the low grid-to-plate capacity of the four-element tube. Any coupling due to the common source of the master oscillator and power-amplifier screen-grid voltage has been eliminated by a combination of impedance and resistance in series with these elements. The tank circuit of the power amplifier is practically identical to that of the master oscillator, the only difference being in the tapping of the inductance.

The antenna-load coil, antenna current transformer, and antenna changeover relay are also mounted in the upper compartment (Fig. 30). In the lower right-hand compartment (Fig. 31) are the high-voltage by-pass condenser, the fuses, the voltmeter resistance, the filament transformer with its associated rheostat, and the terminal board. All of the apparatus located in the lower compartments and operated from the front panel is supported by straps extending from the frame to the central panel.

The Circuits.—The master-oscillator tuned circuit is made up of the inductance L_2, the condenser C_6, the plate "stopping" condenser C_5, the grounding condenser C_4, and the choke coil X_5. The oscillator furnishes its own grid-bias voltage by passing the rectified grid current to the ground through the resistance R_7. This resistance also supplies the grid-bias voltage for the two power-amplifier tubes. The screen-grid tube is by-passed to the ground through the condenser C_1 and any radio-frequency coupling due to the common screen-grid lead between the oscillator tube and power-amplifier tubes is prevented by the combination of choke coils and resistance units X_1 and R_1 with X_3 and R_8. The filaments are by-passed to the ground through the condenser C_3. The choke coil X_5 is placed in the plate circuit to reduce the excitation somewhat at high frequencies. The audio-oscillator circuit is composed of the transformer T_2 with the tank capacity C_{10}. The grid is coupled through the condenser C_9 and its grid-bias voltage is supplied by the voltage drop across the grid leak R_6. A condenser C_8 by-passes the screen-grid tube to the ground and the screen-grid grid-bias voltage is passed through the resistance R_2. The power-amplifier tuned circuit is composed of the inductance L_1 and capacity C_{18}. The plate power is supplied through the choke coil X_4 which prevents the radio-frequency voltage from going to the ground through the generator. The screen grids of the two power-amplifier tubes are by-passed to the ground through the condensers C_{16} and C_2.

"Keying" is accomplished by removing a high negative grid-bias voltage from the grids of all the tubes. This high grid-bias voltage is obtained by connecting all the grid leads to the negative high-voltage terminal and placing the resistance R_3 between the negative high-voltage terminal and the ground. The drop across R_3 furnishes this high negative grid-bias voltage as long as the key is not pressed down. When the key is closed it operates a relay key and this short-circuits the resistance R_3, thus removing the high negative grid-bias voltage, and permitting the tubes to operate properly. The resistance R_{10} and the capacity C_{11} act as a spark suppressor across the contacts of the relay key.

The antenna is coupled either conductively or inductively to the power-amplifier tank circuit, depending on the type of antenna system used. When an antenna-ground system is used, the circuit is tuned by the inductance L_3 and the capacity C_{19} and is coupled inductively by the inductance L_4. If a transmission line supplies a single-wire antenna, the line may be coupled by means of the coupling coil L_4 or by being connected conductively to the tank inductance L_1. In either of the above cases where a transmission line is used, the antenna loading coil L_3 is short-circuited completely out of the circuit to minimize the unbalancing of the transmission line. The magnetically operated antenna change-over relay S_2 is connected between the antenna-coupling coil L_4 and the tuning circuit L_3C_{19}, thus operating at a low-potential point. The antenna-current transformer T_3 is connected to one of the antenna leads so that the leads to it will not have to be changed, no matter which antenna system is used. This antenna-current transformer is used so that one antenna meter may serve as the indicating device under all probable antenna currents in widely varying systems.

Installation of Coils for Different Frequency Bands.—Two sets of coils are needed to cover the frequency range from 17.15 megacycles to 2,000 kilocycles (17.5 to 150 meters). For the three higher-frequency bands, namely, 17.15 to 8.2 megacycles (17.5 to 36.6 meters), 12.8 to 6.15 megacycles (23.4 to 48.8 meters), and 11.4 to 5.55 megacycles (26.3 to 54.0 meters), a set of two coils consisting of 15 turns of ¼-inch copper tubing are used. The coils used for these high-frequency bands have a link-and-tap arrangement for the selection of bands. Lugs are attached to the coils at the proper points to give the desired frequency bands, and the link system makes the connection to any of these lugs a simple operation. This permits the convenient change from one band to another. On the master-oscillator coil there are two separate link systems S_4 as shown in Fig. 32. One of these systems short-circuits the turns on the coil L_2, while the other one is for changing the ground point on the coil. On the power-amplifier coil L_1 there is also the link system S_4, but here it is only for short-circuiting the turns on the coil.

To operate on any of the three high-frequency bands it is only necessary to change the three links on the coils L_1 and L_2 to the proper lugs on the coils. To operate on the 17.15- to 8.2-megacycle (17.5- to 36.6-meter) band, one link on the master-oscillator coil should be adjusted to short-circuit approximately 8 turns of the coil, and the other should be placed so that there is only 1 turn in the grid circuit. The range switch S_3 is used to enable the whole band to be covered from the front panel. The power

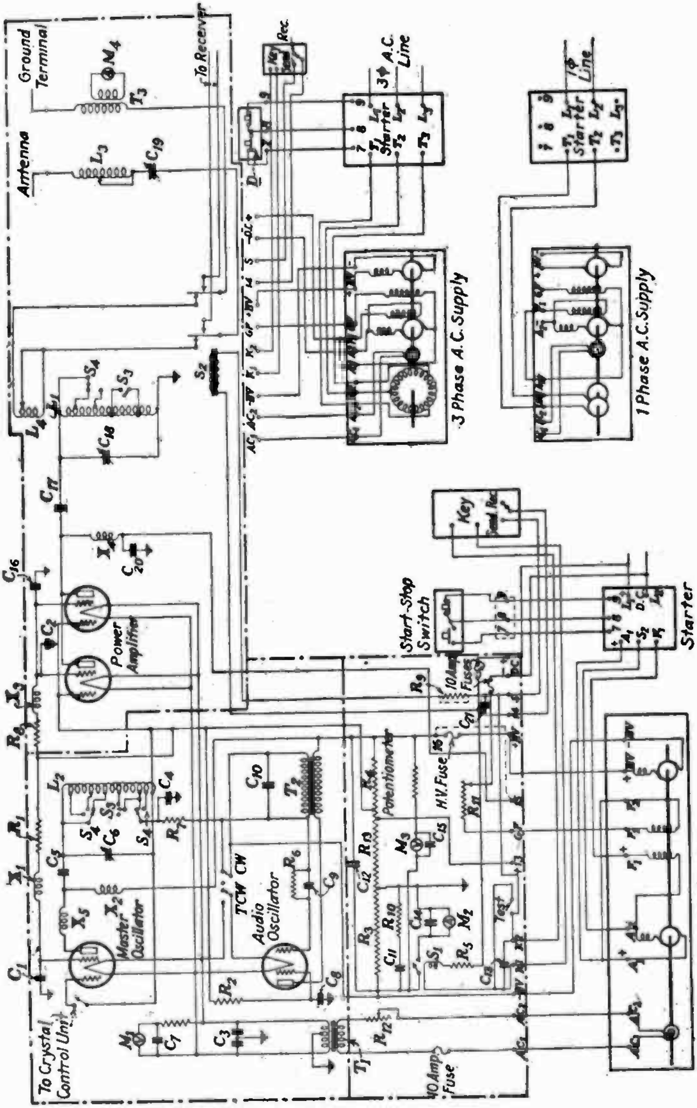
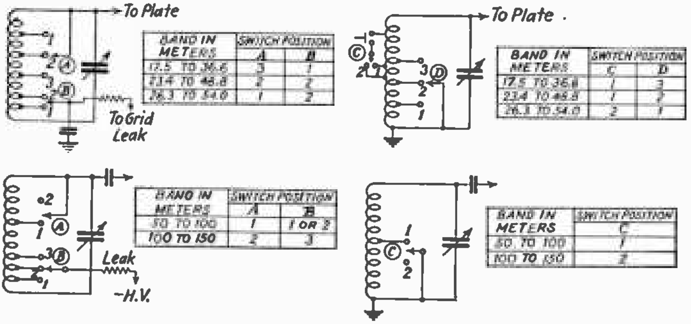


FIG. 32.—Complete wiring diagram of master-oscillator type of transmitter.

amplifier should also have its link adjusted to short-circuit approximately 8 turns. For operation in the 12.8- to 6.15-megacycle (23.4- to 48.8-meter) band, the links on the master-oscillator coil are adjusted so that the grid circuit contains 2 turns and 4 turns are short-circuited. On the power-amplifier coil approximately 4 turns should be short-circuited. Two clips are mounted directly below the equalizer choke coil X_5 for the purpose of short-circuiting this choke coil when operating in the 12.8- to 6.15-megacycle (23.4- to 48.8-meter) band and the 11.4- to 5.55-megacycle (26.3- to 54.0-meter) band. When it is not desired, therefore, to work in the 17.15- to 8.2-megacycle (17.5- to 36.6-meter) band, a short piece of wire should be placed between these clips thereby removing X_5 from the circuit. In a similar manner, for operation in the 11.4- to 5.55-megacycle (26.3- to 54.0-meter) band, there should be two turns in the master-oscillator grid circuit



BAND IN METERS	SWITCH POSITION A	SWITCH POSITION B
17.5 TO 36.6	3	1
23.4 TO 48.8	2	2
26.3 TO 54.0	1	2

BAND IN METERS	SWITCH POSITION C	SWITCH POSITION D
17.5 TO 36.6	1	3
23.4 TO 48.8	1	2
26.3 TO 54.0	2	1

BAND IN METERS	SWITCH POSITION A	SWITCH POSITION B
50 TO 100	1	1 OR 2
100 TO 150	2	3

BAND IN METERS	SWITCH POSITION C
50 TO 100	1
100 TO 150	2

FIG. 33.—Diagram of arrangements of link system.

and two short-circuited turns on both the master-oscillator and the power-amplifier coils. The number of turns short-circuited by the range switch must be changed on the power-amplifier coil. For operation in this band, the range switch is adjusted to short-circuit 6 turns, and in the other two bands, only 4 turns are short-circuited.

When the frequencies from 6,000 to 2,000 kilocycles (50 to 150 meters) are to be covered, the coils used in the master-oscillator and power-amplifier tank circuits consist of 39¾ turns of No. 10 bare copper wire on forms 3½ inches in diameter. Adjustment for operation between 6,000 and 3,335 kilocycles (50 to 90 meters) is made in the same manner. On the master-oscillator coil there should be 2 or 3 turns in the grid circuit and approximately 20 turns short-circuited, and the power amplifier should have 22 turns short-circuited. For operation in the 3,335- to 2,000-kilocycle (90- to 150-meter) band there should be 4 turns in the grid circuit of the master oscillator, and no short-circuited turns on either the "master" or power-amplifier coils. The tables and diagram in Fig. 33 give the exact setting of the links and the switches to cover any required band. Besides the two sets of coils mentioned before there is a set of four choke coils for each set of tank coils. When the high-frequency coils are needed, the choke coils used are wound with 75 turns on a 1½-inch diameter tube. When the transmitter is to operate between 6,000 and 2,000 kilocycles (50 to 150 meters), the choke coils used are wound with 180 turns on a 1½-inch-diameter tube.

Operation in Steps.—(1) The filament voltage is adjusted to 10 volts and the plate voltage to not more than 1,000 volts. When the motor-generator set is started, the field of the generator should be as low as possible. A generator starting on full field would generate an excessively high voltage which might be dangerous to the tubes. The next step is to turn the C.W.-I.C.W. switch to the C.W. position. (2) The master-oscillator control is set to the scale reading shown on the calibration chart for the wave length desired. (3) The antenna-tuning condenser is turned to a minimum value. (4) The power-amplifier control is adjusted until the plate current has its minimum value. (5) The antenna inductance and the antenna series condenser are adjusted until the antenna current has its maximum value. (6) The power-amplifier tuning control is readjusted for its minimum plate current. (7) The antenna series condenser is readjusted for its maximum antenna current. (8) The plate voltage is slowly increased, while the indications of the antenna ammeter and the plate-current meter are observed. If the plate current exceeds 0.5 ampere, a different adjustment of the antenna coupling and the loading coil should be tried. This will mean readjusting the antenna-tuning condenser and possibly a slight retuning of the power-amplifier control. If the antenna meter reads too high, the coupling of the current transformer should be loosened. The best adjustment for full power is that which gives a maximum antenna current with a plate current of 0.5 ampere (or slightly less), a plate voltage of 2,000 volts, and with cool plates in the power-amplifier tubes. The proper value of the filament voltage is 10 volts. If the filaments are operated at more or less than 10 volts, the life of the tubes will be decreased. (9) For operation on I.C.W. service, the C.W.-I.C.W. switch is turned to to the I.C.W. position and the filament rheostat is adjusted to 10 volts. This turns on the audio-frequency oscillator and modulates the output at 700 cycles per second. The purpose of this modulation is to spread out the waves so that it is easy to tune in, thus enabling a call to be accomplished more effectively than in C.W. operation.

The UX-860 tube, which is of the four-element type, eliminates the necessity of neutralizing. A direct-current voltage having a value of about

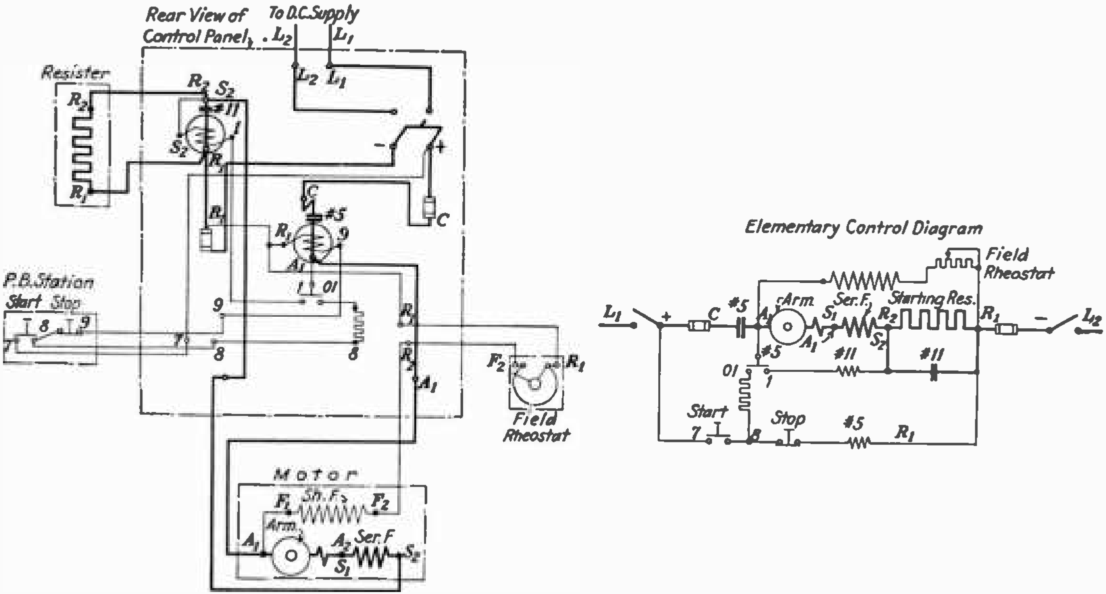


FIG. 34.—Wiring diagram of motor-generator starter for push-button control.

one-quarter of the plate voltage is applied to the screen grid so that it does not impede the flow of electrons from the filament to the plate.

The direct-current motor generator consists of a 2-horsepower, 110-volt, direct-current, compound-wound, four-pole motor and a 1-kilowatt, direct-current generator mounted on the same shaft and in the same frame. The generator supplies direct current at 2,000 volts. Slip rings on the armature provide an alternating current at 60 cycles and 77 volts for lighting the filaments of the tubes. The field excitation is obtained from the 100- to 125-volt direct-current line. The motor starter, shown in the wiring diagram of Fig. 34, is the type with push-button control. When the starting button on the transmitter is pressed, the contacts in the starter are closed. This unit should be mounted vertically near the motor-generator set.

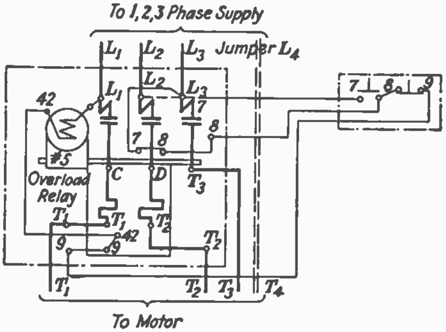


FIG. 35.—"Line" starter for motor generator with alternating-current power.

For alternating-current power, this motor-generator set is directly connected to another motor, the two machines being fastened to a common bedplate. Under these conditions the direct-current motor of the motor-generator set becomes a direct-current generator and furnishes exciting current for the field relay key of the high-voltage generator and also the change-over relay. The alternating-current power for the filaments is supplied by the slip rings on this generator. The starter for alternating-current power operation as shown in Fig. 35 is a "line" starter; that is, it has only one starting position.

Part 7

CRYSTAL-CONTROL ATTACHMENT

(Model AA-H1566)

Description of Units.—The crystal attachment is used with the ET-3655B transmitter (page 575) to obtain greater stability of frequency than can be obtained with the transmitter alone. As the frequency increases it becomes more difficult to procure frequency stability. The circuit used is of the oscillator and frequency "doubler" type (page 476), using one UX-210 tube as an oscillator and two UV-211 tubes, both operating as frequency doublers. The output of the last tube is carried to the grid of the master-oscillator tube in the transmitter, which may either amplify without any frequency change or it may again double the frequency. The unit is capable of controlling the transmitter between 17.15 megacycles (17.5 meters) and 5.55 megacycles (54 meters). The circuits are so designed that quartz crystals ground to operate between 3,000 kilocycles (100 meters) and 1,360 kilocycles (220 meters) cover the required frequency range. Between the frequencies of 5,550 and 11,000 kilocycles (54 to 27.5 meters) the first UX-860 tube in the transmitter is to be operated as an amplifier, with no frequency change, which means that the crystals will be ground to operate between the above range of 3,000 kilocycles (100 meters) and 1,360 kilocycles (220 meters). At frequencies between 11,000 and 17,150 kilocycles (27.5 to 17.5 meters), the master oscillator is operated as a frequency doubler. The crystals, when operating in this manner, will be ground to operate between 2,140 and 1,360 kilocycles (140 to 220 meters).

The unit is mounted in a cabinet with a removable cover and a panel of aluminum. In a corner of the cabinet is the "crystal" box which contains two crystals. The temperature in the box is to be maintained constant within one-quarter of 1°C. A bimetallic thermostat and two 2,000-ohm, 60-watt resistances used for heaters are also contained in this box. The bimetallic thermostat "makes and breaks" the circuit of the heater resistances. A thermometer extending into the box indicates the inside temperature. A selector switch allows the use of either crystal.

Along the lower part of the panel are the three tuning controls which operate three 250-micromicrofarad variable condensers. The first C_1 is used to tune the plate circuit of the crystal oscillator tube, the middle one C_2 tunes the first frequency doubler, and the third one C_3 tunes the second frequency doubler. Above the three condensers are three plate and current meters M_1, M_2, M_3. Behind the tuning condensers are the tuning inductances or tank coils with three plate choke coils X_1, X_2, and X_3, and three grounding condensers C_7, C_8, and C_9. The unit also includes resistances for a high-voltage potentiometer, a grid-leak resistance, and a terminal board.

The Circuits.—The tuned-circuit crystal oscillator as shown in Fig. 36 is made up of the inductance L_3, the condenser C_3, the grounding condenser C_9, and the plate choke coil X_3. The inductance L_3 has a tap brought out at its center. The grid circuit of the crystal oscillator consists of the crystal and the grid-leak resistance R_8 through which the oscillator furnishes its grid-bias voltage by passing the rectified grid current to the ground. The tuned circuit of the first frequency doubler is composed of the inductance L_2, the condenser C_2, the grounding condenser C_8, and the plate choke coil X_2. The inductance L_2 is the same as L_3 except that it contains fewer turns. The choke coil X_2 is the same as X_3 except that it contains fewer turns. The grid circuit consists of the coupling condenser C_6 and the grid leak R_7. The circuit of the second frequency doubler is identical with that of the first except that the inductance and the choke coil have fewer turns. The condenser C_4 and the grid leak R_5 are included and comprise the grid circuit of the oscillator tube of the transmitter. This tube, when the crystal attachment is used, is not an oscillator but becomes an amplifier or frequency doubler. The high-voltage potentiometer for distributing the proper voltage to the tubes is made up of four resistances (R_1, R_2, R_3, and R_4).

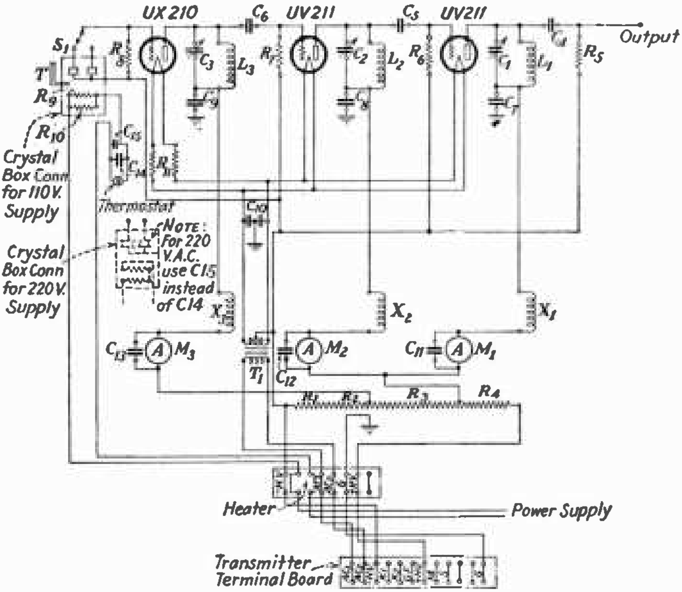


FIG. 36.—Crystal-oscillator circuit.

Steps in Tuning and Operation:

1. In tuning the transmitter, the plate voltage should be lowered to a minimum by turning the field rheostat as far to the left as possible. This

should be done with the key in the elevated position and the filaments of the tubes turned as low as possible. Then the filaments should be adjusted for 10 volts on the meter of the transmitter M_1.

2. The crystal oscillator is the first tube to bring into adjustment. To do this the crystal tuning is adjusted until the plate current starts to drop off as indicated on the meter M_3. This adjustment is continued in the same direction until the plate current falls to a minimum value and then suddenly rises to a high value. This sudden rise in current indicates that the crystal has stopped oscillating. To obtain the maximum output from the crystal, the tuning should be adjusted as closely to the point where the current suddenly increases as stable operation will permit. After noting approximately where this point lies on the dial by the above procedure, the tuning control is turned back and the point is approached more slowly until the minimum plate current is obtained.

3. The key can now be closed, but the high voltage should be kept at a reduced value. If this value is lower than 1,000 volts it may be increased to this amount.

4. To tune the first frequency doubler, an adjustment is made for the minimum plate current on the meter M_2. Precautions should be taken to make sure that the doubler is tuned to double the frequency of the oscillator and not to the same frequency. This can occur when crystals of a frequency very close to a rating of 3,000 kilocycles are used because the tuning circuit of the doubler may be used in tuning to 3,000 kilocycles or slightly less. For this reason the operator should keep in mind at which end of the tuning range the setting is going to be. The second frequency doubler is tuned in the same way.

5. The second frequency doubler is adjusted for the minimum plate current on the meter M_1 of the crystal-control unit as was done for the first frequency doubler. The crystal unit should now be tuned and ready for operation.

6. Before tuning the transmitter it is well to be sure that the crystal unit is operating at its best efficiency. When crystals between the frequencies of 3,000 and 2,000 kilocycles are used, the plate current of the first frequency doubler may be higher than the normal value and the tube may be excessively heated when in operation. This is corrected by placing a "jumper" across the middle tap and the end of the plate inductance L_3 of the crystal oscillator. This changes the efficiency of the oscillator and allows the frequency doubler to operate more normally. It may be necessary in some cases to place a jumper between the middle tap and one end of L_2, the plate inductance of the first frequency doubler. This procedure is necessary only for conditions where the plate current of the tubes of the frequency doubler exceeds the normal value. It may be taken as a rule to proceed as above

when the plate current of either of the UV-211 tubes exceeds a value of 85 milliamperes.

7. In tuning the transmitter the procedure to be followed depends slightly on whether the first UX-860 tube is to operate as a frequency doubler or as a straight amplifier, to obtain the frequency desired for transmission. Assuming, first, that the tube is to operate as a frequency doubler, the procedure is as follows: The short-circuiting links S_4 on the tank coil of the first UX-860 tube are adjusted so that they will tune to the 17.15- to 8.2-megacycle (17.5- to 36.6-meter) band, and then the range switch may be closed. The ground link is then set one turn from the end of the inductance and this stage is ready for the final tuning.

8. The control marked "master-oscillator tuning" on the transmitter panel is adjusted for maximum plate current on the meter M_2. If at this point the plate current rises to an excessive value, the plate voltage must be reduced again until a safe current is flowing.

9. The short-circuiting links of the power-amplifier tuning inductance are set so that they may be used to tune the 17.15- to 8.2-megacycle (17.5- to 36.6-meter) band. This allows the power amplifier to be adjusted to 17.5 meters but no lower. If the crystal used gives a frequency higher than 17.15 megacycles (17.5 meters) after doubling, the copper strap connecting the coil and short-circuiting switch S_3 must be moved up to within one turn of the plate end of the coil. With this change the power amplifier will tune to 21.4 megacycles (14 meters).

10. The power amplifier can now be tuned by adjusting its control for minimum plate current on the meter M_2.

11. The plate voltage is increased to between 1,600 and 1,800 volts but no more. The antenna can now be connected and the coupling circuit shown at L_3, L_4, and C_{19} in Fig. 32 can be adjusted for the maximum antenna current. This is done exactly as described for the adjustment of the transmitter.

12. It is well, at this point, to go back and start on the first frequency doubler with a very careful final adjustment for the minimum plate current in each stage. When such final adjustments are being made, the operator should remember that if any stage is detuned too much the plate current will rise to a dangerous value with a possibility of rendering the tubes inoperative or of burning out the high-voltage fuse. For this reason the final adjustments must be made very carefully.

13. The voltage can now be increased to the normal value of 2,000 volts, and the transmitter should be in satisfactory operating condition.

For the case in which the first UX-860 tube is not operated as a frequency doubler but as an amplifier the procedure above is followed except for the adjustment of the taps on the tank coils. Here the adjustments are identical with those used when only the transmitter is operating, between the frequencies of 12 and 6 megacycles (25 to 50 meters). Whether the first UX-860 tube is acting as a frequency doubler or as an amplifier, the main precaution to observe is that the tank circuits of both the first tube and the power amplifier are adjusted to work in the same frequency band just as when the transmitter is operating alone.

Part 8

MODULATOR UNIT

(Model AT-747)

The modulator unit is designed to work in conjunction with the model ET-3655B transmitter to produce a signal modulated approximately 60 per cent (page 482).

The Circuits.—The modulator unit has one UV-211 tube which is used as a speech amplifier and one UV-849 tube used as a modulator. When the "C.W.-phone" switch is moved to the "phone" position, the filaments of the tubes of the modulator and the speech amplifier become operative and the short circuit is removed from the modulation reactance X_1 in Fig. 37. In the C.W. position this reactance is short-circuited to insure good keying.

Referring to Fig. 37, the "hand-set" microphone is shown connected to terminals marked "Mic." and the microphone switch as joining the key terminals of the transmitter. When this switch, or the button on the microphone, is closed, the relay key of the transmitter operates and removes the grid-bias voltage from the tubes, thus making the transmitter ready for operating service. Speech is introduced into the microphone and the speech currents are passed through the speech-input transformer to the grid of the UV-211 tube, where they are amplified and reproduced in the plate circuit to be passed on through the modulator tube to the plate circuit of the radio-frequency amplifier.

Power Supply.—The negative grid-bias voltage is supplied to the grids of the tubes of the speech amplifier and the modulator, as shown in Fig. 37, by using the voltage drop across part of the resistance R_3. The microphone current is obtained by utilizing the voltage drop across part of the resistance R_4 which furnishes approximately 12 volts to the microphone.

The filaments of the UV-211 and UV-849 tubes are connected in parallel across the secondary winding of the filament transformer T_1 in the modulator unit. Suitable resistances R_2 are connected in series with the filament of the UV-211 tube to furnish the correct filament voltage to that tube. As in the case of the transmitter unit the filament voltage is regulated by a rheostat R_6 which should be adjusted to obtain the correct reading on the filament voltmeter.

The plate power is supplied by a three-unit motor set, the motor being either of the direct-current or the alternating-current induction type (page 228), depending on the source of power. The generator delivers a current of 0.8 ampere at 1,800 volts.

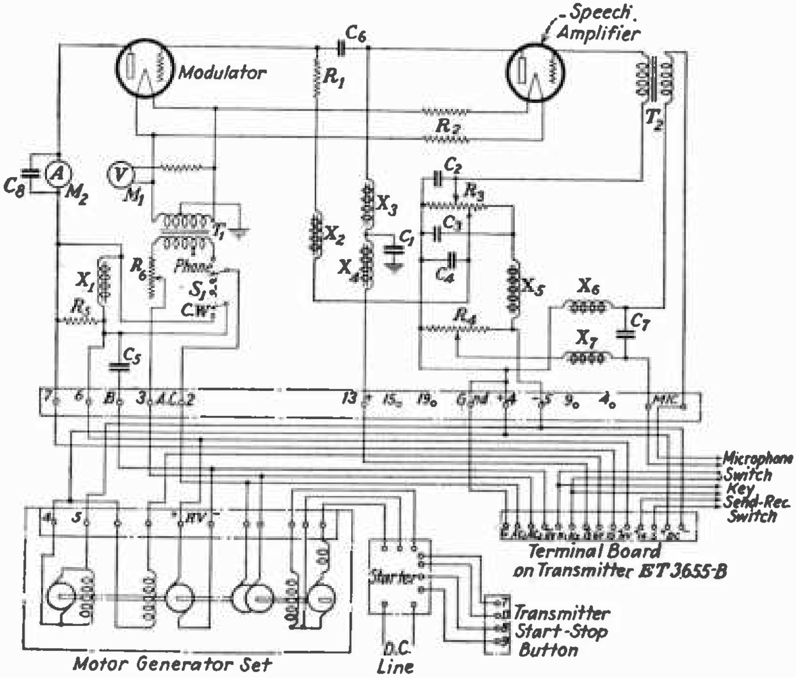


FIG. 37.—Circuit diagram of modulator unit.

Installation and Operation.—External connections and interconnections between the various units are clearly shown in Figs 35, 36, and 37. On the terminal board of the transmitter is the terminal marked "plus 13," which is connected to a flexible lead on the potentiometer of the transmitter. This lead is to be placed on the potentiometer in the proper tap to supply approximately 400 volts to the plate of the speech-amplifier tube in the modulator unit. Adjustment of this tap must be made after the units are set up and, in all other respects, in operating condition. The transmitter should be tuned to the desired frequency and the antenna system resonated in the usual way; then the modulator unit will be made operative by placing the "C.W.-phone" switch in the "phone" position. Ths gives the actual conditions under which the potentiometer in the transmitter will be operating. The tap can then be adjusted for the best speech conditions, as well as efficiency of operation.

Due to slight differences in the characteristics of individual tubes, it may be necessary to change the grid-bias voltage when a modulator tube is changed. This is done by adjusting the position of the grid tap on the grid-bias potentiometer R_3 in the modulator unit. The best operating point is obtained by adjusting the grid-bias voltage until the plate-current meter of the modulator indicates between 100 and 120 milliamperes with 1,800 volts on the plate. When the transmitter is operating on "phone," the total plate current on the transmitter unit should not vary materially with the voice currents. For best operation the plate current on the modulator unit should not vary more than 20 milliamperes in either direction, and the antenna current should increase an amount depending on the loudness of the speech to be transmitted.

Part 9

EMERGENCY OPERATION AND REPLACEMENTS

Emergency Measures for Apparatus Failure.—In cases of emergency it is often necessary to operate under conditions which are not suitable for continuous service. Some emergency procedures are outlined here:

1. *Insulation Breakdown.*—When charring of insulation results from continued arcing over and burning, the insulation should be cut away if possible; otherwise the winding should be cut and sufficient turns removed to avoid the trouble. Before a cut is made in the wire at each end of the turns to be removed, the ends of the remaining winding should be made fast with cord, and a temporary jumper put in to close the circuit. If the insulation is at the terminal blocks in the switches, and the arcing cannot be stopped by cutting away the insulation, the connections should be removed and the circuit completed by a temporary jumper.

2. *Filament Voltmeter Inoperative.*—The filament voltage should be reduced until the tubes begin to heat or until the antenna current drops off rapidly. Then the filament voltage may be increased slowly until the tubes operate at the normal temperature and the antenna current is not rising rapidly.

3. *Plate Ammeter or Voltmeter Inoperative.*—The generator field rheostat should be maintained at not more than its usual position and the unit operated with the normal temperatures of the tube.

If the plate ammeter is not functioning and other adjustments are to be made, a 50-watt, 110-volt lamp may be inserted in place of the ammeter.

4. *Antenna Ammeter Inoperative.*—Adjustments should be made in accordance with the tuning record card, and the plate ammeter observed for final resonance.

5. *Filament Transformer or Filament Rheostat Burned Out.*—The filament transformer and rheostat should be disconnected. Five cells (in series) of a lead-acid storage battery may be connected directly to the filament buses with leads to carry 20 amperes. The voltage of the battery is practically correct for the tube filaments without rheostat control.

6. *Grid Leak Open.*—The grid leak of the master oscillator or power amplifier may be replaced by a resistance of equal value. A column of water, 12 inches long, in a rubber hose plugged at each end and having wire electrodes will be satisfactory. If the resistance seems to be too high, a little salt or washing soda should be added.

Possible Troubles and Their Causes.—The procedure to be followed in correcting troubles and discovering their causes is outlined below:

1. *Pressing Start Button Does Not Start Motor Generator.*—The main switch is open or a main fuse is defective, or the line voltage has failed or is too low. The line voltage may be tested by operating the telegraph key which will cause the relay to work if the line voltage is satisfactory.

2. *Start Button Causes Start Contactor to Close, but Motor-generator Set Does Not Start.*—Starting resistance on the back of the starting panel is burned out, or a connection between the starting panel and the motor-generator set is open, or the motor-generator set has a "frozen" bearing, due to lack of oil.

3. *Starter and Generator Satisfactory as Indicated by Plate Voltage on Radio Panel, but Tube Filaments Do Not Light.*—A connection is loose on the filament transformer or the terminal boards, or there is a defective brush on the motor slip rings.

4. *Set Operates Normally when Key Is Closed, but Tubes Heat Badly when Key Is Elevated.*—The tubes may not be blocking properly because of low grid-bias voltage, caused by a defective resistance R_3 of Fig. 32. The tubes should be examined to see if the grid and screen-grid elements are intact. It may be possible that either might have been burned off due to excessive heating and that consequently not enough control grid voltage is available.

5. *Tubes Heat Badly as Soon as Key Is Closed.*—The master-oscillator tube is defective or the exciter circuit is not oscillating. The tubes should be changed and the circuit examined for loose connections. When all but the master oscillator are removed from their sockets, the master-oscillator tube will still heat badly when the key is closed if the tube or the circuit is defective.

6. *Amplifier Tubes Heat Excessively when Key Is Closed.*—The amplifier circuit is out of tune.

7. *Audio-frequency Oscillator Does Not Operate when Switch Is Turned to I.C.W. Position and Key Is Closed.*—The connections to the *C.W.-I.C.W.* switch and also the connections to the transformer and the condensers should be examined. The resistance should be checked for an open circuit.

SECTION XII

LABORATORY EQUIPMENT AND TESTING METHODS

Part 1

APPARATUS

Attenuation Networks.—In a laboratory specializing in communication engineering a device is often needed which may be used to make a radio signal weaker, or *attenuated*, by a definite amount. For instance, it may be convenient to measure one radio signal in terms of another by decreasing the louder until both are of the same intensity, a method frequently used in measuring the *gain in power* in amplifiers. One method of doing this is illustrated in Fig. 1, which shows a familiar type of *potentiometer*. In this case a fixed resistance R is connected across the terminals of the source of current, while a variable resistance r is connected across the "sink" receiving the attenuated signal. If this sink is a voltage-operated device, drawing no current, the potential at its input terminals will be equal to the output voltage of the source multiplied by the simple ratio $r:R$. The impedance of the potentiometer (viewed from the source) will be equal to R and should be made equal to the characteristic impedance of the source (viewed from its output terminals) if the best working conditions are to be attained. Under these conditions the attenuation of the potentiometer may readily be calibrated in terms of transmission units TU (page 596). If, however, the sink is a current-consuming device, then the expression for the attenuation of the potentiometer becomes more complicated, involving the characteristic impedance of the sink. Furthermore, the impedance of the

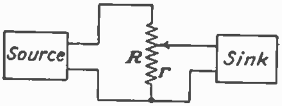


FIG. 1.—Simple attenuation network.

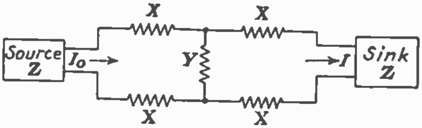


FIG. 2.—H-type of attenuation network.

potentiometer, viewed from either end, is a variable, changing with each setting of the adjustable contact. This will give rise to so-called *electrical reflections* which will tend to produce wave distortion and kindred troubles.

To produce a distortionless and easily computable attenuation between a source of current and the sink, each having the same characteristic impedance Z, the attenuation network shown in Fig. 2 may be used. This so-called *H type* of network comprises four equal series resistances X and an additional shunt-resistance element Y, connected between the source and the sink in the symmetrical manner indicated. If such a network is intended to introduce a definite number N of transmission units of attenuation, then the values of X and Y may be computed from the equations

$$X = \frac{Z}{2}\left(\frac{k-1}{k+1}\right)$$

$$Y = 2Z\left(\frac{k}{k^2-1}\right)$$

where

$$k = \frac{I_0}{I} \text{ and } k \text{ is less than 1.}$$

The ratio of the current I_0 leaving the source to the current I entering the sink is expressed as k.

Expressed in terms of *transmission units of attenuation,*

$$k = 10^{\frac{N}{20}} = \text{antilog } \frac{N}{20}$$

where N equals the attenuation in transmission units (T.U.).

A single network of this kind offers a definite amount of attenuation determined by the values of X and Y. If the five branches of the network are made adjustable by steps, as indicated schematically in Fig. 3, and if the five switch arms are moved in unison to the corresponding switch points, then, by a proper calibration of the X and Y branches, the *characteristic impedance* Z of the network may be maintained constant while its attenuation is varied by any desired steps.

In certain lines of work it may be desirable to ground the center point of the Y shunt branch. This can be accomplished by using a network with six adjustable switch arms, wherein the shunt resistance Y is divided into two equal parts.

Each instrument of the attenuation network described in this section contains two "decade" (H-type) networks which may be used individually or joined in series. In one set of these instruments the decades are calibrated in steps of 5 and 0.5 transmission units, respectively, giving a total attenuation of 55 transmission units; in the second set the decades are calibrated in steps of 2 and 0.2 transmission units, giving a total attenuation of 22 transmission units. These instruments are usually available for a calibrated characteristic impedance of either 600 or 6,000 ohms. The attenuation is controlled by a single-dial switch for each decade.

Instead of varying the attenuation of the five branches of a single-network section, as previously described, the same results may be obtained by adding two or more fixed sections in series. In that case a four-pole, double-throw switch serves to insert or remove each particular section at will. Given the characteristic impedance and the desired attenuation in transmission units of such a section, the necessary values of resistance of the X and Y branches may be computed directly from the previous equations.

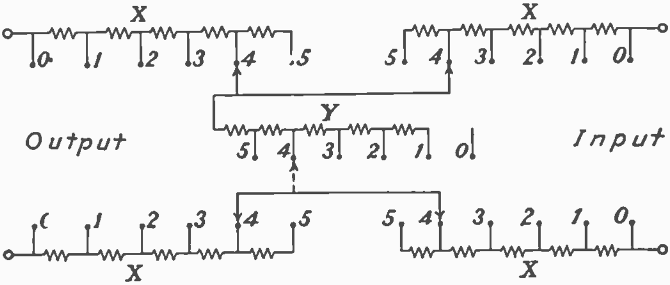


FIG. 3.—Branched type of attenuation network.

In place of the symmetrical H-type network, it is frequently permissible to utilize the simpler but unbalanced T-type network for attenuation purposes. Here a double-pole, double-throw switch is provided to throw each section in or out of the circuit. The resistance values are calculated in the same manner as for the symmetrical H type, except that each of the two X branches has the value $2X$ in order to maintain the same total series resistance in the network.

For certain kinds of experimental work an adjustable attenuation box (type 249) having one transmission unit as the smallest unit is sufficient. This type is made with either six or eight fixed sections which are controlled by individual switches. The eight-section boxes are calibrated in steps of 1, 2, 3, 4, 10, 20, 30, and 40 transmission units, affording thereby a total attenuation, by one-unit steps, up to 110 transmission units. The six-section boxes are calibrated in steps of 1, 2, 4, 8, 16, and 32 units, totaling 63 transmission units.

TABLE XLI.—TRANSMISSION UNITS (T.U.) CORRESPONDING TO GAIN OR LOSS IN POWER RATIO

No. of T.U.	Power ratio		No. of T.U.	Power ratio		No. of T.U.	Power ratio	
	Gain	Loss		Gain	Loss		Gain	Loss
0.1	1.023	0.977	3.6	2.29	0.437	7.1	5.13	0.195
0.2	1.047	0.955	3.7	2.34	0.427	7.2	5.25	0.191
0.3	1.072	0.933	3.8	2.40	0.417	7.3	5.37	0.186
0.4	1.096	0.912	3.9	2.45	0.407	7.4	5.50	0.182
0.5	1.122	0.891	4.0	2.51	0.398	7.5	5.62	0.178
0.6	1.148	0.871	4.1	2.57	0.389	7.6	5.75	0.174
0.7	1.175	0.851	4.2	2.63	0.380	7.7	5.89	0.170
0.8	1.202	0.832	4.3	2.69	0.372	7.8	6.03	0.166
0.9	1.230	0.813	4.4	2.75	0.363	7.9	6.17	0.162
1.0	1.259	0.794	4.5	2.82	0.355	8.0	6.31	0.158
1.1	1.288	0.776	4.6	2.88	0.347	8.1	6.45	0.155
1.2	1.318	0.759	4.7	2.95	0.339	8.2	6.61	0.151
1.3	1.349	0.741	4.8	3.02	0.331	8.3	6.76	0.148
1.4	1.380	0.724	4.9	3.09	0.322	8.4	6.92	0.144
1.5	1.413	0.708	5.0	3.16	0.316	8.5	7.08	0.141
1.6	1.445	0.692	5.1	3.24	0.309	8.6	7.24	0.138
1.7	1.479	0.676	5.2	3.31	0.302	8.7	7.41	0.135
1.8	1.514	0.661	5.3	3.39	0.295	8.8	7.59	0.132
1.9	1.549	0.645	5.4	3.47	0.288	8.9	7.76	0.129
2.0	1.585	0.631	5.5	3.55	0.282	9.0	7.94	0.126
2.1	1.622	0.617	5.6	3.63	0.275	9.1	8.13	0.123
2.2	1.660	0.603	5.7	3.72	0.269	9.2	8.32	0.120
2.3	1.698	0.589	5.8	3.80	0.263	9.3	8.51	0.118
2.4	1.738	0.575	5.9	3.89	0.257	9.4	8.71	0.115
2.5	1.778	0.562	6.0	3.98	0.251	9.5	8.91	0.112
2.6	1.820	0.550	6.1	4.07	0.245	9.6	9.12	0.110
2.7	1.862	0.537	6.2	4.17	0.240	9.7	9.33	0.107
2.8	1.906	0.525	6.3	4.27	0.234	9.8	9.55	0.105
2.9	1.950	0.513	6.4	4.37	0.229	9.9	9.77	0.102
3.0	1.995	0.501	6.5	4.47	0.224	10.0	10.00	0.100
3.1	2.04	0.490	6.6	4.57	0.219	20.0	100	0.01
3.2	2.09	0.479	6.7	4.68	0.214	30.0	1,000	0.001
3.3	2.14	0.468	6.8	4.79	0.209	40.0	10,000	0.0001
3.4	2.19	0.457	6.9	4.90	0.204	50.0	100,000	0.00001
3.5	2.24	0.447	7.0	5.01	0.200	60.0	1,000,000	0.000001

Table XLI gives the power ratios, gain or loss, corresponding to the number N of transmission units. The numerical value of N is equal to ten times the common logarithm of the power ratio; thus:

$$N = 10 \log \frac{P_1}{P_2}.$$

Expressed in terms of the transmission unit, gains or losses in successive stages are, therefore, additive.

When operating between a source and a sink of the same impedance, the power ratio is equal to the square of the voltage or current ratio, giving

$$N = 20 \log \frac{E_1}{E_2} = 20 \log \frac{I_1}{I_2}.$$

Under this condition of equal impedances, the table may be used to obtain the voltage or current ratios by multiplying the values of transmission units given in the table by the factor 2.

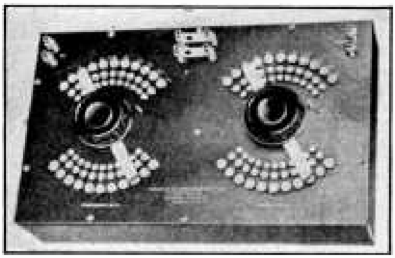


Fig. 4.—Commercial type of attenuation network.

Audibility Meter.—In the course of measurement work it is sometimes desirable to reduce the current in a load without greatly changing the characteristic impedance of the load, viewed from the source. A properly designed attenuation network will present a constant impedance to the source while reducing the load current to any desired degree. For some purposes, however, such as comparing the intensities of two radio signals by means of a so-called "listening test" with telephones, a complex form of network is not required. For such approximate work at a single frequency it is entirely satisfactory to add series resistance as the load is shunted.

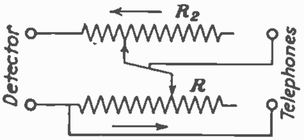


Fig. 5.—Audibility meter.

The audibility meter is intended for use with telephones for signal comparisons. It consists of a resistance system and switches arranged to add series resistance as the resistance across the telephone terminals is reduced, presenting an approximately constant impedance across the input terminals. The elementary connections are shown in Fig. 5, where R is the resistance used to shunt the telephone and R_2 is the compensating resistance; as R decreases R_2 increases.

The scale of this instrument is marked with an arbitrary scale of "audibility" depending on the relation

$$K \text{ (audibility constant on scale)} = \frac{S + T}{S}$$

where S is the resistance of the shunt section and T the impedance of the telephones. The scale was computed on the basis of a telephone impedance of 8,000 ohms.

Galvanometer Shunt.—A galvanometer shunt has two general uses: (1) to protect a galvanometer from injury while adjustments are being made and (2) to extend its range. For the latter use the so-called "universal" type of shunt is most convenient. This type may be calibrated directly in ratios, as the relative multiplying power is the same for all galvanometers, regardless of the galvanometer resistance. This feature is best understood by reference to Fig. 6. The total tapped resistance R is connected directly across the galvanometer, and the bridge connects to one side of the tap switch and to the galvanometer; the resistance of the latter being R_g. The solution of the circuit gives the following equation for the value if the current I_b (amperes) in the circuit:

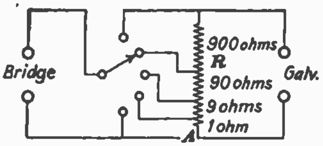


FIG. 6.—Universal type of galvanometer.

$$I_b = I_g \frac{R_g + R}{R} N$$

where N is the ratio of the total resistance R to the resistance between the tap and A. This ratio is independent of the galvanometer resistance, and the shunt may be calibrated in terms of this ratio. It is the constancy of this "relative" multiplying power that gives the name universal to this type of shunt. The multiplying power of the shunt with the tap switch set at unity is $\frac{R_g + R}{R}$. It is therefore important that R should be large compared to R_g for maximum sensitivity.

When used in connection with the ballistic galvanometer method of comparing capacities, the constant resistance across the galvanometer terminals is a distinct advantage, since it insures constant damping for all settings of the shunt.

This galvanometer shunt is of the Ayrton-Mather universal type having a total resistance of 1,000 ohms. Taps are provided for ratios of 0.001, 0.01, 0.1, and 1.0. A short-circuit point is also provided to give complete protection to the galvanometer. A dial switch is used to adjust the shunt for suitable control.

BRIDGES

The simplicity and accuracy of bridge methods of measurement have led to their general adoption for the determination of resistance, inductance, and capacity. While there are a number of standard bridge circuits, differing in detail, all depend on balancing the voltage drops through the several arms of an impedance network so that no current flows through a null (zero) indicator connected across the network.

Bridge measurements may be divided into two classes, depending on whether direct or alternating current is used as a source. Direct current is used only in resistance measurements. A storage battery or other convenient source of direct current is required to supply the bridge. The voltage of the source is determined by the resistance in the circuit and by the safe wattage dissipation of the bridge arms. The sensitivity of the bridge increases with the applied voltage. A direct-current galvanometer, protected by a suitable shunt, is used as a null indicator.

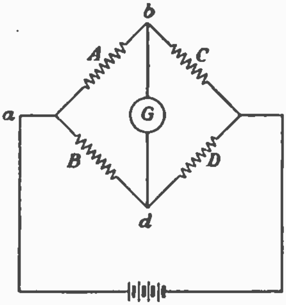


Fig. 7.—Simple bridge circuit.

Direct-current Measurements.—The simplest form of bridge circuit, the Wheatstone, consists of four resistances A, B, C, and D, the currents in these resistances being designated by corresponding subscripts (Fig. 7). When no current flows through the null indicator G, the voltages a-b and a-d are equal, as are b-c and d-c; that is,

$$I_A A = I_B B$$

and

$$I_A C = I_B D,$$

or

$$AD = BC.$$

If three of the resistances are known, the fourth is readily calculated.

Alternating-current Measurements.—A change in current is required for the measurement of inductance and capacitance. Modern practice has abandoned various forms of interrupters in favor of a steady source of alternating current which should be practically sinusoidal. For this purpose a microphone hummer is suitable if measurements are made at a single frequency, or a vacuum-tube oscillator if measurements are to be made at a number of frequencies. The following instruments, described elsewhere, will be found suitable for use as sources for bridge measurements: audio-frequency oscillator (microphone hummer); beat-frequency oscillator (15 to 9,000 cycles); low-frequency oscillator (65 to 70,000 cycles).

The impedance network for alternating-current measurements is subject to a variety of modifications of the simple bridge circuit, depending on the particular requirements of the problem. A number of such bridges are described in the following pages.

If measurements are made at audio frequencies the most sensitive form of null indicator is the telephone. The impedance of the telephone should approximately equal the impedance of the bridge for maximum sensitivity. Where telephones of the proper impedance are not available, an impedance-adjusting transformer may be used to adapt the bridge impedance to that of the telephones. A suitable telephone head set is the Western Electric type 1002-C.

The sensitivity of the bridge will be increased by the use of an amplifier between the bridge and the telephones. This is particularly recommended in factory testing where there is considerable noise and where speed is a factor. When using a source such as the audio oscillator, described later, a filter may be used between the bridge and the telephones.

If bridge measurements are to be made at commercial frequencies, the telephone is not a satisfactory null indicator, owing to the comparative insensitivity of both the telephone and the ear at such frequencies. For this work a "vibration" galvanometer is recommended.

When telephones and an audio-frequency source are used, trouble may be encountered in balancing the bridge, due to a charging current flowing in the telephones in consequence of a difference in potential between the observer and the telephones. This trouble may readily be overcome by the use of a transformer with a shield between its primary and secondary windings. Where a transformer is not available, the *Wagner earth connection* shown in Fig. 8 may be used to bring the telephones to the ground potential.

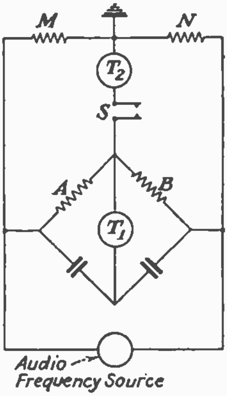


FIG. 8.—Wagner earth connection.

The extra circuit required for the Wagner earth connection consists of two resistances M and N which may be the so-called "decade" boxes of about the same total resistance as the bridge arms, an additional telephone set, and a switch. The junction of M and N is grounded. With the switch S open, the bridge is balanced as closely as possible in the usual manner. The switch is then closed and the secondary bridge $ABMN$ is balanced, using the telephones T_2 as a null indicator. All adjustments are made on M and N so as not to disturb the setting of the main bridge. With the secondary bridge balanced, the telephones T_1 are at earth potential, and the final balance on the main bridge may be obtained with the switch open.

Numerous modifications of the fundamental bridge circuit are required to meet specific requirements. Several types of bridges which meet the requirements of communication will be described.

Ratio-arm Box.—The simplest type of bridge is made up from a set of ratio arms together with a suitable standard, the unknown resistance forming the fourth arm of the bridge. The use of ratio arms instead of a permanent bridge set-up provides for the greatest possible utility of equipment in the small laboratory.

One type of ratio-arm box consists of two similar arms, each having 1,000 ohms total resistance, tapped at 1, 3, 10, 30, 100, and 300 ohms. The resistances are of the Ayrton-Perry type. This type of resistance is practically free from inductance and capacity effects at audio frequency. The current-carrying capacity is 50 milliamperes and the adjustment is accurate to within 0.1 per cent. The dial switches are of the multi-leaf type, to obtain low and constant resistance.

Decade Bridge.—This bridge is adapted to general bridge measurements of resistance, inductance, and capacity which are outside the field of special-purpose bridges. The bridge circuit shown in Fig. 9 consists of three resistance arms, of the non-inductive type.

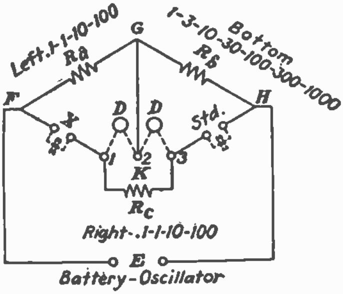


Fig. 9.—Decade bridge circuit.

Resistance Measurements.—In making measurements of resistances with the decade bridge, the null indicator is connected between points 1 and 2, and the "std" posts connected together. R_c is used as the *resistance standard* in ohms. The unknown resistance is connected at X and the bridge is then balanced. The solution of the network gives for the value of unknown resistance R_x (ohms), the following:

$$R_x = \frac{R_a R_c}{R_b}$$

where R_a is the resistance in ohms of the first arm, R_b is the resistance in ohms of the second arm, and R_c is the standard resistance in ohms in the third arm.

This method is suitable for the measurements of either direct- or alternating-current resistance, a suitable source of current being connected at E. The accuracy of the bridge for resistance measurements is to within 0.2 per cent, if proper care is exercised by the operator.

Inductance Measurements.—In inductance and capacity measurements, the bridge must be balanced for resistance as well as for reactance. The third resistance arm R_c is used to obtain a resistance balance of the bridge. Since R_c must be connected in the arm having the lower resistance (either standard R_s or unknown R_x) and this is not generally known in advance, it is desirable to provide the bridge with a switch so arranged that the null indicator may be readily transferred from points 1 to 3, placing R_c in either arm. The bridge is then balanced, the condition of zero current in the null indicator requiring simultaneous balance of both resistance and inductance. The solution of the network gives the value in henrys of the unknown inductance L_x in the following equation, where L_s is the standard inductance in henrys:

$$L_x = \frac{R_a L_s}{R_b}.$$

The resistance balance gives the following relation when R_c is connected in series with the standard resistance R_s

$$R_x = \frac{R_a(R_s + R_c)}{R_b},$$

But when R_c is connected in the unknown arm

$$R_x = \frac{R_a R_s}{R_b} - R_c,$$

The accuracy of inductance measurements is within 0.2 per cent of the actual value for air-core inductances. Owing to the change of inductance with saturation (page 64) it is impossible to obtain an exact balance with iron-core inductances, since the degree of saturation changes with every adjustment. The error is consequently greater in this type of measurement. The range for inductance measurements is from about 20 microhenrys to several henrys.

An inductance may be compared with a capacity C by connecting the capacity across the resistance R_a. The unknown inductance L_x is then connected at the "std" posts, the null indicator to points 2 and 3, and the X posts are connected together. The solution of this network gives the equation

$$L_x = R_b \times R_c \times C.$$

Capacity Measurements.—This type of decade bridge is suitable for the measurement of small as well as comparatively large capacities, where extensive shielding is not required. For capacity measurements the bridge is set up with a switch for transferring R_c from the standard to the unknown arm as before. The unknown condenser C_x is connected at X and a standard capacity C_s at "std." When there is no current flowing through the null indicator the bridge is balanced for both capacity and resistance. The capacity balance gives the equation

$$C_x = \frac{R_b C_s}{R_a} \text{ (farads)}$$

Since the bridge is in balance for resistance as well as capacity the resistance equation follows as before; thus:
$R_x = R_a(R_s + R_c)/R_b$, when R_c is in the standard arm; or when R_c is in the unknown arm

$$R_x = \frac{R_a R_s}{R_b} - R_c,$$

The accuracy of this bridge for capacity measurements is within 0.2 per cent of the actual. The range is from 0.01 microfarad to several microfarads.

Description.—Elements of the bridge circuit are mounted in a cabinet with a hard-rubber panel, the resistance units being of the Ayrton-Perry non-reactive type. The current-carrying capacity of the 0.1-ohm units is 1 ampere; of the 1-ohm units, 250 milliamperes; of the 10-ohm units, 100 milliamperes; and of the 100- to 1,000-ohm units, 50 milliamperes. The cabinet is copper lined to provide shielding.

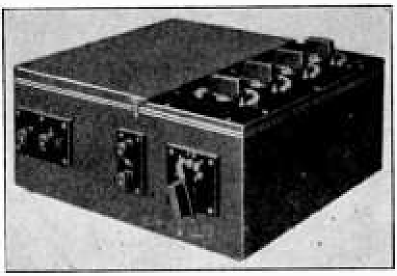


FIG. 10.—Capacity bridge.

Capacity Bridge.—For precise measurements of small capacities, or accurate determination of dielectric losses, the ordinary type of bridge is unsatisfactory, since the stray capacities in the circuit are of the same order of magnitude as the capacity to be measured. A bridge for the measurement of small capacities requires complete shielding of all its elements.

The bridge, illustrated in Fig. 10, has been designed for the measurement of small capacities. The elementary circuit is similar to that of the decade bridge described on page 603. It consists of three resistances: two ratio arms and a power-factor resistance. The cabinet containing the bridge is copper lined and divided into several shielded compartments. In order to isolate the bridge from stray capacity effects, transformers with grounded shields between the primary and secondary windings are used both at the input to the bridge and at the null detector.

Since this bridge is designed for the measurement of small capacities where the substitution method is used with equal total capacities in the bridge arms, the so-called "ratio" arms have equal resistances. The use of equal arms without switches makes possible a very accurate adjustment of the resistances. Since the arms are identical, any slight changes of power factor with changes of frequency will balance and produce no resultant error. The third resistance arm may be connected in series with either capacity arm as required to balance the bridge. A switch F is provided for convenience in making the change.

It is very often desirable to calibrate a *vernier condenser* (page 40) having a total capacity of 3 or 4 micromicrofarads. For this work the bridge is first balanced, using capacities of about 1,000 micromicrofarads. If one of the resistance ratio arms is increased 1 part in 1,000, that is, from 5,000 to 5,005 ohms, the ratio of the capacities is changed accordingly, by the amount of 1 micromicrofarad. In order that the ratio arms may be changed in this manner, resistance units are supplied with the bridge. These units may be added to either ratio arm. Although the equipment of each bridge includes three of these resistance units so as to give ratios of unbalancing of 0.001, 0.01, and 0.1, they can be furnished to give any ratio desired.

Since the impedance of small capacities at 1,000 cycles is high—that of 1,000 micromicrofarads being 160,000 ohms—it is desirable that a high-impedance detector be used to denote the balance point of the bridge. As the impedance at 1,000 cycles per second of a pair of sensitive telephone receivers is only about 20,000 ohms, it is evident that this is too low. For this reason an impedance-adjusting transformer is used, this transformer being designed to work between an impedance of 200,000 and one of 20,000 ohms. This arrangement provides the correct impedance in both the bridge and the telephone circuits and makes it possible to detect a very small difference in potential, such as that caused by the unbalancing of the condenser arms to the extent of 0.01 micromicrofarad.

In order to prevent errors due to capacity between the observer and the telephones a grounded shield is used between the primary and secondary windings of this transformer. The junction of the two resistance arms is also grounded. An accurately calibrated decade resistance arm provided for power-factor measurements is valuable for measuring dielectric losses.

Uses.—This capacity bridge is adapted to the measurement of capacities up to about 0.5 microfarad with great accuracy and will indicate an unbalance of 0.01 micromicrofarad. When greater accuracy is required, an accurately calibrated condenser of small capacity should be connected across the precision condenser. As most errors come from stray fields and moving leads, a permanent and substantial set-up is necessary for accurate work.

This bridge is also suited to the determination of the power factor of dielectrics. The resistance adjustment may be made to 1 ohm, although the impedances measured are often in the neighborhood of 200,000 ohms. This value of 1 ohm, however, may be a considerable percentage of the change of resistance, and for this reason from 5 to 10 per cent is a conservative figure for the accuracy of resistance measurements.

The testing of small samples of cable or the study of temperature changes in dielectrics is made possible because of the sensitivity of this instrument. An example of this latter use is the testing of samples of hard rubber. If a sample, which is three inches square and one-half inch thick, is placed between two metal plates, at 54°F., it has a capacity of 11 micromicrofarads and a phase angle (page 74) of 48 minutes. When the sample is heated to 100°F., the capacity increases to 12 micromicrofarads and the phase angle to 1 degree and 55 minutes (angular measure).

For the usual capacity and power-factor measurements, the *audio-frequency oscillator* (page 621) is suitable. Where measurements are to be made over a wide range of frequencies, the *low-frequency oscillator* (page 623) is preferable. This instrument offers a range extending from the upper commercial frequencies, through the audio and carrier frequencies, and into the radio frequencies.

The bridge circuit is thoroughly shielded in a cabinet, and the resistance box is in a separate shielded compartment.

Portable Capacity Bridge.—Certain classes of capacity measurements where accurate determination of power factor is not important can be obtained with a simpler type of bridge than the capacity bridge. In the design of delicately adjusted radio receivers it is necessary to give considerable attention to the interelectrode (grid-filament, plate-filament, and grid-plate) capacities of vacuum tubes. For this reason, the measurement of these capacities is of particular interest to the manufacturers of vacuum tubes and radio receiving sets. The very small capacities involved, about 5 micromicrofarads, render the usual type of bridge measurement unsatisfactory for this use. The portable capacity bridge is particularly designed for this type of work. A conventional type of bridge circuit shown in Fig. 11

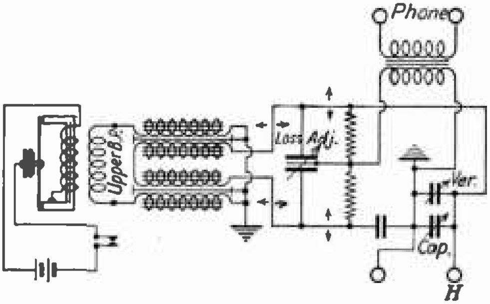


FIG. 11.—Portable capacity bridge.

is used. It consists of two resistance and two capacity arms. It is actuated by a self-contained *microphone buzzer* (page 38) supplied from a 4.5-volt dry battery. The output from the buzzer, at a frequency of about 800 cycles per second, passes through a transformer to the bridge circuit. The transformer has a shield between its primary and secondary windings and is, in addition, wound in two sections so as to reduce the capacity effects. The telephone receivers are supplied from another transformer, the primary winding being connected across the bridge and the secondary winding being brought out to the lower terminals as shown. There are three adjustments on the bridge panel, marked "loss adj.," "zero adj.," and "capacity." These names correspond to the condensers labeled "loss adj.," "ver.," and "cap.," respectively, in the diagram. The loss-adjusting condenser, shunted across the resistance arms of the bridge, compensates for the variation of the power factor of the unknown capacity. This adjustment is not calibrated, as it is not intended for a means of measuring power factor. It is intended merely to compensate for the loss of current in the condenser arm which might otherwise render a balance of the bridge impossible. It is generally necessary to make this adjustment only when rather high loss is associated with the capacity to be tested. The zero-adjusting condenser is included across the balancing condenser and the unknown capacity, in order to balance stray capacities of leads and sockets. Since the ratio arms and the standard condenser are fixed, the total capacity in the fourth arm of the bridge (including the unknown capacity with its leads), the zero-adjusting condenser, and the measuring condenser must be constant for a balance. In making measurements the leads, sockets, or other associated apparatus are connected to the terminals, and the capacity of the zero-adjusting condenser is reduced sufficiently to balance the bridge with the "cap." condenser set at its maximum capacity. The dial on this condenser is set, for maximum capacity, to read 180 degrees out of phase with the "cap." condenser; that is, the dial is set at zero.

The unknown capacity is then connected, and the condenser marked "cap." is rotated (reducing its capacity) until the bridge is again balanced. The loss-adjusting condenser is adjusted as required in each case. The capacity of the unknown condenser is obtained by multiplying the reading of the measuring condenser by a factor appearing on the dial.

A very convenient accessory in making measurements on the *interelectrode capacities* of vacuum tubes is a socket which is equipped with three plugs so spaced as to fit the binding posts of the bridge and connected to grid, plate, and filament. In measuring vacuum-tube capacities, this socket is plugged in and the bridge balanced for zero. The vacuum tube is then placed in the socket and its capacities are measured directly. Readings can be made to about ½ division on a 100-division scale with telephones, or somewhat more accurately if an amplifier and a suitable voltmeter for use with vacuum tubes are used.

This type of bridge is made in two models. One of these has a range extending to 30 micromicrofarads and is designed for the measurement of small capacities. Another has a range extending to 600 micromicrofarads and is particularly useful in matching condenser units for use in single-control set-ups. The accuracy of the instrument makes it very useful for this purpose, as it will indicate differences of less than 1 micromicrofarad between such units. The use of this device for condenser matching is very simple in comparison with quartz-controlled oscillators (page 616) and other instruments.

A useful adjunct to the capacity bridge is a two-stage amplifier. A vacuum-tube voltmeter can then be used to indicate the "balance," and somewhat greater accuracy is possible than can be attained with telephone receivers. Another advantage of the voltmeter is that it permits tolerance limits to be marked on the dial of the voltmeter, a useful practice in factory-inspection work.

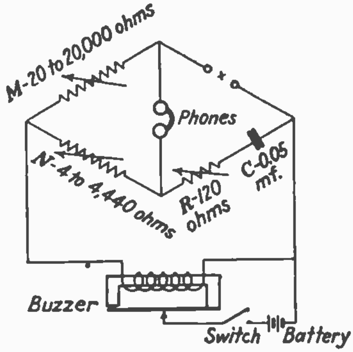


FIG. 12.—Capacity meter.

Capacity Meter.—For test work a direct-reading bridge of fair accuracy is a great convenience. The capacity meter is a direct-reading bridge adapted to general laboratory and commercial uses in obtaining capacity measurements ranging from 0.001 to 10 microfarads with an accuracy to within 0.5 per cent. Its simplicity of operation makes it useful in factory-inspection work for measuring or comparing capacity values.

The instrument consists of a capacity bridge with variable resistances in the ratio arms, and capacities in the unknown and standard arms. A schematic diagram of the whole assembly is shown in Fig. 12. The input is from a specially designed *microphone buzzer* (page 38) supplied with current from a 4.5-volt dry battery contained in the case. Provision is also made for the use of a suitable external battery, when more convenient.

The resistances *M* and *N* shown in the figure are wound on thin bakelite strips to reduce distributed capacity (page 86) and inductance. A rheostat of 120 ohms resistance is marked *R*.

The standard condenser *C* is built up of copper plates interspaced with sheet mica for the dielectric. The copper plates and sheet mica are assembled under pressure and impregnated with paraffin. The condenser is firmly clamped in a heavy brass frame.

Operation.—Before the capacity meter can be operated, the battery must be connected to the proper leads as marked, so that the battery terminals make contact with the metal strips on the ends of the buzzer leads.

The unknown capacity to be measured is connected to the two clips at *X*. The three dials marked "microfarads," "tenths," "hundredths," and the one marked "multiply by" should be set approximately at the capacity to be measured, if its approximate value is known. The buzzer switch is then turned and the dials set, beginning with the dial marked "microfarads" and adjusting the three lower dials in turn until the minimum sound is heard in the telephone receivers. After this has been done, the dial marked "power factor" is adjusted until the sound heard in the receivers is still further reduced, readjusting the capacity dials, if necessary.

The capacity is read on the three lower dials, beginning at the left. The reading of the dials times the multiplier is the capacity in microfarads. The power factor in per cent is read from the power-factor dial. For greatest accuracy the multiplier dial should be set as follows: For capacities from 1.0 to 10.0 microfarads, multiply by 1; from 0.1 to 1.0 microfarad multiply by 0.1; from 0.01 to 0.1 microfarad multiply by 0.01; and from 0.001 to 0.01 microfarad multiply by 0.001.

If the meter is to be stored or shipped, the battery should be removed; otherwise the electrolyte in the battery may seep out and damage the meter.

Uses.—The capacity meter is adapted for general laboratory and commercial use in measuring capacities. It is especially suitable for an inspection instrument to test condensers. When condensers supposedly of the same capacity are being measured it is necessary only to vary the setting of one of the capacity switches within the limits of the tolerance allowed. The power-factor dial offers a ready means of detecting condensers with high losses.

Vacuum-tube Bridge.—A bridge intended for the measurement of vacuum-tube constants does not have the conventional type of impedance network. The type of bridge for this use depends on the balancing of the amplified signal voltage in the plate circuit by an opposing voltage. A null point is indicated by telephone receivers, and the balancing method is similar to that of the standard bridge circuits.

The usual tube-testing devices consist of a series of meters and rheostats, with or without enclosed batteries, and are designed to check *filament power* and to measure certain so-called *static characteristics*, such as the joint emission to the grid and the plate of a vacuum tube or the steady plate current passing under any particular conditions of filament current or voltage, plate voltage, and direct-current grid-bias voltage. From characteristic curves obtained in this manner, the static amplification constant (page 33) and other data of value may be determined. Under certain conditions, however, the so-called *dynamic characteristics* of a vacuum tube are of more fundamental importance. To obtain such data it is necessary to apply an alternating-current voltage to the grid of the tube and to make use of certain "balanced-bridge" measurements. This bridge provides for the measurement of filament emission (page 273) and certain static characteristics. When used as a direct-reading bridge, it gives the three *fundamental dynamic characteristics* of a tube, namely: the amplification constant, the plate resistance, and the mutual conductance (page 302). To measure these dynamic characteristics the bridge must be supplied with current from an audio-frequency source of voltage, preferably sinusoidal (page 72) in character. Then the bridge is balanced for a null setting in the telephone head set in the manner of the ordinary impedance bridge (page 601).

All changes in the bridge to obtain the different circuits used are made by means of throw switches. The balancing adjustments are on a decade-type dial. The vacuum tube to be measured is inserted in a detachable socket, mounted externally on the panel of the bridge. A 10-volt meter is provided for measuring the voltage directly across the filament terminals of the tube and, by means of a multiplier, the plate battery voltage. A 5-milliampere meter is used for measuring the plate current. This is equipped with a shunt extending its range to 25 milliamperes. Provision is made for inserting any desired grid voltage in the grid circuit. Thus, by varying the filament voltage, plate voltage, and grid bias (all by means external to the bridge), the data for the customary static-characteristic curves may be read conveniently on the bridge meters.

The bridge is equipped with three telephone keys and two four-dial resistance arms the proper manipulation of which enables the operator to determine quickly the three dynamic characteristics for any particular specifications of filament voltage, plate voltage, and grid bias. Thus, in a similar manner, the dynamic-characteristic curves of any particular tube may be obtained easily and rapidly, and research or routine inspection work is greatly facilitated. The resistances are of the non-inductive, low distributed-capacity type, and the bridge is well shielded. The transformer in the input circuit has a shield between its primary and secondary windings. This type of vacuum-tube bridge is designed to measure vacuum tubes intended for either alternating or direct current. The precision of results obtained from the bridge may be improved by the substitution of a resistance of 100 ohms for the telephone receivers and the use of an amplifier for balancing. This reduces the impedance effect of the telephone receivers and the direct-current resistance drop through the telephones so that they are equivalent to that of the 100-ohm resistance. The units constituting the bridge may be arranged in any of the circuits described below by manipulation of the key switches.

The circuit of Fig. 13, obtained by moving the key marked "amplification constant," provides for the direct measurement of the voltage-amplification constant u (page 33) of the vacuum tube being tested. The resistance R_a in the four-dial arm A of the bridge is adjusted until the voltage drop through it due to the current balances the voltage E_g multiplied by the amplification constant u, resulting in the *plate circuit* when the voltage E_g is impressed on the grid. Minimum sound in the telephone receivers indicates the balance point. The voltage E_g results from the flow of current through the 10-ohm *resistance in series* with R_a.

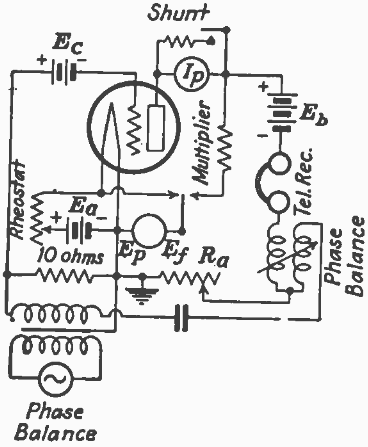


FIG. 13.—Vacuum-tube bridge circuit.

In order that there may be no flow of current in the telephone receivers, the voltage in the plate circuit E_p must equal the voltage drop in the resistance R_a, so that

$$E_p = uE_g = R_a \times I_t$$

where I_t is the current in amperes, and the voltage E_g is opposite in phase to $R_a \times I_t$; but

$$E_g = 10 \times I_t \text{ (ohms} \times \text{current), and } u \times 10 \times I_t = R_a \times I_t;$$

therefore,

$$u = R_a \div 10.$$

The resistance R_a is numerically equal to ten times the amplification constant u, and, consequently, this instrument is calibrated directly in terms of the amplification constant.

A variometer (page 96), by means of which the *component* of the voltage introduced by the tube capacity may be balanced out, greatly facilitates balancing. The amplification constant may be read to two decimal places. The resistance of the instrument provides for the measurement of amplification constants up to 100.

To measure the plate resistance of a vacuum tube the bridge is set for the circuit of Fig. 14.

The value of the amplification constant just determined is set on the arm A, and the bridge is balanced by adjusting the four-dial arm B. It will be noted that R_a has been switched to the grid circuit and has been replaced by a 1,000-ohm resistance and also that a resistance R_b has been added in the grid circuit. The condition of balance requires that the voltage drops across the 1,000-ohm plate resistance and across the resistance R_a shall be equal. When balance is obtained,

$$R_a \times I_t = 1{,}000 I_p,$$
$$I_p = uE_g \div (R_p + 1{,}000),$$
$$E_g = I_t(R_b + 10).$$

where I_p is the plate current and R_p is the plate resistance of the tube.

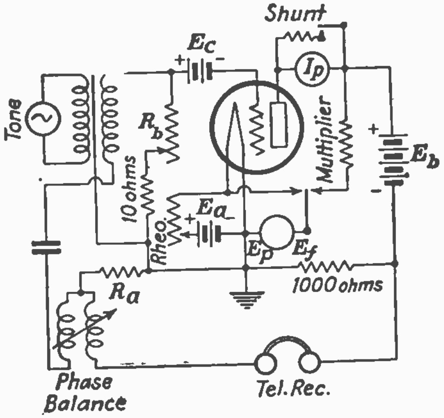


Fig. 14.—Circuit for measuring plate resistance.

Then substituting and dividing:

$$R_a = 1{,}000(R_b + 10)u \div (R_p + 1{,}000),$$

but

$$u = R_a \div 10,$$

and, therefore,

$$100(R_b + 10) \div (R_p + 1{,}000) = 1,$$

or

$$R_p = 100R_b.$$

The resistance R_b is calibrated to read directly in terms of plate resistance in ohms.

As before, use is made of the variometer (page 96) for balancing the component of the voltage introduced by the tube capacity in an accurate adjustment of the bridge. Measurement may be made of plate resistances up to 100,000 ohms in 10-ohm steps.

For the measurement of *mutual conductance*, the bridge circuit is transformed to that of Fig. 15 (the 1,000-ohm plate resistance of Fig. 14 is reduced to 100 and the grid resistance becomes 1,000). Balance is obtained by adjusting the resistance R_a and the variometer. When the bridge is balanced,

$$R_a \times I_t = 100I_p = 100uE_g \div (R_p + 100),$$

$$E_g = 1{,}000I_t,$$

$$R_a = 100{,}000u \div R_p \text{ (when } R_p \text{ is large compared to 100),}$$

$$u = R_aR_p \div 100{,}000.$$

$$\text{Mutual conductance} = u \div R_p = R_a \div 100{,}000.$$

Since the arm A is marked with one-tenth of its true resistance, the mutual conductance in mhos = reading of arm $A \times 10^{-4}$. Values up to 0.01 mho may be read in steps of 1 micromho.

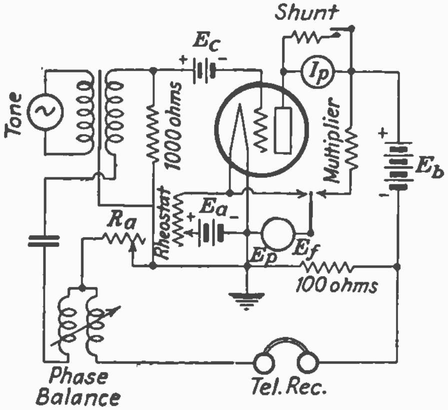


FIG. 15.—Circuit for measuring mutual conductance.

It should be noted that some error is involved in the assumption that R_p is large, compared to 100. This error may become quite great when measuring vacuum tubes of low plate resistance. The percentage error is $100 \div R_p$. The bridge reading is less than the true value of mutual conductance.

Figure 16 is the circuit for obtaining the static characteristics. The voltmeter shown in the figure is normally connected across the terminals of the filament. Depressing a switch connects it across the plate battery and introduces a multiplier. The maximum reading is 200 volts. The ammeter is provided with a shunt, having a maximum scale reading of either 5 or 25 milliamperes.

Mutual-conductance Meter.—Of the three fundamental dynamic constants of the three-element vacuum tube (plate impedance, amplification constant, and mutual conductance), the mutual conductance gives the most positive indication of the tube behavior, since it involves the ratio of the other two constants (page 303). While the mutual conductance is not a complete indication of the comparative merit of tubes of different types, it is a positive indication among tubes of the same type. If a tube fails to meet the standard specification of its type, either through faulty filament emission (page 273) or through an incorrect spacing of its elements, the mutual conductance will always be lowered. Since the mutual conductance is very easily measured, its value is the one most suited for use as an acceptance standard for purchasers and for use in factory, store, or laboratory for rapid checking of tubes against a standard value. This device should not be confused with the vacuum-tube bridge described on page 610, which is a laboratory instrument designed to give accurate measurement of the three dynamic constants of vacuum tubes.

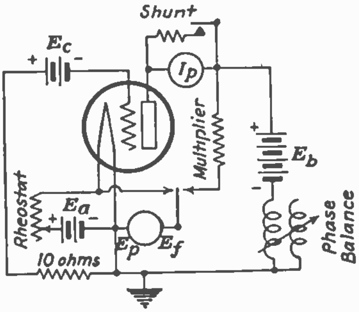


Fig. 16.—Circuit for obtaining static characteristics.

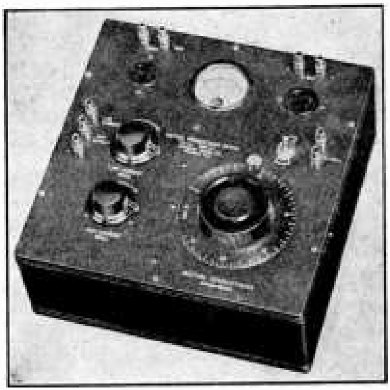


Fig. 17.—Mutual conductance meter.

The mutual-conductance meter shown in Fig. 17 is a null-point bridge instrument excited by a self-contained microphone buzzer (page 38) and battery. A standard UX-type of socket is provided as well as a socket for the five-prong separately heated tubes. Any desired plate voltage may be applied to the tube as well as any desired value of grid-biasing voltage. The instrument is equipped with a voltmeter for indicating the voltage across the filament. By the use of one or the other of the rheostats mounted on the panel it is possible to adjust the filament voltage to the correct value for any standard vacuum tube. Telephone receivers are used as a null indicator. If the bridge is operated in a noisy environment, an "external" stage of amplification (page 355) will be found desirable.

Values of mutual conductance having a precision of within 5 per cent are quickly obtained by the manipulation of a single dial to give silence in the telephone receivers. This dial is calibrated to read mutual conductance directly in micromhos from 0 to 2,500 micromhos. The dial spacing is not uniform but is so graduated as to maintain an approximately equal percentage precision of reading over the entire scale.

FREQUENCY STANDARDS

Frequency standards may be considered in two classes: (1) fundamental laboratory calibration standards for which *piezo-electric oscillators* are now used and (2) *secondary standards* of the *resonant-circuit type.* The former have been supplemented by *magnetostriction oscillators* for use at the upper audio and lower radio frequencies.

Piezo-electric Oscillator.—The piezo-electric properties (page 125) of crystalline quartz make it particularly well adapted for use as a frequency standard. Plates of this material, when properly prepared and placed in the circuit shown in Fig. 18, will hold the frequency within very narrow limits. The oscillating frequency is nearly independent of the electrical constants of the circuit. The frequency is principally dependent on the physical dimensions of the quartz plate which may be ground very closely to a specification.

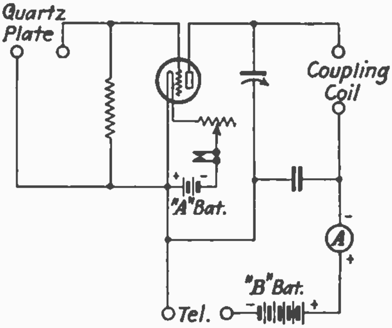


FIG. 18.—Piezo-electric oscillator.

The oscillator circuit as shown in Fig. 18 has a UX-199 tube which is used as the oscillator. The meter, mounted on the front of the panel, indicates when the circuit is oscillating. The circuit between the plugs marked "tel" must be closed. The tuned circuit must be adjusted approximately to the frequency of the quartz plate, or the system will not oscillate. The system will oscillate only at the frequency determined by the quartz plate and not at the frequency of the tuned circuit. When the plate has several frequencies of oscillation, the tuning of the vacuum-tube circuit determines at which of the frequencies the plate will oscillate. The coil is mounted externally and is suitable for coupling to other apparatus.

Limits are imposed by physical conditions on the fundamental frequencies for which it is possible to provide quartz plates. The lower frequencies require very large plates, while for the higher frequencies the plates are very thin, difficult to handle, and fragile. The practical limits at present are about 100 and 2,000 kilocycles. Lower and higher frequencies are readily obtained from these fundamentals, since the oscillator output is rich in harmonics. Reasonable care should be taken in handling the quartz plates, as they will fracture if subjected to too great a mechanical shock.

Where it is desired to use the weaker harmonics of a vacuum tube, one or two oscillating vacuum-tube circuits may be coupled to the oscillator output and adjusted to *zero beats* (page 126). If different harmonics are used for each oscillator, harmonics as high as the three hundredth may be utilized. Lower frequencies than the fundamental may also be obtained by means of an auxiliary vacuum tube. The auxiliary tube is adjusted to the lower frequency by tuning it for zero beat between its harmonic of the desired order and the frequency of the quartz-controlled oscillator. By means of this device, a single quartz plate may be used to obtain a great number of frequencies.

This device is intended primarily for a frequency standard. The frequency is determined almost entirely by the constants of the quartz plate and holder and therefore is maintained practically constant, once the physical dimensions are fixed.

Since the plate is mounted on the front of the panel with a plug-in arrangement, plates may be readily exchanged in order to extend the frequency range.

For use in broadcasting stations there has been developed an instrument which incorporates an oscillator, similar to the piezo-electric oscillator, and a two-stage amplifier. The addition of the amplifier makes this unit suitable for *monitoring* (page 509) in the operating room. When this oscillator is placed in the operating room and connected to a loud-speaker, the beat note becomes plainly audible when the station frequency differs from that of the standard.

Four classes of quartz plates are provided. Where a wave-meter standard is desired, and the exact points of calibration are immaterial, a plate can be provided without special grinding. Plates of this class are provided with the usual mounting, and the fundamental frequency, measured to within 0.1 per cent, is engraved on the cover. They can usually be supplied to within 25 per cent of any specified frequency within the above range. By making use of harmonics, one plate may be used for a number of calibration points. Where a closer approximation to a specified frequency is desired, quartz plates may be provided to within 5 per cent of the required frequency. Where the requirements are still more rigid, plates may be ground to within 0.1 per cent of the specified frequency. The calibration on all plates is to within 0.1 per cent. This calibration is not guaranteed, however, if the plate is used to control a greater power than is obtained with a type UX-201A tube with normal plate voltage.

A fourth class of quartz plates is intended particularly for broadcasting stations, which are required by federal regulations to maintain their frequencies within 500 cycles of that assigned. The plates are within 500 cycles of the specified frequency, when used in the oscillator with which they are supplied. These plates are intended for use only as standards. Their high degree of accuracy will not be maintained if they are used in power oscillators.

Magnetostriction Oscillators.—Recent laboratory researches have made possible the development of *controlled oscillators* for use at low frequencies, analogous to the piezo-electric oscillators which have been in use at radio frequencies for some time. These standards are the result of recent investigations of the phenomena of *magnetostriction* by Prof. G. W. Pierce, of Harvard University.

Just as properly prepared quartz crystals expand and contract under the influence of a varying electrostatic field, due to their piezo-electric properties, so also do rods of certain materials expand and contract under the action of varying magnetic fields by virtue of their magnetostrictive properties. Pure iron and steel, although strongly magnetic, show only very feeble magnetostrictive effects. On the other hand, pure nickel, which is only slightly magnetic, gives a strong magnetostrictive response. Alloys of nickel and iron in certain proportions are active, especially those having about 36 per cent nickel and 64 per cent iron, which is the approximate composition of *invar* and *stoic metals*. Alloys of chromium, nickel, and iron, of which nichrome metal is an example, and monel metal which is an alloy of nickel and copper, are among the most active materials which are easily obtained. Alloys of cobalt and iron are also strongly magnetostrictive. All of these metals are improved in this respect by annealing.

If a rod of some magnetostrictive material is surrounded by a coil through which an alternating current is passing, the rod is magnetized at the peak of each half cycle and is thereby made to expand along its length, regardless of the polarity of the magnetization. Thus, the rod will expand and contract; that is, it will vibrate longitudinally, with a frequency which is twice that of the alternating current in the coil.

If, on the other hand, the rod is at the same time subjected also to a steady magnetizing force greater than the peaks of the alternating force, then the net magnetization will rise and fall with the alternating-current wave but will never reverse its polarity. As a result, the rod will now vibrate with the same frequency as the alternating current. If this frequency falls within the range of audition, these forced vibrations of the rod imparted to the surrounding air will, of course, be audible.

Instead of forcing the rod to vibrate in step with any impressed frequency, the rod can, by the use of the circuit shown in full lines in Fig. 19, be made to control the oscillations of the "hi-mu"[1] vacuum tube T_1 to a single frequency (and its harmonics) corresponding to the natural frequency of vibration of the rod, which is inversely proportional to its length. In this manner a controlled or standardized frequency is produced, closely analogous to the control of a vacuum-tube oscillator by means of a piezoelectric crystal.

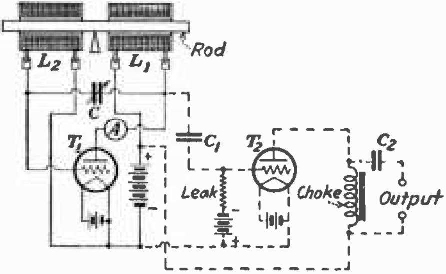


Fig. 19.—Circuit for magnetostriction oscillator.

As shown in the figure, two equal coils L_1 and L_2 are inserted in the plate and grid circuits of a vacuum tube and C is a variable condenser which is used to resonate the total reactance of these coils to the natural frequency of the rod. The coils surround but do not touch the rod, which is balanced or clamped at its center point. The direction of winding of the coils is such that the filament emission currents (page 273) flowing in the plate and the grid circuits would magnetize the rod with the same polarity. This is exactly the opposite of the condition existing in the familiar *Hartley oscillator* circuit (page 390); that is, the magnetostriction oscillator with the rod removed is degenerative rather than regenerative in character.

The direct-current milliammeter A gives an indication of resonant tuning of the circuit as the capacity of the condenser C is varied. The dotted circuits show how, by the use of a second tube T_2, a stage of amplification

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[1] The term *hi-mu* when used to describe a characteristic of a vacuum tube means one with a high ("*hi*") amplification factor, u or μ (*mu*).

may be added to the oscillator. The *coupling condenser* C_1 has a capacity of about 0.1 microfarad. The choke coil and the 2-microfarad condenser C_2 in the plate circuit of the amplifying tube constitute the *speaker filter* for removing a direct-current polarization from the output terminals. The grid leak has a resistance of about 50,000 ohms.

When such a circuit is tuned by means of the variable condenser C until resonance with the natural frequency of the rod is approached, the reading of the milliammeter A rises sharply to a maximum as the rod goes into strong vibration. When this optimum point is reached the capacity of the condenser may be increased or decreased by a considerable amount, while the frequency of the oscillator remains unchanged; that is, the circuit is stabilized at the natural frequency of the rod.

Various types of vacuum tubes may be used at T_1, the plate voltage may be changed from 67 to 135 volts, or the filament voltage may vary from practically zero emission to destruction of the filament with a resultant change of less than 1 part in 30,000 in the stabilizing frequency of the circuit. A reasonable control of these variables gives, of course, a much more precise standardization of the frequency.

The relation between the length and natural frequency of a rod is given by the simple equation

$$V = 2LF$$

where F is the frequency in cycles per second, L the length of the rod, and V the velocity of sound in the rod expressed in corresponding units. For a given material, V is a constant essentially independent of L and F, so that a whole series of rods of definite frequencies is easily prepared. Such rods have been made with fundamental frequencies varying over a wide range from a few hundred to 30 kilocycles per second. Harmonics of these frequencies up to several millions are readily detected. Since great difficulty is encountered in obtaining large enough piezo-electric crystals to give fundamental frequencies below 25 kilocycles, the lower range of frequency standardization has been greatly increased by the invention of the *magnetostriction oscillator.* Magnetostriction rods are calibrated with much greater ease than are piezo-electric crystals, since the rods remain continually active and are not subject to the vagaries of crystals.

As the length of the rod is decreased and its frequency increased, greater stabilization is attained by occasionally reducing the inductance of the two exciting coils. This is readily accomplished by having three or four different pairs of coils mounted on jack plugs (page 39) for easy substitution in the oscillatory circuit.

The *Pierce magnetostriction oscillator* incorporates the circuit shown in Fig. 19, which as supplied is mounted in a cabinet without coils, rods, or vacuum tubes. It includes a stage of amplification and has provision for extending the range of the condenser *C*, as well as other control features. It consists of two separate and complete oscillators and amplifiers mounted in a single unit, with provision for varying the capacity coupling between them. One oscillator may be controlled by a rod, while the other takes the form of a variable *Hartley oscillator* to be used in frequency calibration, or both oscillators may be controlled by rods, and definite fixed beats between them obtained. Suitable coils are supplied for any frequency in the range for which rods are furnished. Standard rods are available in the frequency range of 10 to 50 kilocycles. Two classes of rods are provided: (1) approximate rods where no attempt is made to obtain a precise frequency and (2) rods prepared to within 0.1 per cent of a specified frequency. In each case the actual frequency of the rod is accurately determined and specified to within 0.1 per cent.

OSCILLATORS

Oscillators are required in the communication laboratory for bridge and other measurements at a fixed frequency and for the observation of the characteristics and behavior of apparatus over a range of frequencies. For fixed frequencies and for bridge measurements, a simple form of tuning-fork or microphone hummer is satisfactory. Variable-frequency oscillators are generally of the vacuum-tube type. A number of such oscillators for specific purposes and ranges are described in this section. Fixed-frequency oscillators for frequency standards are listed in the section on frequency standards.

Audio-frequency Oscillator.—A multitude of bridge measurements require a source of alternating current of low power of which the frequency must remain constant.

The output of a typical audio-frequency oscillator is about 0.06 watt at 1,000 cycles. External binding posts are so arranged that three output voltages may be obtained. The outputs obtainable with these three different connections are as follows:

Point	Voltage, volts	Current, milliamperes
Low	0.5	100
Medium	1.5	40
High	5.0	12

For some capacity measurements it is desirable to use a high voltage. This increased voltage may be obtained by connecting an inductance and a capacity in series across the high-voltage output terminals of the oscillator. By adjusting this circuit to resonance, voltages as high as 50 or 100 volts may be obtained by connecting output leads across the condenser. This instrument will operate satisfactorily on from 4 to 8 volts. The input current is approximately 0.13 ampere. When operating, the oscillator may be heard at a distance of approximately 25 feet or may be made silent by enclosing it in a sound-proof box. When the oscillator is used in close proximity to the bridge or to other apparatus it will be found advisable to shield the oscillator to prevent the pick-up of stray currents in other circuits.

The circuits of this oscillator are shown in Fig. 20. The closing of the switch places the field-magnetizing coil directly across the battery terminals. Also across the battery is the primary winding of the input transformer which is in series with the microphone button. The resonant circuit consists of the secondary winding of the input transformer, the primary winding of the output transformer, the armature coil, and the condenser. The secondary winding of the output transformer has three taps to permit obtaining three different output voltages.

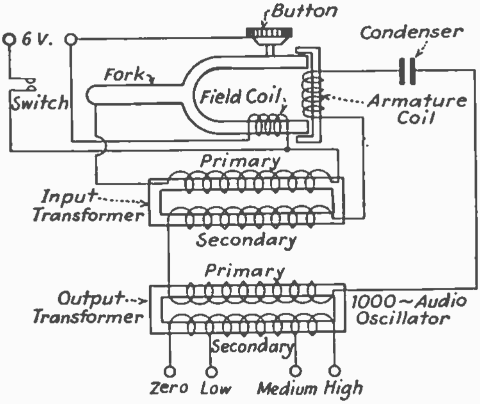


FIG. 20.—Audio-frequency oscillator.

Each transformer core has a small air gap to prevent distortion of the wave form. Since the oscillator is self-starting, it may be located at a point distant from the bridge and operated by a switch placed at the bridge. The tuning fork maintains the frequency within the narrow limits determined by temperature variations. Due to the loading of the tine or prong of the fork the mean frequency is about 990 rather than 1,000 cycles per second.

By using the field-magnetizing coil on one tine or prong of the vibrating fork, instead of relying on its permanent magnetism, the polarity and intensity of the magnetization of the fork with respect to the armature are permanently maintained.

Success or failure in the operation of an audio oscillator or "hummer," depends largely on the qualities of the microphone button. If the button heats so that the oscillator cannot be run indefinitely, if the adjustment of the button is not permanent, or if slight mechanical shocks change its operating characteristics, the oscillator has little commercial value. A distortion of as small an amount as one five-hundredth of an inch from the normal position will destroy the perfect operation of the button. In order that the button may be insensitive to mechanical shocks and yet operate properly at 1,000 cycles per second, use is made of its high inertia effect at the latter frequency. One side of the button is attached to the tuning fork by means of a short, flat spring. The other side, which has a projecting mounting post, is held in position by a specially designed self-centering spring. This combination of the two springs makes the button durable enough to withstand severe mechanical shocks and yet gives it sufficient inertia.

This oscillator does not displace the larger types of oscillators used where several watts of output are required. It is intended rather for general laboratory use where power of good wave form is desired for a single bridge. Since the purity of wave form is dependent on the load on the oscillator, whenever a pure wave form is essential the oscillator should not be overloaded. This oscillator is adapted for the usual alternating-current measurements of inductance and capacity.

Low-frequency Oscillator.—Many forms of electrical and physical research require a source of alternating current of good wave form, variable over a wide range of frequencies. The properties of the oscillating vacuum tube make it inherently adapted for use as such a source.

The low-frequency oscillator may have a frequency range from 65 to 75,000 cycles per second, extending through the audio- and carrier-frequency ranges into the lower radio frequencies. The simplified circuit of one type of such an oscillator is shown in Fig. 21. The frequency of the oscillating tube (left) is controlled by tuning the plate circuit. The output of the oscillating tube goes through a coupling potentiometer (page 121) to the amplifier tube (right). The plate of the amplifier tube is connected directly to the output terminals. The parallel-feed system of plate supply is used on both tubes.

The meters on the front panel are so equipped with switching arrangements that the filament or the plate voltage, and also the oscillator or the amplifier plate current, may be read. A grid-current meter is provided to indicate overloading.

The output of the oscillator is adjustable and may be held constant over the frequency range by means of the potentiometer coupling to the amplifier tube. The resistance marked "feed-back" is in the plate circuit of the oscillator tube and controls the oscillation. For the most satisfactory wave form the feed-back control should be set at the point at which the tube just begins to oscillate.

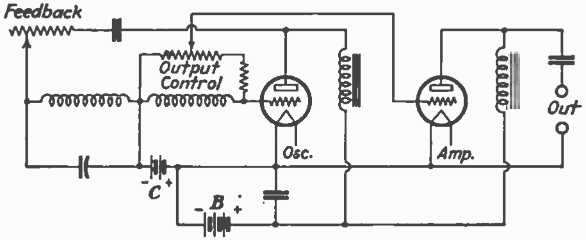


FIG. 21.—Low-frequency oscillator.

The frequency is changed by means of seven controls. There are three coils so tapped as to give six switch positions, and a decade capacity system (page 35) extending from 0.0001 to 1.0 microfarad. An air condenser with a maximum capacitance of 0.0011 microfarad makes the capacity system continuously variable.

An approximate calibration, good to within 5 per cent, giving the settings of the controls at frequency intervals of about 10 per cent for the entire frequency range, is provided with each instrument. This calibration is accurate only when the instrument does not take excessive grid current. The oscillator should be adjusted so as to keep the reading of the grid-current meter as low as possible, and in no case should it exceed one-half milliampere. This oscillator is intended to be used with UX-201A, UX-112A, or UX-210 tubes. For average use the UX-112A type will be found satisfactory.

The wave form of the oscillator output is very nearly a sine wave (page 72), provided the tube is not overloaded, as indicated by the grid-current meter. The largest single-harmonic component (page 72) in the voltage wave is about two per cent. Where particularly good wave form is required, it is advisable to use tubes of the UX-210 type. The load does not affect the wave-form unless the amplifier tube is overloaded and does not affect the frequency, since it is not applied directly to the oscillating tube. Frequency does not vary more than one per cent with ordinary variations in tube conditions.

The power output of the instrument will vary with the plate voltage and the type of tube. With a UX-210 tube, the output is about 0.2 watt with 120 volts on the plate, and about 0.5 watt with 220 volts on the plate.

Uses.—The low-frequency oscillator may be used for bridge measurements at audio, carrier, and low radio frequencies and for the study of the response curves of transformers and loud-speakers, the characteristics of filters, cables, and dielectrics.

Beat-frequency Oscillator.—For measuring the characteristics of loud-speakers and audio-frequency systems in general, it is often desirable to move through the entire frequency range quickly. The conventional type of vacuum-tube oscillator, although it may be so designed as to be continuously variable, requires the adjustment of a number of controls in order to vary the frequency through the entire audio-frequency range. Since the change in frequency involved is large, about 500:1, it cannot be obtained by the operation of a single oscillator of practicable construction. If, however, the measuring frequency is obtained by "beating" two oscillators together, a small percentage change in frequency of one of the oscillators will cause a relatively large change in the beat frequency (page 408).

The *beat-frequency oscillator* shown in Fig. 22, with a range of approximately 20 to 9,000 cycles per second, consists of two oscillator tubes, a detector tube, and an amplifier tube. The frequency of one of the oscillators is fixed at about 60 kilocycles per second, while that of the other is variable from approximately 50 to 60 kilocycles. Both oscillators are coupled to the grid circuit of the detector tube. The oscillators are so constructed and shielded as to maintain a constant frequency over long periods without adjustment. The system of coupling the oscillators to the detector tube, supplying it with a low voltage from each oscillator, is such that any tendency of the two oscillators to pull into synchronism as "zero beat" is approached is eliminated. The output of the detector tube flows to an amplifier tube through a double-impedance coupler, giving nearly constant amplification over the wide range of frequencies used. The output of the oscillator is taken off across a 10,000-ohm resistance, used as a voltage divider, permitting the adjustment of the output voltage without changes in the actual oscillator circuit that might affect the wave form or the frequency.

Three devices for variable capacities are indicated in Fig. 22. One of these is a small compensating condenser mounted inside the instrument. The purpose of this condenser is to correct any slight inaccuracy in the fixed condenser in this circuit. Slight changes in frequency of either of the oscillators due to changes in circuit conditions, may be compensated by means of this condenser, which is adjusted so as to bring the two oscillators to zero beat. The frequency is changed by means of two other variable condensers, the main tuning unit of 500-micromicrofarads maximum capacity, and a vernier condenser (page 40) shunted across it for fine adjustment.

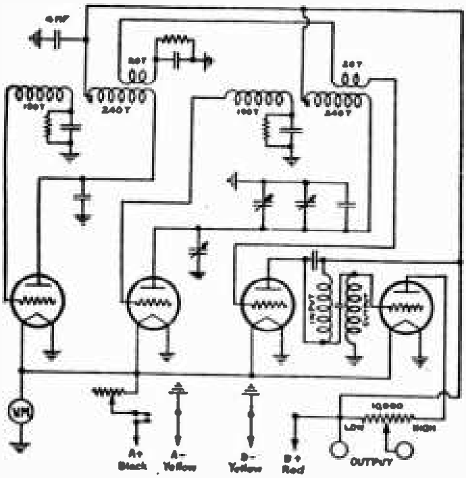


FIG. 22.—Beat-frequency oscillator.

The beat-frequency oscillator is designed for use with either WX-12 or UX-199 tubes, space being provided in the cabinet for three 1.5-volt dry cells and three 22.5-volt plate batteries. Vacuum tubes of the UX-201A type may be used with an external battery if desired. A 5-volt meter on the panel and a rheostat inside the cabinet permit the adjustment of the filament voltage to the rated value. The beat-frequency oscillator has an output of about 1.5 volts. The wave form is satisfactory for most purposes, the total of the voltage harmonics being 4 per cent of the wave at maximum values. This oscillator is useful for the measurement of all devices operating in the audio-frequency range. It is helpful in the study of loud-speaker response curves, since the complete frequency range is available by one-half revolution of the main dial. Peaks or hollows in a loud-speaker response curve are immediately evident, and any tendency to blast at particular frequencies is quickly revealed. It may also be used to modulate the output of the radio-frequency oscillator, a description of which follows.

The modulated radio-frequency output thus obtained may be used for testing receiving sets for both radio- and audio-frequency response. The audio modulated frequency can be compared quickly with that of the audio-frequency output of the receiver by using an oscillograph (page 38) as, for example, the string oscillograph.

Radio-frequency Oscillator.—A small radio-frequency oscillator has a wide range of usefulness in the laboratory. For maximum utility such an instrument must have a wide frequency range and be portable.

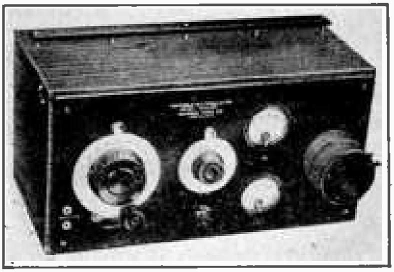


Fig. 23.—Radio-frequency oscillator.

The radio-frequency oscillator shown in Fig. 23 is of the plug-in coil type. The range of wave lengths may be extended from 15 to 30,000 meters by means of nine coils. A single UX-199 tube is used. A plate milliammeter is provided to indicate the oscillations. The oscillator may be used as a power source in the high-frequency measurements of coils and condensers. Input terminals are provided so that a beat-frequency oscillator (page 625) may be used as a modulator (page 38). It is also adapted for use as the auxiliary oscillator that is required in conjunction with a piezo-electric oscillator (page 616) when using harmonics of the plate frequency for the calibration of frequency standards.

Plug-in coils having the following range of wave lengths (in meters) may be obtained: 15 to 30; 30 to 80; 70 to 200; 190 to 575; 565 to 1,700; 1,700 to 4,400; 4,400 to 12,000; 12,000 to 30,000; and 200 to 600. The last is a figure-eight coil designed to have a minimum external field.

Standard-signal Generator.—A vacuum-tube generator of known radio-frequency voltage has a number of applications in the testing of radio receiving sets and in the measurement of field strength of radio devices by comparison methods. The generator should be variable in voltage over a wide range and so thoroughly shielded that no external field is set up. The standard-signal generator shown in Fig. 24 has a range of 1 microvolt to 200,000 microvolts, which is suitable for the measurement of the most sensitive type of receiver now available. It consists of a radio-frequency oscillator with fixed-frequency modulation by means of a self-contained audio oscillator and a calibrated attenuator (page 595).

In addition to the tests of "receiver-gain" (page 409) measurements, the signal generator may be used for field-strength measurements by comparison methods, for gain measurements on radio-frequency amplifiers, or for the measurement of detector-tube characteristics and of the combined characteristics of detector and audio-amplifier stages.

It is designed for use with external unshielded batteries and external modulation where variable-frequency is desired for fidelity tests. To this end the leads to the battery terminals and to the external modulation terminals are equipped with filters which confine the radio frequency entirely within the instrument. The leads to the meters on the panel are also provided with filters, thus eliminating the necessity for screening the fronts of the meters. The oscillator covers a frequency range of 500 to 1,500 kilocycles per second. The radio-frequency output is passed through an attenuator to the output terminals of the instrument. The attenuator is controlled by two knobs. The first of these, controlling the multiplier, changes the output in decade steps ("by tens") for a given radio-frequency current. The second knob, controlling the output scale, provides a continuous variation of the output voltage, proportional to the scale divisions at any value of radio-frequency for any given point of the multiplier scale. The radio-frequency current input to the attenuator is indicated by a thermal instrument, the direct-current galvanometer of which is mounted on the front panel and marked "radio current." A current calibration is provided for this instrument. The oscillator and attenuator are thoroughly shielded. The maximum error of voltage ratio in the attenuator is about 4 per cent.

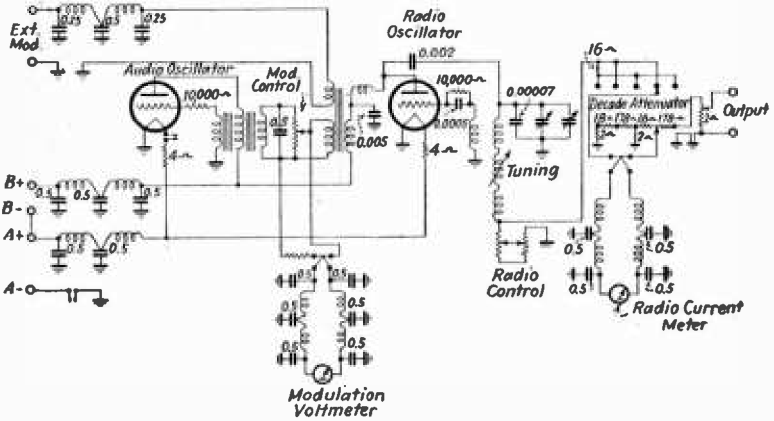


FIG. 24.—Standard-signal generator.

The signal generator is provided with an internal audio-frequency oscillator which modulates the radio-frequency signal at 400 cycles per second. The modulating voltage is impressed across a transformer winding in series with the total plate-battery circuit and the plate circuit of the radio-frequency oscillator. The root-mean-square (page 10) value of this voltage is indicated by a thermal voltmeter, the direct-current galvanometer of which, calibrated in root-mean-square volts, is mounted in the front panel. This voltmeter indicates the audio-frequency voltage impressed on the oscillator with either internal or external modulation, which may be varied by means of the knob marked "modulation."

The standard-signal generator is applied to the measurement of overall characteristics of radio receivers in accordance with the conventional assumption that the effects of a wave field upon an exposed antenna or loop of known constants may be simulated in all respects by the introduction into the receiver of a known locally generated radio voltage, through a local ("dummy") antenna or coil aerial having the same constants at the operating frequency. This signal generator is particularly adapted for use with antenna-operated receivers, in which the factor for conversion of the local signal in microvolts to an equivalent field strength is simply a length or "effective height" (page 409). By the use of a suitable coil-conversion factor, however, the generator may be used to measure radio receiving sets operated with a coil or loop aerial. For the conventional measurements of sensitivity, selectivity, and fidelity, two pieces of equipment are required in addition to the signal generator: (1) a local aerial circuit; (2) a receiver-output meter, comprising a resistance load of a magnitude appropriate to the output tube of the receiver being tested, together with a thermal meter for measuring the audio-frequency current of the load or a vacuum-tube voltmeter for measuring the voltage across the load. Both of these instruments can be easily assembled from standard laboratory equipment. It is recommended that the results of all receiver measurements be expressed in terms of microvolts input to the local antenna circuit to yield "normal-signal" output from the receiver at different audio and radio frequencies, when "on" and "off" resonance. The conventional value for normal signal is 50 milliwatts in a load of from 2,000 to 6,000 ohms. The revised *Report of Subcommittee on Receiving Sets* of the Institute of Radio Engineers, a copy of which may be obtained from the secretary of the institute, contains details of a suitable technique for making these measurements by means of a signal generator. The entire instrument is shielded, and the external leads are fitted with a filter. The shielding is sufficiently complete so that the generator may be used for tests of unshielded receivers.

Filter Sections.—Electrical filters are used extensively in studying the characteristics of communication equipment and in the transmission of electrical impulses of multiple frequency, such as speech or music. Such filters consist of capacity and inductance networks so designed that they allow certain frequencies to pass through them readily while at the same time other frequencies are highly attentuated (page 169). By the use of filters, for instance, a composite sound may be divided into several parts or a fault in telephone apparatus may be remedied by attenuating or placing emphasis on certain ranges of the frequency spectrum (page 3).

Filters may be divided into four general classes as follows: (1) low-pass filters, which cut off all frequencies above a definite predetermined value; (2) high-pass filters, which cut off all frequencies below a predetermined value; (3) band-elimination filters, which cut off all frequencies between two predetermined values; (4) band-pass filters, which cut off all frequencies below the lower and above the upper of two predetermined values. These four classes of filters can be formed in a variety of networks, some simple and others more complicated in their structure. An electrical filter may consist of a single network or section, or it may be rendered more effective by containing several recurrent sections joined in series. For a theoretical discussion of such filter networks the reader is referred to "Transmission Circuits for Telephone Communication," by K. S. Johnson, and "Electric Oscillations and Electric Waves," by G. W. Pierce.

As an aid to the study of the characteristics of such filters or for their use in communication circuits, a series of simple high-pass and low-pass filter sections may be obtained, the filter sections being mounted in individual cases. The high-pass filters take the form known as a *T-type* section, while the low-pass filters are constructed in the form of a π section.

In order to determine the electrical constants of the elements of such a filter it is necessary to know two things: (1) the desired cut-off frequency F; and (2) the iterative impedance Z of the circuit in which the filter is to be placed, *iterative impedance* being the characteristic impedance of an artificial line made up of an infinite number of sections. The values of the capacity C and inductance L of a high-pass filter section may then be computed from the equations

$$C_1 = \frac{0.07958}{FZ} \text{ farads,}$$

$$L_2 = \frac{0.07958Z}{F} \text{ henrys,}$$

where F is the frequency in cycles per second and Z the iterative impedance in ohms. The subscript 1 applies to values of C or L which are placed in series with the line, and 2 applies to values in shunt with the line.

For the low-pass filter;

$$C_2 = \frac{0.3183}{FZ} \text{ farads,}$$

$$L_1 = \frac{0.3183Z}{F} \text{ henrys.}$$

A list of high-pass and low-pass *filter sections* having impedances standardized at 600 or 6,000 ohms and cut-off frequencies specified as 500, 1,000, or 2,000 cycles per second are given in Table XLII. These individual sections are built into shielded metallic cans, each comprising a suitably designed laminated iron-core inductance unit and two calibrated wax-paper condensers. Any number of similar or different sections may be joined in series to produce a *multisection filter*.

The types listed are made by the General Radio Company and represent arbitrarily chosen values of impedance and cut-off frequency which find rather extensive use in practice. Similar sections having any desired electrical constants may be obtained.

TABLE XLII.—IMPEDANCE AND CUT-OFF FREQUENCY OF FILTER SECTIONS

Type number	Form	Iterative impedance, ohms	Cut-off frequency, cycles per sec.
330 A	Low pass	600	500
330 B	High pass	600	500
330 C	Low pass	6,000	500
330 D	High pass	6,000	500
330 E	Low pass	600	1,000
330 F	High pass	600	1,000
330 G	Low pass	6,000	1,000
330 H	High pass	6,000	1,000
330 J	Low pass	600	2,000
330 K	High pass	600	2,000
330 L	Low pass	6,000	2,000
330 M	High pass	6,000	2,000

Amplifier Testing Set.—A test method of taking audio-frequency amplifier characteristics should reproduce as nearly as possible the working conditions of the amplifier and should neither omit any factor tending to affect the characteristic nor introduce any effects not present in the amplifier. The coupling device which is always used in the plate circuit of the vacuum tube in an audio-frequency amplifier has impedance effects that influence the action of the amplifier. It is, therefore, necessary either that the test instrument be so arranged that the coupling device is connected in the plate circuit of the vacuum tube or that the effect of the plate impedance be reproduced in some manner. It is also important that no current be allowed to flow in the secondary winding of the transformer, since even a very slight secondary current will entirely alter the characteristics of the tube.

In the amplifier testing set shown in Fig. 25 all the neccssary elements are assembled in a single unit. In the circuit a resistance R_p is used to *simulate the impedance* in series with the primary winding of the transformer. This resistance is variable in 5,000-ohm steps and covers the usual range of vacuum-tube impedances. A vacuum-tube voltmeter is used as a measuring device. The constants of the voltmeter are so adjusted that the grid of the vacuum tube of the voltmeter cannot take current while the pointer or needle of the galvanometer is on the scale.

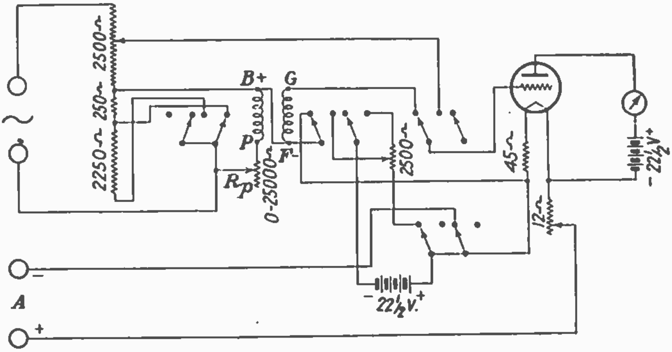


Fig. 25.—Amplifier testing set.

The input voltage of the transformer being tested is taken from a portion of the high resistance across which the oscillator output is impressed. The remainder of this resistance is used for checking the voltage of the secondary winding of the transformer. The voltmeter is used only as a "transfer" instrument.

In order that the effect of the capacities of the transformer windings may be reproduced correctly, it is desirable that the terminals marked "B plus" and "F minus" be connected together, so that both will be at the ground potential for alternating currents, as under working conditions. As the vacuum-tube voltmeter is also used to check input voltage, a transfer switch is provided.

The method of testing is as follows: The input voltage is adjusted to the desired value by varying the oscillator output. The voltmeter connection is transferred to the secondary winding of the transformer, and the deflection of the galvanometer pointer is observed. If the secondary voltage of the transformer is high enough to move the galvanometer pointer off the scale, an adjustable source of grid-bias voltage may be added to the oscillator output, and the potentiometer should be adjusted until the reading is repeated. The voltage amplification of the transformer is then indicated on the scale attached to the potentiometer. When impedances, or other coupling devices whose ratios are less than unity, are being checked, a multiplier resistance is connected into the circuit. Amplification factors as high as 10 are measurable with this instrument.

Operating Instructions.—When the testing set is received, the panel should be removed, a UX-199 tube should be placed in the socket, and the two 22.5-volt dry batteries connected. The red wires are connected to the plus-battery terminals. The batteries are not connected together. In making amplification measurements with this set, the following procedure should be followed: (1) The transformer to be measured is connected to the proper terminals; (2) the connections are made to the battery supplying the vacuum-tube voltmeter; and (3) the oscillator is connected and placed in operation. The plate impedance R_p is set at a value corresponding to the type of vacuum tube which would normally be used with the transformer being tested.

The galvanometer is set to zero deflection by adjusting "fil" rheostat while the oscillator is disconnected or inoperative, and the input voltage is adjusted as follows: The "amplification" dial is set to the reciprocal of the desired voltage (0.5 for 2 volts, 1 for 1 volt, 2 for 0.5 volts, 10 for 0.1 volts, and so on). The oscillator output is adjusted until the voltmeter registers 1 volt, and the voltmeter is then switched to the transformer. If the reading is off the scale, the grid-bias voltage should be adjusted to bring the reading on the scale. After the meter reading has been observed and the meter transfer switch is moved, the amplification dial is adjusted until the meter reading is the same as when connected to the transformer. The figure appearing under the indicator on the amplification scale is the *amplification of the transformer.* The process outlined above is repeated for each point on the curve. The input voltage should be checked at each point.

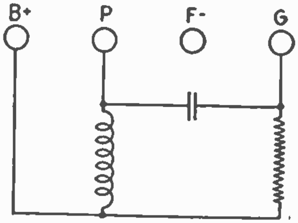


FIG. 26.—Impedance-coupling units.

When measurements are to be made of impedances or other units of which the amplification is less than unity, the multiplier scale X_1 is used. The procedure in measurement is the same as with transformers, except that the reading of the amplification scale is multiplied by 0.1. In setting the input voltage the amplification dial should read as follows: For 1 volt read

"10," for 2 volts "5," for 5 volts "2," and so on. Impedance-coupling units are connected as shown in Fig. 26.

If it is desired to measure the effect of *direct-current saturation* in the primary winding of the transformer, a battery and meter may be connected externally, in series with the transformer. If this is done, the battery should be disconnected when checking the input voltage.

String Oscillograph.—In many lines of work, including experimentation with alternating currents, there is frequently a need for a simple, sensitive, portable, and inexpensive oscillograph, with which one may observe either sustained wave forms or transient currents and voltages existing at any point in an electrical circuit or network. The string oscillograph shown in Fig. 27 may be used for the following two distinct purposes: (1) As an oscillograph which operates with much less power than is usually required by such instruments, but which affords a means for the visual examination of wave forms over a wide range of frequencies. The wave of either current or voltage is traced by the shadow image of a very fine vibrating wire rather than by a spot of light reflected from a mirror attached to a moving system. The vibrating element can, accordingly, be made much lighter, resulting in excellent sensitivity of the instrument. The uses for such an instrument are manifold, as, for example, the observation of large or small alternating currents; the visual examination of telephonic currents in simple or complicated circuits; and, when combined with some form of microphone, the study of mechanical vibration occurring in moving machinery, bridges, or other structures subject to intermittent stresses. (2) As a reliable vibration galvanometer, the string of which may be tuned to give a good degree of sensitivity over a considerable range at any desired frequency. In this respect the instrument is especially useful as a null-point detector in alter-

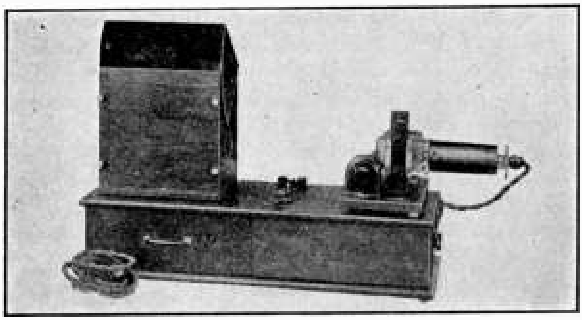


FIG. 27.—String oscillograph.

nating-current bridge measurements when using low frequencies at which the telephone receiver becomes insensitive and otherwise unsatisfactory. Since the galvanometer has no coil in the magnetic field, its reactance is practically nil when the string is not vibrating, this being a desirable feature for certain applications.

An idea of the sensitivity of the instrument may be obtained from the following data. Using a string of 0.0004-inch tungsten wire, undamped, and tuned to the fundamental of the applied *alternating-current frequency*, the following voltages are required to produce a wave form having an amplitude of one millimeter on the screen of the instrument:

At 60 cycles	0.2 millivolt
At 250 cycles	1.0 millivolt
At 500 cycles	2.4 millivolts
At 1,000 cycles	8.5 millivolts

The direct-current sensitivity of the same string when tuned to various *frequencies* is seen from the following data, which gives the *direct-current* voltages that are required to give a deflection of one millimeter on the screen:

At 60 cycles	0.0047 volt
At 250 cycles	0.065 volt
At 500 cycles	0.30 volt
At 1,000 cycles	1.31 volts

The resistance of the instrument strung with the 0.0004-inch tungsten wire is about 45 ohms.

The complete equipment of the string oscillograph comprises a galvanometer, a rotating mirror box, an oscillograph base cabinet, and a carrying case. A convenient piece of auxiliary apparatus consists of an adjustable rheostat, having a total resistance of 100,000 ohms. This rheostat, when placed in series with the oscillograph, enables the instrument to be used with voltages up to 500 volts. Another useful piece of auxiliary equipment consists of a step-down transformer to adapt the oscillograph to obtain efficient operation in high-impedance circuits.

The galvanometer is sensitized by two permanent magnets, thus eliminating the need of a source of direct current for producing the necessary magnetic field. Two specially shaped pole pieces afford a long, narrow, vertical gap in which the string vibrates and at the same time serve to support the optical system, which consists of a large and a small condenser lens, together with a microscope objective. The large lens and a standard automobile-headlight bulb are located in the lamp chamber, while two small lenses are located within a tube passing through the pole pieces. All three lenses are adjustable along the optical axis, while the lamp is adjustable in three dimensions. This makes it easy to focus the system to give a uniform field of illumination. A thumbscrew, located at the end of the lamp chamber, slides the optical system as a whole with reference to the string and thereby focuses the shadow image of the string on the observing screen.

The string is mounted on a metal rocker arm, which, in turn, is attached to the rear of a vertical bakelite strip. Two adjustment screws protrude through the front of this strip. One of these varies the tension on the string, while the other serves to move the string across the light beam in order to center the image on the screen. Provision is made for damping the vibrations of the string, if desired, by means of a drop of oil. The whole string assembly is readily removed, electrical contact being made through two springs on the galvanometer base. Two string mountings are provided with the equipment, each strung with a fine tungsten wire of about 0.004-inch diameter. These strings, which are 3 inches in length, may be overloaded considerably without damage. As they carry no mirror, their replacement is a comparatively simple operation.

On the left of the galvanometer base is mounted an enclosed potentiometer for adjusting the potential applied to the string, thereby controlling its amplitude of vibration.

The mirror box contains a rotating octagonal metallic mirror which affords the necessary time element of linear motion perpendicular to the vibration. The mirror is mounted on the shaft of a small induction motor (page 228) and is provided with jeweled bearings. This motor is of simple construction, consisting of a circular disk the periphery of which passes through a gap in a rectangular, laminated core. The core is energized by a high-impedance coil carrying a 60-cycle current, and around one-half of the cross-section of each pole is a copper ring acting as a *shading coil.* The unsymmetrical distortion of the resulting field affords the driving force. This motor is not inherently "synchronous" (page 227), as its speed may be controlled over a wide range merely by varying the voltage impressed on the energizing coil. This is done by means of a potentiometer. A very constant speed of any desired value may be maintained in this manner, making it easy to synchronize the motor to any frequency impressed on the string, producing thereby a stationary *wave pattern.* For observing transient phenomena of some duration, it is desirable to have the mirror run quite slowly, whereas the maximum speed of the motor is necessary to separate the individual wave forms at the higher frequencies. The 60-cycle wave length at maximum speed is from 2½ to 3 inches and the wave length at 3,000 cycles per second is about $\frac{1}{16}$ inch.

A screen bent into the arc of a circle is observed when looking down into the mirror box, which is provided with an adjustable metallic cover that serves as a hood for shielding the screen. The observer may stand at some distance from the screen and still watch the wave form while manipulating other apparatus. A cylindrical lens is mounted in the mirror box for concentrating the light beam into a narrow line. This sharpens and intensifies the image considerably. The front vertical wall of the mirror box is easily removable for inspection and adjustment of the enclosed parts.

Terminal posts, together with a cord and plug, are provided for attaching the equipment to a source of 60-cycle, 110-volt current which may be turned on or off by a toggle switch mounted on the central portion of the cabinet. This is the only source of power required, since the lamp is lighted through a step-down transformer. The instrument requires about 40 watts of power. The cabinet contains a 3-microfarad wax-paper condenser which is frequently useful for eliminating a direct-current component from the string of the oscillograph.

Part 2

LABORATORY MEASUREMENTS

Measurement of Antenna Resistance.—The "resistance-variation" method is commonly used for the measurement of antenna resistance when accuracy is necessary. A typical circuit diagram is shown in Fig. 28.

The source of power is a radio-frequency vacuum-tube oscillator. The output of the oscillator must be constant or the measurements will be inaccurate. Lead-acid batteries may be used to prevent variations in output due to changes in filament temperature or plate voltage. A 5-watt tube may be used, but higher power is desirable.

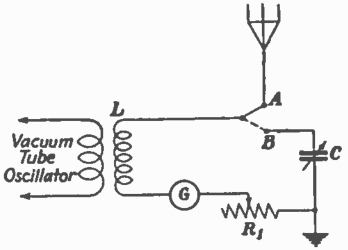


Fig. 28.—Circuit for measuring antenna resistance.

The variable condenser C must be shielded, and the shield should be grounded to the oscillator battery to eliminate the so-called *body capacity* which is the capacity of the condenser formed by a human body as one plate and the ground as the other plate. A vernier adjustment should be provided for accurate tuning. The condenser is substituted for the antenna in this measurement and must, therefore, have sufficient capacity for this purpose.

The resistance R_1 may be of the non-inductive type in a box and should be inserted next to the ground connection. For resistance measurements at very high frequencies the straight-wire type of resistance should be used because it has a very low inductance and will not cause detuning. At frequencies above 1,500 kilocycles per second (200 meters) a resistance box of the non-inductive type is objectionable as it may cause detuning.

The resistance of the thermocouple (page 46) galvanometer G may be about one ohm and should be small compared with that of the measuring circuit. The galvanometer and the resistance box R_1 must be kept away from the lead-in of the antenna and from other high-voltage wires in order that tuning may not be affected by body capacity.

The antenna circuit is coupled to the oscillator by the loading coil (page 37) L which must have a low radio-frequency resistance. A different coil is used for each frequency at which a measurement is made. The resistance of the coil does not, however, enter into the calculation.

The coupling must be kept constant during each measurement, in order that the voltage induced in the antenna circuit may not change. Between measurements the coil L must not be moved with reference to any metal such as the case of the condenser. It is essential that loose coupling with the oscillator should be used. For this reason a low-power vacuum tube is not desirable. On the other hand, a high-power tube may introduce objectionable electric coupling effects. If the coupling between the two circuits is too tight, an excessive amount of power is taken from the oscillator. This changes the output of the oscillator and consequently also changes the value of the voltage induced in the antenna circuit. The location of the coupling coil of the oscillator should be such that the coupling between the oscillator and the coil L, or the lead-in of the antenna, will not be affected by body capacity.

The first step is to put the oscillator into operation, placing the lead of coil L on the point A and tuning the oscillator to resonance with the loaded antenna. A reading is made of the galvanometer indication. In this condition of resonance

$$I = \frac{E}{R}$$

where I is the galvanometer current in amperes, E is the induced voltage in volts, and R is the circuit resistance in ohms. Then a resistance R_1 is added to reduce the galvanometer reading to about half its former value. The current then changes to a value I_1, and, since the voltage is constant,

$$I_1 = \frac{E}{R + R_1}.$$

From these two equations the circuit resistance R is obtained from the relation

$$R = R_1 \div \left(\frac{I}{I_1} - 1\right).$$

Next, the lead of the coil L is moved to the point B. The coupling must be reduced slightly because the resistance of the condenser usually is less than that of the antenna. Then the circuit is tuned to resonance by the condenser C. By following a procedure similar to that used for the first circuit, a value is obtained for the total resistance R_c of the circuit with the substitution condenser.

The resistance R_a of the antenna (without the loading coil L) may be stated as

$$R_a = R - R_c.$$

The resistance of the loading coil does not enter into the calculations, because it is common to both circuits.

Another method which gives only approximate results utilizes the existing connection of the antenna to a transmitting set. An ammeter is connected in the ground lead and a current I is observed under normal operation. Then a small known resistance R is inserted in series in the ground lead and the current I_1 is observed. The antenna resistance R_a is given by the equation

$$R_a = R \div \left(\frac{I}{I_1} - 1\right).$$

Similar measurements may be made at different frequencies, using various values of R_1 at each frequency.

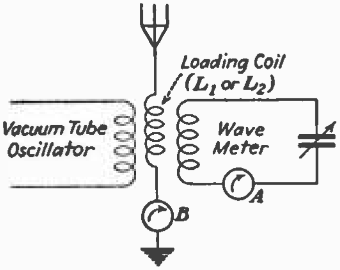


FIG. 29.—Circuit for measuring antenna constants.

Measurement of Antenna Constants. The inductance L and the capacity C of an antenna may be obtained by the method of inserting two loading coils in the antenna circuit in succession and measuring the wave length of the antenna circuit in each case. The apparatus required is a vacuum-tube oscillator, two loading coils L_1 and L_2, a wave meter (page 111) provided with some form of current-indicating instrument A, and a current-indicating device B for the antenna circuit. The loading coil L_1 should have an inductance which is about five times that of the antenna, and the inductance of L_2 should be about ten times that of L_1. The apparatus is arranged as shown in Fig. 29.

The first step is to put the oscillator into operation. Then the length of the wave produced by the oscillator is varied until it equals the resonant wave length of the antenna. This point is determined by the indication of the meter in the antenna circuit. When this is done the antenna is detuned and the length of the wave produced by the oscillator is measured by means of the wave meter. Then the coil L_1 is inserted in the antenna and the wave length W_1 of the antenna is measured. Similarly, W_2 is measured when the coil L_2 is inserted. The values of the inductance, capacity, and wave length of an antenna are combined in the equations

$$W_1 = 1{,}884\sqrt{(L_1 + L)C}$$
$$W_2 = 1{,}884\sqrt{(L_2 + L)C}$$

where L_1 is the apparent inductance of the first loading coil at the measured wave length in microhenrys, L_2 is the apparent inductance of the second coil at the measured wave length in microhenrys, C is the capacity of the antenna in microfarads, and L is the inductance of the antenna in microhenrys.

From these equations the inductance L is found to have a value of

$$= \frac{W_1^2L_2 - W_2^2L_1}{W_2^2 - W_1^2}.$$

The value of C is found by substituting this value of L in the equation for W_2. The values for C and L that are determined by this method are accurate to one or two per cent.

Measurement of Antenna Wave Length.—An approximate value for the *fundamental* wave length of an antenna may be found by the use of a single-turn loading coil. The apparatus required consists of a single-turn coil, a current-indicating device, and a vacuum-tube oscillator. The oscillator is put into operation and tuned to resonance with the antenna circuit. The length of the wave produced by the oscillator is approximately equal to the fundamental wave length of the antenna, but this value is slightly high because of the inductance of the coil.

Measurement of Effective Height of Antenna.—The effective height of an antenna is defined as equal to one-half the length of an equivalent antenna system having a counterpoise (*Hertzian*). An approximation sometimes made in practice is that the effective height of an antenna with a flat top is equal to about 60 per cent of its mean height.

The effective height may be measured by taking observations of the strength of the current received by the antenna from a loop transmitter. The apparatus required is shown in Fig. 30. The condenser C and the inductance L are used for tuning the antenna. A loop antenna used as a transmitter is placed about one wave length away from the receiving antenna. The plane of the loop should be in the direction of the receiving antenna. A comparatively large loop is required. A rectangular form about 20 feet high and 40 feet long with five turns of wire spaced 30 inches apart is satisfactory. The oscillator must have power enough to produce a readable deflection of the galvanometer pointer. The path between the antenna and the transmitter should be selected so that there are no tuned circuits near the measuring circuit. Any form of wave collector near the receiving antenna or the loop will absorb some of the radiated energy, thus reducing the calculated effective height of the antenna.

The effective height of the transmitting loop is needed for this measurement. It may be calculated from the equation

$$h_s = \frac{2\pi nhl}{W}$$

where h_s is the effective height of the loop in meters, n the number of turns of wire in the loop, h the height of the loop in meters, l the length of the loop in meters, and W the wave length in meters at which the measurement is made.

The first step in the measurement of the effective height is to put the oscillator into operation. Long waves should be used because they are less affected by refraction and reflection. Then the antenna circuit is tuned to the wave radiated by the oscillator. Next the radio-frequency resistance of the antenna at this wave length is measured by the method described on page 637. This gives the resistance of the antenna circuit including the galvanometer, the condenser, and the coil. The value of the current received by the antenna is obtained from a reading of the galvanometer.

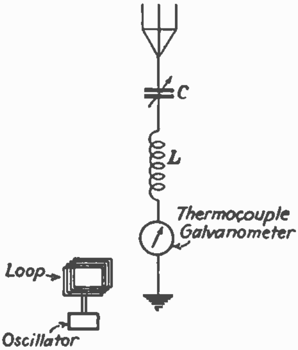


Fig. 30.—Circuit for measuring antenna height.

The effective height of an antenna may then be calculated by the equation,

$$h_r = \frac{dWRI_r}{120\pi h_s I_s}$$

where h_r is the effective height of the antenna in meters, W the wave length in meters, R the radio-frequency resistance of the antenna in ohms, I_r the value of the antenna current in amperes, h_s the effective height of the loop in meters, I_s the value of the loop current in amperes, and d the distance in meters.

When the effective height of this antenna has been determined, the effective height of any other antenna may be calculated from it by the use of this equation.

Measurement of Audio-frequency Amplification.—The circuit used for this measurement as shown in Fig. 31 consists of the amplifier to be measured, a pair of head-set telephones, a double-pole double-throw switch, a source of audio-frequency power, two variable resistances R_1 and R_2 each of about 10,000 ohms, a fixed resistance R which has a value that is determined by the voltage of the source and by the required intensity of the signal, and a slide wire r. By means of the switch, the telephones may be connected either across the fixed resistance R or across the output of the amplifier. The measurement is made by comparing the intensity of the signal across R with the intensity of the signal across the output of the amplifier which is connected across r. The junction of R and r is grounded in order to eliminate any signal which might result from capacity coupling.

First the source of power is adjusted to produce a voltage of five or six volts. When the apparatus is ready for a measurement, the resistances R_1 and R_2 are varied to adjust the intensity of the signal to a suitable value, and r is varied until the telephones indicate a signal of equal intensity for either position of the switch.

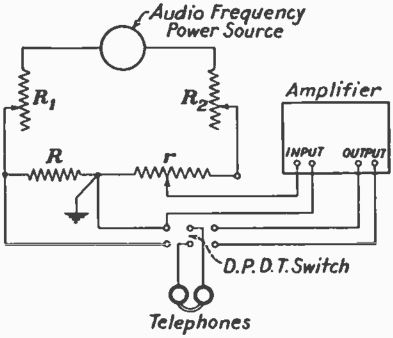


FIG. 31.—Circuit for measuring amplification of tube.

The ratio of the voltage across the telephones to the voltage across the amplifier input is equal to the ratio of the resistances $R:r$. When equal signals are obtained, it follows that

$$\text{Voltage amplification} = \frac{R}{r}.$$

Measurements are made at a number of points over the required frequency range. The values obtained from the calculations may be used to plot a curve of voltage amplification against frequency. If only one measurement is required, a frequency of 1,000 cycles per second is generally used.

Measurement of Audio-frequency Amplification of Tube and Transformer.—The circuit used in this measurement permits a higher degree of accuracy than when the audibility method is applied. The wiring diagram is shown in Fig. 32, the source of power P being variable in frequency over the desired range, and the transformer T having a suitable step-down ratio. A resistance R is used to control the current flowing through the resistance r. The tubes V_1 and V_2 are coupled by the audio-frequency transformer T_1. The voltage drop on a portion of the sectional resistance r is impressed on the grid circuit of either of the tubes V_1 or V_2, by the use of the single-pole double-throw switch *S*. The grid-bias voltage of these tubes is adjusted by means of the resistance R_1.

The output of this circuit is connected to the grid of an audio-frequency amplifier, the input voltage to this amplifier being the voltage across the telephones shown in the figure. The current from the amplifier goes through a "one-to-one ratio" transformer to an indicating device consisting of a crystal detector *D* and a galvanometer *G* which indicates microamperes of current.

First the source of power is adjusted for the required frequency and is connected to the circuit. Then the switch *S* is set at the point *B*, and the movable arm of the sectional resistance *r* is set for the maximum value. The filament rheostat and the grid-bias resistance for tubes V_1 and V_2 are adjusted for the proper values. The intensity of the signal in the telephones is brought to a moderate value by means of resistance *R*.

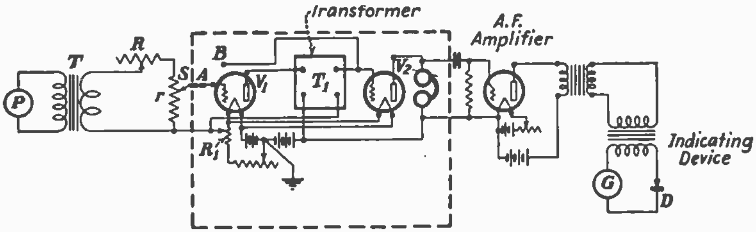


Fig. 32.—Circuit for measuring amplification of tube and transformer.

Next the tube in the amplifier is lighted, and at the same time the detector tube must be adjusted so that a satisfactory deflection is obtained on the galvanometer. Readings are made of the value of the resistance *r* and of the galvanometer deflection.

The next procedure is to bring the arm of *r* to its maximum position and set the switch at the point *A*. Then the resistance *r* is increased to a value r_a at which the galvanometer deflection equals that obtained before. Since the voltages applied to the tubes are proportional to the resistances, the values of amplification also are proportional to these resistances. Thus the amplification resulting from the use of the tube and transformer is given by the relation

$$\text{Amplification} = \frac{r}{r_a}.$$

The effect on amplification of changes in transformer constants, grid-bias voltage, plate voltage, and frequency may be observed by making another set of measurements in which these factors are varied.

Measurement of Oscillation Frequency of Coils.—The apparatus required consists of a coil L which is to be measured, a vacuum-tube oscillator, a circuit for the detection of resonance, and a radio-frequency ammeter. This circuit contains a crystal detector, a galvanometer which will respond to very small currents, and a coupling coil of several turns, connected in series. As shown in Fig. 33, the apparatus is arranged so that the coil L is coupled to the oscillator, and the coil of the resonance indicator is coupled to the coil L but not to the oscillator.

The oscillator is put into operation and its frequency is varied until resonance is indicated by the deflection of the galvanometer. The frequency of the oscillator, then, is equal to the fundamental frequency of the coil L. It is possible, however, that this frequency may represent a natural period of the resonance detector and not an oscillation in the coil; or, the observed frequency may represent a harmonic and not the fundamental frequency of the coil. If the frequency is that of the oscillations in the coil L, the pointer of the galvanometer will swing back when the coil L is removed or short-circuited. If a condition of resonance is not obtained at a lower frequency, the measured frequency represents the fundamental of the coil; harmonic oscillations will be observed if the frequency of the oscillator is increased.

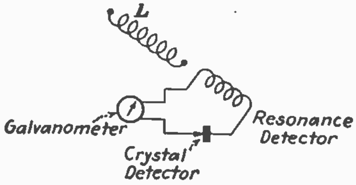


Fig. 33.—Circuit for measuring oscillation frequency.

This apparatus may be used to locate the nodes and the loops of the voltage in the coil L. When a finger of the operator's hand passes over a voltage *loop* (*antinode*) of the coil, the pointer of the galvanometer wil-swing back, and when the finger passes over a node, the pointer of the gallvanometer swings to a maximum value. If it is desired to maintain conditions as in actual practice, one end of the coil may be grounded. The coil and the ground wire then represent an antenna circuit, and the state of oscillation is detected by the flow of current in a radio-frequency ammeter inserted in the ground wire.

Measurement of Resistance, Inductance, and Capacity of Coils.—The method described on page 637 for the measurement of the radio-frequency resistance of a circuit may be adapted with slight changes for measuring the resistance of a coil. The condenser used in the measuring circuit should be of the low-loss type which has a negligible resistance. The resistance of the coil, then, is equal to the circuit resistance minus the direct-current resistance of the thermocouple galvanometer. From the values of resistance corresponding to different frequencies a curve may be drawn of resistance against frequency. Such a curve shows that the radio-frequency resistance increases as frequency is increased; or, in other words, the resistance decreases as the wave length is increased.

The apparent inductance of the coil may be found from this measurement also. The term *apparent inductance* means that the capacity of the coil is included with its inductance. It is possible to represent the coil by a fixed value for the inductance, called the *pure* inductance, and a value for the capacity. In the absence of skin effect and similar factors, the pure inductance of a coil is identical with its low-frequency inductance. The apparent inductance of a coil at a given wave length can be calculated, if the capacity and the wave length are known, from the equation

$$L_a = \frac{W^2}{3.553 \times C \times 10^6}$$

where L_a is the apparent inductance in microhenrys, W the wave length in meters, and C the capacity in microfarads.

Tables of the values of $C \times L$ are given on page 17, from which the value of $C \times L$ corresponding to the given wave length may be selected. The value of apparent inductance is obtained by dividing the value of $C \times L$ by C, which represents the capacity of the condenser.

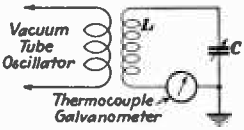


Fig. 34.—Circuit for measuring distributed capacity.

The *distributed capacity* of a coil may be found with the circuit shown in Fig. 34. The apparatus required consists of a vacuum-tube oscillator, the coil L to be measured, a variable condenser C, and a thermocouple galvanometer. The oscillator is put into operation and coupled to the coil L with its associated apparatus. The coil circuit is tuned to resonance with the oscillator by varying the condenser C. This value of capacity is observed and designated as C_1. Then the capacity of the condenser is reduced until the circuit is tuned to the second harmonic. This new capacity is also observed and designated as C_2. This value of C_2 would be equal to $C_1 \div 4$ if the coil had no *distributed capacity* (page 86) but actually C_2 is less than $C_1 \div 4$. The distributed capacity C_0 of the coil is found from the equation

$$C_0 = \frac{C_1 - 4C_2}{3}.$$

All the capacities must be expressed in the same units. An average value for the distributed capacity should be obtained by taking measurements in which the oscillator is set for different wave lengths.

In another method of finding the distributed capacity C_0, it is necessary to obtain the apparent inductance of a coil at different wave lengths. The distributed capacity C_0 is then calculated from the equation

$$C_0 = \frac{C_1C_2}{C_2 - C_1}\left(\frac{L_1}{L_2} - 1\right)$$

where L_1 is the apparent inductance at one wave length in microhenrys, L_2 the apparent inductance at another wave length in microhenrys, C_1 the capacity corresponding to L_1 in microfarads, and C_2 the capacity corresponding to L_2 in microfarads. The inductances should be expressed in the same units, such as microhenrys or millihenrys, and the distributed capacity C_0 is usually expressed in micromicrofarads, so that C_1 and C_2 should also be expressed in these units.

The true inductance L_0 may be found, after the distributed capacity C_0 is known, from the equation

$$L_0 = \frac{L_1}{\left(1 + \frac{C_0}{C_1}\right)}$$

where L_0 is the true inductance in microhenrys, C_0 is the distributed capacity in micromicrofarads, L_1 is the apparent inductance in microhenrys at a certain wave length, and C_1 is the capacity in micromicrofarads of the tuning condenser at the same wave length.

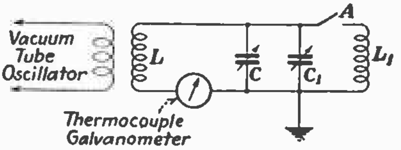


FIG. 35.—Circuit for measuring choke coils.

Measurement of Reactance, Inductance, and Capacity of Choke Coils.—The apparatus required for these measurements consists of a vacuum-tube oscillator, a thermocouple galvanometer, a coupling coil L, the radio-frequency choke coil L_1 which is to be measured, a calibrated condenser C, and a condenser C_1 for approximate tuning. The apparatus is connected as shown in Fig. 35. Both condensers must be shielded and grounded. The coil L_1 must be placed so that the condenser is not in its field. Although this method is intended primarily for choke coils, the formulas may be used for any coil.

The oscillator is put into operation, the ungrounded end of coil L_1 is left unconnected, and the circuit is tuned to be in resonance with the oscillator as indicated by the deflection of the galvanometer. The setting of the calibrated condenser C is noted and the corresponding value of capacity is designated as C_a. Then the connection at the point A is closed, the circuit is tuned again, and the new value of capacity is designated as C_b. The reactance X_L of the coil L_1 may be calculated from the equation

$$X_L = \frac{10^6}{2\pi f(C_a - C_b)}$$

where X_L is the reactance of L_1 at the frequency f in ohms, f is the frequency per second of the oscillator in cycles, C_a is the capacity of the condenser in microfarads when L_1 is not connected, C_b is the capacity in microfarads when L_1 is connected, and π is 3.1416. A curve of reactance against frequency may be drawn if a number of measurements are made at different frequencies of the oscillator.

The reactance of the coil is inductive if the fundamental wave length of the coil is less than the wave length of the oscillator. In this case the capacity C must be increased to obtain resonance when the coil is connected into the circuit. The reactance is capacitive if the fundamental wave length of the coil is greater than the wave length of the oscillator. In this case the capacity C must be decreased to obtain resonance when the choke coil L_1 is connected.

The values thus obtained may be used for the calculation of the apparent inductance and the distributed capacity of the choke coil. When the reactance is inductive, the apparent inductance of the coil is given by the equation

$$L_a = \frac{10^{12}}{(2\pi f)^2(C_b - C_a)}$$

where L_a is the apparent inductance of the choke coil in microhenrys, f the frequency of oscillation in cycles per second, C_a the distributed capacity with L_1 disconnected, in microfarads, and C_b the distributed capacity with L_1 connected, in microfarads. It should be noted that when the reactance is capacitive, the apparent distributed capacity is given by the term $-(C_b - C_a)$ or $C_a - C_b$.

The measured values for inductance and distributed capacity differ from the true values by an amount which depends on the relation between the wave length at which the measurement is made and the fundamental wave length of the coil. Thus the value for *apparent* inductance is 4 per cent higher than the *true* inductance L_0 if the fundamental wave of the coil is one-fifth of the wave length at which the measurement is made; but this increase drops to 1 per cent if the fundamental wave length of the coil is one-tenth of the oscillator wave length. The difference in the capacity values, however, varies in an inverse proportion. If the fundamental wave length of the coil is five times the wave length at which the measurement is made, the apparent capacity is 4 per cent less than the true value of the distributed capacity C_0; and if the fundamental is ten times the oscillator wave length, the apparent capacity is 1 per cent less than the value of C_0.

The difference at any wave length between the measured values and the true values is given by the following equations. The apparent inductance may be expressed in terms of the true inductance by the equation

$$L_a = \frac{L_0}{[1 - (2\pi f)^2 L_0 C_0 \times 10^{-12}]}$$

where L_a is the apparent inductance in microhenrys, L_0 the true inductance in microhenrys, f the frequency of oscillation in cycles per second, and C_0 the true distributed capacity in microfarads. The difference in per cent between L_a and L_0 is determined by the term $(2\pi f)^2 L_0 C_0 \times 10^{-12}$, and L_a may be considered equal to L_0 if this term is negligible compared to 1. Also L_a approaches L_0 in value as the wave length, at which the measurement is made, is increased.

The apparent distributed capacity may be expressed in terms of the true distributed capacity by the equation

$$C_a = C_0\left[1 - \frac{1}{(2\pi f)^2 L_0 C_0 \times 10^{-12}}\right]$$

where C_a is the apparent distributed capacity in microfarads, C_0 the true distributed capacity in microfarads, f the frequency of oscillation in cycles per second, and L_0 the true inductance in microhenrys. The value C_a may be considered equal to C_0 if the term $(2\pi f)^2 L_0 C_0 \times 10^{-12}$ is very large; that is, C_a approaches C_0 in value as the wave length is decreased. In using this term for finding the difference in per cent between the apparent and true values, it is allowable to use L_a and C_a instead of L_0 and C_0 because the error is small compared to the total values; and if the corrected values are again introduced into the term, the magnitude of the error is decreased.

Calibration of Condensers.—In this method the capacity of a condenser is to be measured by comparison with a standard condenser. The exact procedure to be followed depends on the magnitude of the unknown capacity as compared to that of the standard capacity.

Unknown Capacity Equal to or Less than Standard.—When the unknown capacity is of the same magnitude of or less than that of the standard condenser, the circuit shown in Fig. 36 may be used. The apparatus required consists of a vacuum-tube oscillator, a coupling coil L, a variable tuning inductance L_1, a thermocouple galvanometer, the unknown capacity C_2, the standard capacity C_1, and a single-pole, double-throw switch S. The shields of the two condensers are to be connected together and grounded, and the wires leading from the switch to the condensers should be as short as possible and of equal length. It is essential that no change be made in the coupling between the oscillator and the circuit until the measurements are finished.

The first step in the measurement is to put the vacuum-tube oscillator into operation, turn the switch S to the unknown capacity C_2, couple the oscillator loosely to the coil L, and adjust the oscillator to resonance with the circuit. A reading is taken of the setting of C_2, and after this has been done the standard condenser C_1 is connected into the circuit by means of the switch. The condenser C_1 may then be adjusted so that the circuit is again in resonance with the oscillator and the capacity of C_1 at this setting is noted. At this point the two capacities are of equal value. If this measurement is repeated over the range of the unknown capacity C_2, values are obtained for a calibration curve. This curve is drawn with capacity in micromicrofarads against condenser setting in degrees. A simple test may be used to detect any error caused by the location of the condensers with respect to the other parts of the circuit. An error of this kind is determined by tuning each condenser to the oscillator, first in its own position and then in the position of the other condenser. If there has been no error, the settings of the condensers at the point of resonance should be the same. With proper precautions, this method of throwing the switch from one condenser to the other can be just as accurate as when only one condenser is used in the circuit at a time.

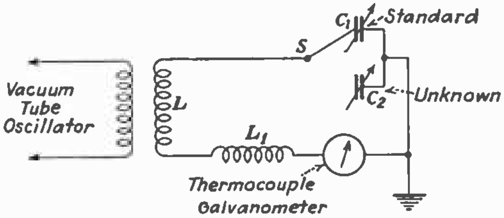


FIG. 36.—Calibration of condensers with capacity equal to or less than standard.

Unknown Capacity Greater than Standard.—A condenser C_2 which has a capacity greater than that of the standard condenser C_1 is first calibrated up to the maximum capacity of the standard by the method already described. For the rest of the measurement, the circuit is changed to that shown in Fig. 37. In this circuit a permanent connection is made between the fixed end of the switch S and the unknown capacity C_2 so that the two condensers are in parallel when the switch is closed.

Then the unknown capacity C_2 is set at the highest value which has been measured by the method described previously. The value of this capacity may be designated as C_x. Next the capacity of the standard C_1 is increased by a small known amount which is noted and may be designated as C_y. After this the oscillator is adjusted until it is in resonance with the circuit.

Next the standard condenser is disconnected from the circuit by means of the switch, and the unknown capacity C_2 is adjusted to tune the circuit to the oscillator. The setting of C_2 at this point is equal to C_x plus C_y. In the next step, the switch is closed to the condenser C_1, and the capacity of C_1 is again increased by a small known amount. The oscillator is resonated to the circuit, C_1 is disconnected, and C_2 is adjusted to retune the circuit. This new setting of C_2 is equal to the last setting plus the increase made in C_1. This procedure is repeated until the unknown condenser has been calibrated over its entire range. To avoid the introduction of any errors, no changes should be made in the settings of the condensers during the measurements.

A more rapid procedure may be followed if the capacity values of the condensers are such that the changes in capacity made during the measurements are small compared to the totals. In this method, the switch is first closed to the condenser C_1, the condenser C_2 is set at its highest known value, the condenser C_1 is set at its maximum value, and the circuit is adjusted for resonance to the oscillator. Then the capacity of the condenser C_1 is reduced by a small known amount, while the capacity of the condenser C_2 is increased by the same amount, to restore the condition of resonance. Then another reduction is made in the capacity of C_1, and the capacity of C_2 is again increased. When the minimum capacity of the condenser C_1 is reached, each condenser is again adjusted for its maximum known value and the oscillator is tuned to the circuit. The procedure of decreasing the capacity of the condenser C_1 by small amounts and increasing the capacity of the condenser C_2 correspondingly is repeated until the range of the unknown condenser is covered.

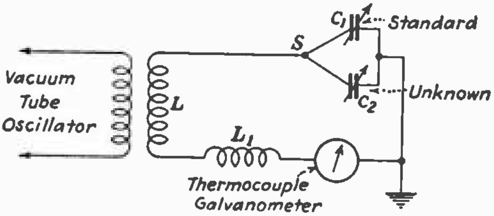


FIG. 37.—Calibration of condensers with capacity greater than standard.

If the capacity of the circuit is increased the circuit may be put into resonance with the oscillator by reducing the inductance of the coil L, or by decreasing the frequency of the oscillator. In either case, however, the final adjustment is made by tuning the circuit to the oscillator.

Measurement of Phase Difference.—The various losses in a condenser may be due to leakage between the plates through or around the dielectric of the condenser, to dielectric hysteresis, to heat loss in the conducting plates, to corona losses (page 53) from the edges of plates, to the resistance of the connecting wires, and to the resistance due to bad contact between plates. Most of these losses can be grouped together and represented as an *equivalent series resistance* which in general is different for different frequencies. The measurement of this resistance depends on the fact that a change in resistance may be observed when a condenser having losses is substituted in a circuit for a standard condenser having negligible losses. The phase difference may then be calculated from this value of the resistance.

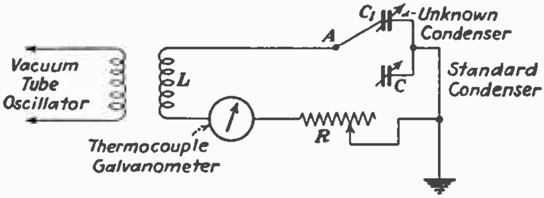


Fig. 38.—Circuit for measuring phase difference.

The apparatus required is connected as shown in Fig. 38. It consists of a vacuum-tube oscillator, a coupling coil L, a thermocouple galvanometer, a resistance box R of the non-inductive type, a standard condenser C having negligible losses, and the condenser C_1 which is to be measured. The two condensers should be placed so that the position of the wire A is changed as little as possible in making the connection from one to the other. The resistance of the galvanometer must be low in comparison with the resistance of the circuit.

After the oscillator is in operation it is coupled to the measuring circuit by the coil L, the standard condenser C is connected into the circuit, and the resistance of the circuit is measured by the resistance-variation method described on page 666. Then the wire A is shifted to the unknown condenser C_1. The circuit is tuned to the oscillator by adjusting C_1, and the value of the capacity at this setting is noted. Next, the resistance of the circuit is measured again. The equivalent series resistance p in ohms of the condenser C_1 is equal to the difference in the two values of circuit resistance. The phase difference w of the condenser C_1 is found from the equation

$$\tan w = \frac{2\pi fpc}{10^6}$$

where w is the phase difference in degrees, f is the frequency of measurement in cycles per second, p is the equivalent series resistance in ohms, c is the capacity of condenser C_1 in microfarads, and π is 3.1416. In a low-loss condenser the angle of current lead is σ and the *power factor* is cos σ or sin w where $w = 90° - \sigma$.

The value of w is usually small and may be considered as equal to tan w. For very small angles the tangent of w is equal to w in radians; and since one radian equals 57.3 degrees, the phase difference is

$$w = \frac{2\pi fpc}{10^6} \text{ (radians)} = \frac{2\pi fpc \times 3.4}{10^3} \text{ (minutes)}.$$

The equivalent series resistance p for a fixed condenser varies directly as the wave length. For a variable air condenser this resistance in general varies inversely as the square of the capacity. If the resistance of a variable air condenser is known for given values of capacity and wave length, the resistance for other values can he calculated from the relation that p varies directly as the wave length and inversely as the square of the capacity. This proportion does not hold if the change in capacity is accompanied by an increase in the amount of imperfect dielectric.

Measurement of Very Small Capacities.—A sensitive method for the measurement of any small capacity is based on the production of beats in an oscillating receiving circuit. The circuit diagram for this method is shown in Fig. 39. The apparatus required consists of a vacuum-tube oscillator and a vacuum-tube receiving circuit which is arranged so that its vacuum tube can be made to oscillate. The receiving circuit has a coupling coil L, a feed-back coil L_1, a variable condenser C for approximate tuning, a variable vernier condenser C_1 of small capacity, the unknown capacity C_2, the vacuum tube with its associated batteries, the telephone receivers H, and a by-pass condenser C_3.

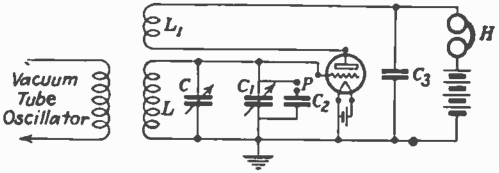


FIG. 39.—Circuit for measuring small capacities.

The condensers C and C_1 must be shielded and the shields grounded. The unknown capacity C_2 is connected across the condenser C_1. The connection on the ungrounded side is arranged so that it can be opened and closed with the least possible change in the position of the wire. The leads from the unknown capacity must be short and are to be connected directly to condenser C_1.

The vacuum-tube oscillator is put into operation at some definite wave length, as, for example, 500 meters. Then, with the unknown capacity in place but disconnected at the point P, the receiving circuit is tuned approximately by the condenser C and then exactly by the condenser C_1 until the zero beat note is observed. A reading is made of the setting of the condenser C_1; and the unknown capacity is connected into the circuit by joining the wires at the point P. When this is done a beat note will be observed in the telephones. Next, the condenser C_1 is adjusted until the condition of zero beat is again obtained, and a reading is made of this new setting of the condenser C_1. The difference between the two capacity readings of the condenser C_1 is equal to the capacity which was to be measured.

Current Measurements.—Measurements of current at radio frequencies are made in transmitting sets, in wave meters, in other testing circuits, and in receiving sets. In high-frequency work, the measurement of current is a fundamental operation, since it is related also to the measurement of resistance, and it is involved in most of the measurements of other quantities. There are three distinct ranges of currents: (1) large currents as in large transmitting sets; (2) moderate currents in small transmitters, wave meters, decremeters (page 112), and other instruments used at a transmitting station; (3) small currents as in receivers and in testing equipment.

The ammeters used generally for low-frequency currents are unsuitable for currents at high frequencies. The inductance and capacity of the circuit within a high-frequency ammeter must be as small as possible to avoid the leakage of current through the dielectric of the instrument. Such a requirement is best fulfilled by a straight small wire, and the current flowing in such a wire is best measured by its heating effect. Hence most *high-frequency ammeters* are of the *hot-wire* or *thermal* type.

Moderate Currents.—Radio currents ranging in value from about 0.003 ampere to 3.0 amperes may be measured with hot-wire ammeters. Several types are available depending on the method used for indicating the production of heat. The *current-square* meter is of the expansion type; a meter designed for full-scale deflection on a current of 0.08 ampere has a resistance of about 5 ohms. The deflections of the indicating pointer are proportional to the *square* of the measured current.

In the *thermoelectric ammeter* the heat developed in the hot wire is indicated by a thermocouple placed near or touching the wire. The voltage produced by the heating of the thermocouple is measured by a direct-current instrument, the deflections of the pointer being proportional to the square of the current. Such instruments may be constructed for currents up to 2 amperes.

The air-thermometer ammeter was formerly used for currents of about 0.05 to 0.5 ampere. This device is really a calorimeter in which the current in a wire heats air in a glass bulb and displaces a quantity of alcohol in one leg of a U-tube.

Large Currents.—Ammeters used in measuring currents of high frequency must not be shunted, because in a shunt circuit the distribution of the current varies with the frequency. To measure high-frequency currents larger than about 3 amperes a single wire will not suffice, and hence for large-current measurements a number of wires or strips in parallel are used. In effect this is a shunt and introduces a considerable error, which varies with the frequency. The heating effect is indicated by an expansion device or by a thermocouple.

The *hot-strip* type of ammeter has a cylindrical arrangement of the heating elements and is used for measuring currents up to 300 amperes. The readings change with the frequency by 1 or 2 per cent, the error being greatest with the highest frequencies. With very fine wires or very thin strips, ammeters for currents up to 20 amperes are reliable for all except the highest radio frequencies.

It should be noted that the so-called "unshunted ammeter" for radio currents up to 20 amperes is entirely unsuitable and has an error of 10 per cent or more.

Very Small Currents.—A number of methods are used for measuring currents of a few milliamperes or less. In addition to the thermal ammeter and the current transformer used for larger currents, use is made of the electrostatic and the magnetic effects of the current and also of rectification into uni-directional current. Thus there is the *crossed-wire thermo-element;* the self-heated thermo-element used with a direct-current galvanometer, which consists of a hot-wire, a thermocouple, and a galvanometer; the *bolometer*, in which a change in resistance of a wire as it is heated causes a deflection of a galvanometer in a bridge circuit; the *electrometer*, which is based on the movement of a light metal vane suspended between two fixed plates upon which voltage charges of opposite sign are induced by an impressed voltage; the *electrodynamometer*, in which a flat disk of silver or copper is suspended concentric with a coil of wire and having its plane at 45 degrees; the shunted crystal detector in connection with a galvanometer; and the vacuum tube in a circuit arranged to measure audibility ratios.

Antenna (Received) Current.—A current produced by a radio signal in an antenna or in a loop circuit can be measured directly either by a thermocouple galvanometer or by a shunted detector and a galvanometer. For currents of moderate strength the thermocouple galvanometer is inserted into an antenna circuit or into a loop circuit as shown in Fig. 40. This drawing shows also the connections for the use of a shunted detector and galvanometer for such measurements; this method having the advantage of high sensitivity, but the crystal being unstable. The circuit is tuned to resonance by means of the vernier condenser C and the coil L. The resistance R may be varied to change the value of the current in the shunt circuit, and the condenser C_1 acts as a by-pass. To avoid any absorption of energy, no tuned circuits should be allowed near the apparatus.

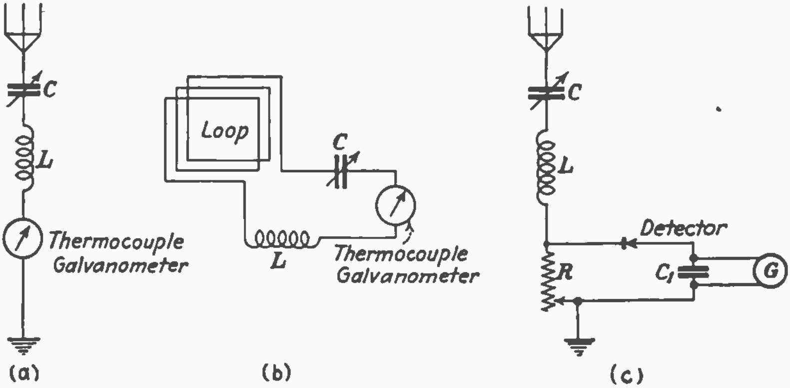


Fig. 40.—Circuits for measuring current in antenna or loop.

The circuit is tuned to resonance with the wave length of the signal to be measured. Then the strength of the received current is observed from the indication of the galvanometer. With a loop circuit, resonance is obtained as before and the indication of the galvanometer is noted. Then the loop is rotated into the position which produces a maximum deflection of the indicating instrument.

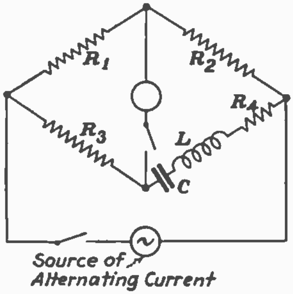


Fig. 41.—Bridge method of measuring frequency.

Measurement of Frequency by Bridge Method.—The bridge shown in Fig. 41 consists of three branches which contain resistances only, which are non-reactive, while the fourth branch contains resistance, inductance, and capacity in series. This bridge will balance at one frequency only, for given values of inductance and capacity. A mica condenser of several sections may be used for the capacity, and a standard variable unit for the inductance. At the condition of balance, the frequency f may be calculated from the expression

$$f = \frac{1}{2\pi\sqrt{LC}}$$

where f is the frequency in cycles per second, L is the inductance in henrys, C is the capacity in farads, and π is a constant (3.1416).

If the source of alternating current supplies a wave having a complex form, a null balance in the telephones will not be obtained for any combination of capacity and inductance. Under these conditions, however, the relation between the intensities of the fundamental frequency and its harmonics do not remain constant if the inductance is varied, and the fundamental frequency may even be made to disappear.

This method may be used to analyze the wave form of a source of alternating current. This is done by measuring first the fundamental frequency and then the harmonics in the order of their intensities. A given frequency may be eliminated by connecting in series with the source a filter section which has been set for parallel resonance so that its impedance for the frequency to be eliminated is very high. After the frequency of the strongest harmonic has been measured, the filter section is adjusted to eliminate this frequency, and the bridge circuit (Fig. 41) is used to measure another harmonic.

Frequency-meter Calibration.—The apparatus required for this measurement consists of a source which will provide an alternating current of variable frequency, such as a vacuum-tube oscillator, the frequency meter which is to be calibrated, and a standard frequency meter. The frequency meters should be provided with an indicating instrument such as a thermocouple galvanometer which is suitable for measuring and detecting alternating currents of small value.

In the application of this method the vacuum-tube oscillator is put into operation, and the uncalibrated frequency meter is coupled to it, as indicated in Fig. 42. Then the condenser in this frequency meter is varied until resonance is indicated on the galvanometer by a maximum reading. The coupling should be weak enough so that the deflection of the galvanometer is less than half the range of its scale. Several readings should be taken in order that an average may be obtained. The next step is to remove the frequency meter and couple the frequency standard to the oscillator to measure the frequency of the oscillator. The same procedure is followed for a number of points over the frequency range of the meter. From these measurements a calibration curve may be drawn for the frequency meter.

Small currents of radio-frequency are generally measured by a galvanometer in connection with a thermocouple or by a shunted detector and galvanometer. The thermocouple used may be the cross-wire type in air or in vacuum; the thermal-ammeter type; or the platinum-tellurium type. The resistance of the thermocouple should be in proportion to that of the galvanometer. If the thermocouple resistance is less than 50 ohms, the resistance of the coil of the galvanometer should not be more than 200 ohms. The deflection of a galvanometer in connection with a thermocouple is assumed to be proportional to the square of the current flowing in the heater element. The instrument must be calibrated to check this proportion and to determine the sensitivity. The current sensitivity is taken as the value of current which corresponds to one division of the galvanometer scale.

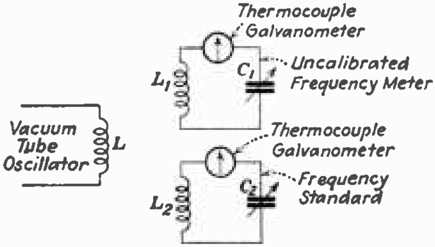


FIG. 42.—Circuit for frequency-meter calibration.

Calibration of Thermocouple Galvanometer with Alternating Current.—This method, as compared with calibration by direct current, has the advantage of greater reliability and should be used if possible. It must be used for calibrating a thermocouple galvanometer of the platinum-tellurium type.

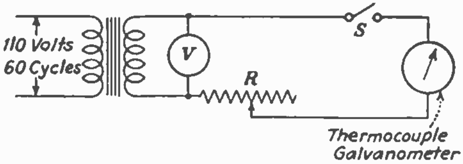


FIG. 43.—Calibration of thermocouple galvanometer with alternating current.

The circuit used is shown in Fig. 43. Power is obtained from a 110-volt, 60-cycle source and is delivered to a transformer which reduces the voltage to about 20 volts. The voltage across the secondary winding of the transformer is measured with the voltmeter V. The resistance R is of the non-inductive type and should be variable from tenths of an ohm up to a maximum value of about 100,000 ohms. In order that the current capacity of the thermocouple may not be exceeded, the maximum resistance of R should be in the circuit when the measurement is begun.

The switch S is closed and the resistance R is decreased until a suitable deflection on the galvanometer is observed. At this point the voltage and the corresponding galvanometer deflection are noted. Then the resistance R is varied so that readings may be obtained of the galvanometer deflection over its working range, together with the corresponding voltages. The current at any setting is calculated from the equation

$$I = \frac{10^6 E}{R_t}$$

where I is the current in microamperes, E is the voltage in volts, and R_t is the total resistance in ohms of the circuit consisting of the thermocouple resistance and the resistance R.

When the values of current corresponding to the galvanometer deflections have been obtained, a calibration curve may be drawn with the values of current plotted against the galvanometer deflections.

Calibration of Thermocouple Galvanometer with Direct Current.—The circuit used is shown in Fig. 44. The resistance R should be variable up to about 10,000 ohms. The instrument A is an ammeter calibrated for milliamperes or microamperes according to the sensitivity of the thermocouple galvanometer. The switch S is of the double-point, double-throw type.

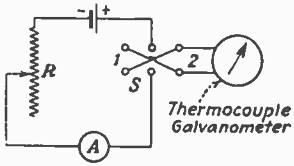


FIG. 44.—Calibration of thermocouple galvanometer with direct current.

In the application of this method, the resistance R is set for its maximum value, and the galvanometer should indicate zero when no current is flowing. Then the switch S is closed and the resistance is adjusted until a suitable galvanometer deflection is obtained. At this point the deflection of the galvanometer and the indication of the ammeter are noted. Next the switch S is reversed and readings are taken of the current and the galvanometer deflection. The ammeter reading will not vary, but the galvanometer deflection may change. For small differences the average may be used, but if the change is considerable the galvanometer must be calibrated with alternating current. If direct current may be used, the procedure is continued by reducing the resistance R in steps and reading at each point the values of current and galvanometer deflection for the two positions of the switch. It may be necessary occasionally to check the galvanometer for zero reading at zero current.

The calibration curve is drawn by plotting the values of current against the galvanometer deflections. It may be shown that the galvanometer deflections are proportional to the square of the current by plotting a curve of the values of the current "squared" against the galvanometer deflections. If the points fall on a straight line, the proportionality holds. The value in milliamperes for one division of the galvanometer deflection may be calculated from the equation

$$I = \frac{I_d}{\sqrt{d}}$$

where I is the current in milliamperes for one division of the galvanometer scale, d is the galvanometer deflection in divisions, and I_d is the current in milliamperes for a deflection d.

Calibration of Shunted Detector and Galvanometer.—A shunted detector and galvanometer circuit, as shown in Fig. 45, consists of a galvanometer which has a high resistance and a high current sensitivity; a fixed condenser C of about 0.5 microfarad capacity, which is connected as a shunt with the galvanometer; a detector D, which may be of the silicon-antimony type; and a resistance R, which must be of the non-inductive type and is variable by small amounts up to about 100 ohms. The sensitivity of the detector varies with exposure to vibration and changes in temperature. To reduce such variations the detector is usually mounted on a felt pad and provided with a wooden cover. The wiring connections between these pieces of apparatus must be as short as possible to minimize induction from stray fields and other local interference. This galvanometer circuit must be calibrated both before and after it is used for measurements, because the sensitivity of the detector is not constant. The circuit is calibrated at radio frequency against a standard thermocouple galvanometer. The

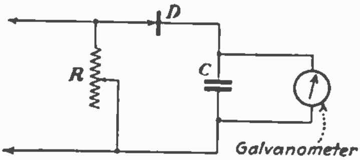


FIG. 45.—Calibration of shunted detector and galvanometer.

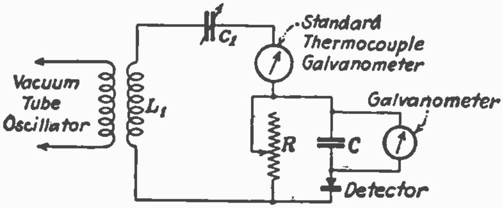


FIG. 46.—Circuit for galvanometer calibration.

arrangement of the apparatus is shown in Fig. 46. The apparatus required consists of a vacuum-tube oscillator, a coupling coil L_1, a variable condenser C_1, a standard thermocouple galvanometer, and the shunted detector and its galvanometer.

The oscillator is put into operation at any convenient radio frequency. The strength of the current flowing in the measuring circuit may be varied by adjusting either the coupling or the capacity of the condenser C_1, or both. These controls are utilized to vary the current until a suitable deflection is obtained on the standard galvanometer. Then the resistance R is set for a low value, the detector is adjusted until a point is found which gives a stable and sensitive contact, and a reading is taken of the deflection of the shunted galvanometer. The current sensitivity of the shunted galvanometer, that is, the value of current corresponding to one division of the shunted galvanometer scale, is calculated from the equation

$$I = \frac{I_s}{\sqrt{d}}$$

where I is the current in amperes corresponding to one division on the scale (current sensitivity) of the shunted galvanometer, I_s is the current in amperes indicated by the standard galvanometer, and d is the deflection in divisions of the scale of the shunted galvanometer, corresponding to the current I_s.

If the value obtained for current sensitivity is not high enough, the resistance R is increased and the sensitivity is calculated again. When a satisfactory value for sensitivity has been obtained, the current flowing in the circuit is increased until the deflection of the shunted galvanometer reaches a desired maximum value. At this point the current sensitivity is again calculated and should be equal to that which was found at the low value of deflection. The equation may also be expressed as

$$I_s = I\sqrt{d}.$$

In this equation I_s is the current in amperes for a deflection of d divisions on the scale of the *shunted* galvanometer.

Any form of dielectric possesses some absorption and consequently causes a loss of electrical energy in the form of heat. The *dielectric constant* (page 55) of materials used for insulators is greater than that of air and hence an insulator may have a considerable capacity. Because of this characteristic an insulator takes a charging current from the circuit in which it is placed. In general there is a loss of power and a phase difference.

Measurement of Power Loss in Insulator.—The method used for determining the losses in an insulator is the same as that for the resistance of a condenser (page 651). The arrangement of the circuit is shown in Fig. 47. The apparatus required consists of a vacuum-tube oscillator, a coupling coil

L, a thermocouple galvanometer, a resistance box *R* of the non-inductive type, a variable condenser *C*, and the insulator to be measured. The condenser should be shielded and this shield should be grounded. It is necessary that the condenser should have a small capacity in order to avoid inaccuracy in measurement, because the capacity of the insulator is small and the introduction of a large capacity during the measurement would minimize the effect of the losses in the insulator. The insulator is connected across the condenser, with the grounded end in the circuit throughout the measurement, and the other end arranged so that the connection can be broken at the point *A*. When the connection is broken the position of the wire should be changed as little as possible. Measurements of the resistance of the circuit are made first without the insulator and then with the insulator. The phase difference of the insulator is determined by the difference between the two measurements. The power loss is calculated from the phase difference.

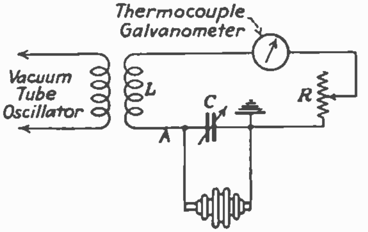


Fig. 47.—Circuit for measuring losses in insulator.

After the oscillator has been put into operation, the connection at the point *A* to the insulator is opened and the resistance of the circuit is determined by the method of resistance variation (page 666). A reading is made of the setting of the condenser. Then the insulator is connected into the circuit at *A*, the setting of the condenser is reduced to tune the circuit, and the resistance of the circuit is determined again. The capacity of the insulator is equal to the difference between the two condenser settings.

The phase difference (page 74) is calculated from the following equation:

$$w = \frac{6.8\pi f p C_1}{10^3}$$

where w is the phase difference in minutes, f the frequency of oscillation in cycles per second, C_1 the capacity of the insulator in micromicrofarads, p the equivalent series resistance in ohms, and π is 3.1416. The equivalent series resistance is found from equation

$$p = \frac{rC^2}{C_1^2}$$

where r is the difference in the measurements of the circuit resistance in ohms, C the capacity of the condenser in microfarads, and C_1 the capacity of the insulator expressed in microfarads. The power loss of an insulator may be determined from the equation

$$P = IE \sin w_0$$

where P is the power loss in watts, E is the voltage in volts, and w_0 is the phase difference in degrees; but $I = 2\pi fC$ where C is in farads and I is in amperes, and for small angles $\sin w_0 = w_0$ (in radians). Hence by the substitution of these values, and by changing C to microfarads and w_0 to minutes,

$$P = \frac{5.88\pi fwCE^2}{10^{10}}$$

where f is the frequency of oscillation in cycles per second, C is the capacity of insulator in microfarads, and w is the phase difference in minutes.

Measurement of Modulation ("see Terry, Advanced Laboratory Practice in Electricity").—In the measurement of modulation by the *transformer method*, the apparatus required consists of an oscillator vacuum tube with its associated input, output, and battery circuits; a thermal ammeter (page 653) for measuring the current in the output circuit; a modulation transformer (page 486), with its primary winding connected to a source of alternating current having a frequency of either 500 or 1,000 cycles per second; and a receiving set. The apparatus should be set up as indicated in Fig. 48, R_1 being a variable resistance used in connection with the upper contacts of the double-throw switch S_1 to obtain a signal from the audio-frequency source. When the lower contacts of the switch are used, a signal is obtained in the telephones through the receiver from the audio-frequency output of the oscillator tube. The coupling of the coil L of the receiver is adjusted in such a way that the intensity of the signal in the telephones is of satisfactory value. The first operation in this measurement is to adjust the oscillator for its normal operation without any modulating voltage. Then the movable arm of the potential divider PD is set so that a small value of voltage is obtained on the primary coil of the transformer as indicated by the reading of the voltmeter V. When the switch S_2 is closed, a reading is taken on the thermal ammeter, and the increase in current is

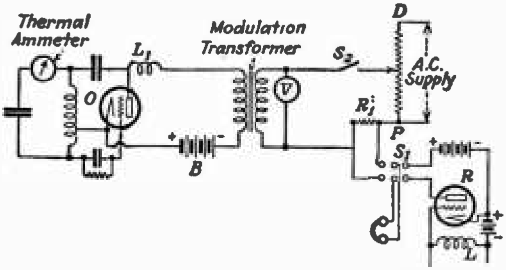


FIG. 48.—Measurement of modulation.

noted. The peak value of the modulation voltage which is impressed on the plate circuit is equal to the voltmeter reading times the transformer ratio times $\sqrt{2}$. The percentage of modulation is equal to the peak value of the modulation voltage multiplied by 100 and divided by the voltage of the battery *B*.

Measurement of Wave Length.—The measurement of the wave length of signals from a continuous wave transmitter is based on the use of a radio receiver provided with a vacuum-tube detector which may be made to oscillate. First the receiver is tuned to the transmitter whose wave length is to be measured. The coupling of the secondary circuit of the receiver is gradually made looser until the signal can just be heard. Then the antenna circuit is adjusted to give a maximum intensity of the signal and the secondary condenser is manipulated until the zero beat note is obtained. The point of resonance is taken at the midpoint of the portion of the condenser scale over which no signal is observed. If the tuning is so sharp that this section of the condenser scale is too wide, the coupling should be made tighter. Next the antenna circuit is opened and a wave meter is coupled to the secondary circuit of the receiver. Then the wave meter is tuned to resonance with the secondary circuit (see wave meter, page 111). The indication of the wave meter is the wave length of the transmitting station. If the radio receiver is shielded, the wave meter cannot be coupled to the secondary circuit. In this case the preliminary adjustments are made as before. Then a continuous-wave oscillator is coupled to the antenna circuit and is made to resonate with the signal by the zero beat method. Next, a wave meter is tuned to the oscillator, and the wave length then observed is that of the transmitting station.

The wave length of a damped-wave signal is measured by the use of a radio receiver and a wave meter provided with a buzzer (page 34). An auxiliary coil of a few turns of wire is connected with the ground wire of the receiver. The receiver is tuned as before to the transmitting station. Then the wave meter is coupled loosely to the auxiliary coil of the receiver and is adjusted for the condition of resonance. A wave meter which has been calibrated for use with a buzzer will indicate, at this setting, the wave length of the transmitting station.

Measurement of Electric Field Intensity.—A determination may be made of the electric field intensity of a signal from a distant transmitting station by measuring the audibility of the received signal. This may be accomplished by the use of an audibility meter or by a telephone-current comparator.

When a vacuum-tube detector which is arranged for oscillation is used (also in heterodyne reception), the telephone current is proportional to the antenna current and to the square root of the antenna power. When a non-oscillating-tube detector, or a crystal detector, is used, the telephone current is proportional to the square of the antenna current and to the antenna power. This telephone current is measured by the audibility meter (page 599) in terms of audibility. With either the oscillating or the non-oscillating detector, the coupling between the primary and secondary cricuits should be set for the most satisfactory value, but regeneration should not be used with the non-oscillating detector. If the non-oscillating tube or the crystal detector is used, the resistance of the antenna should be increased considerably due to the coupling of the resonant secondary circuit. To obtain the most satisfactory value, the coupling is first reduced to the minimum value at which the signal is just audible and both primary and secondary circuits are tuned for maximum intensity of the signal. Next, the coupling is increased to a point which gives maximum response and then is decreased slightly. After this the secondary circuit is retuned. When the receiver has been tuned properly to the signal, the control handle of the audibility meter is moved from zero to a setting just below that at which the signal disappears. The reading of the meter at this setting is the audibility of the signal. The electric field intensity F may be calculated from the following equation:

$$F = \frac{10^6 A\sqrt{wR}}{h}$$

where F is the electric field intensity in microvolts per meter, A the audibility of the received signal (a ratio), w the watt sensitivity of the receiver in watts, R the radio-frequency resistance of the antenna circuit of the receiver in ohms, and h the effective height of the receiving antenna in meters. The *watt sensitivity* of a receiver is the power in watts in the antenna which produces a signal of unit audibility in the telephones. For a loop antenna this equation becomes the following:

$$F = \frac{10^6 A W\sqrt{wR}}{2\pi h l n}$$

where W is the wave length of signal in meters, h the height of loop in meters, l the length of loop in meters, n the number of turns of wire in loop, and π is 3.1416.

Measurement of Logarithmic Decrement.—The following paragraphs cover the calculation of the decrement of a wave meter, the measurement of wave-meter decrement, the measurement of the decrement of a transmitter, and the use of the Kolster decremeter.

In order to calculate the decrement of an isolated circuit such as a wave meter it is necessary to know the values of frequency, radio-frequency resistance at the frequency used, and the inductance or the capacity. The resistance is determined by the method given on page 666, the inductance by the method on page 644, and the capacity by the method on page 645. The decrement of the antenna circuit of a transmitter cannot be calculated in this way, because usually the resistance cannot be measured accurately. The logarithmic decrement D, however, is calculated from the following equations:

$$D = R \div 2fL \text{ or } D = 2\pi^2 fRC$$

where D is the logarithmic decrement, R the radio-frequency resistance in electromagnetic units, f the frequency in cycles per second, L the inductance in electromagnetic units, C the capacity in electromagnetic units, and π is 3.1416. Resistance in ohms is changed to resistance in electromagnetic units by the multiplier 10^9; inductance in microhenrys is changed to electromagnetic units by the multiplier 10^3; and capacity in micromicrofarads is changed to electromagnetic units by the multiplier 10^{-21}.

The decrement of a wave meter may be measured directly by the following resistance-variation method. The apparatus required consists of a continuous-wave vacuum-tube oscillator and the wave meter which is to be measured. The oscillator must have a reserve of power in order that it may not be affected by the wave meter when the frequency of the latter is varied. The influence upon the oscillator of changes in wave-meter frequency increases when the coupling is increased to cause a greater deflection on the meter of the wave meter. The procedure in measuring the decrement is first to set up a condition of resonance in the circuit. Then the capacity of the circuit is varied both below and above the value of capacity at resonance until the induced current in the circuit is decreased to one-half of its value at resonance. At these points readings are made of the condenser setting. Several sets of readings should be taken and a calculation of decrement for each set should be made. The final value of decrement is taken as the mean of these calculations. The current measuring instrument in the wave meter is graduated to indicate the value of the current squared. Hence if the current below resonance is I_1, the current above resonance I_2, and the current at resonance I, then $I_1^2 = I_2^2 = I^2 \div 2$. The presence of a "hump" may be detected by plotting a resonance curve of current squared values against the corresponding values of capacity. The decrement D of the wave meter is calculated from the equation

$$D = \frac{\pi(C_2 - C_1)}{(C_2 + C_1)}$$

where D is the decrement of wave meter, C_2 the capacity at the setting above resonance in micromicrofards, C_1 the capacity at the setting below resonance in micromicrofarads, and π is 3.1416. The decrement calculated in this way is good only for the wave length at resonance. If a curve of decrement or wave length is plotted against the capacity required, the decrement must be measured at a number of points over the capacity range of each coil used in the wave meter.

This method may be used to measure the *decrement of a transmitter.* The value then obtained from the equation for decrement is the decrement of the wave meter *plus* the decrement of the transmitter. Consequently, the decrement of the wave meter must be known. It should be noted that a set of measurements must be made at each wave length for which the decrement is desired. The transmitter must be tuned to resonance and the wave meter must be located so that it is coupled only to the antenna circuit. As in the measurement of the decrement of the wave meter alone, several sets of readings are taken, and the decrement is averaged from the values of decrement thus obtained.

The *Kolster decremeter* is a device consisting of a wave meter designed for the measurement of *logarithmic decrement* and a meter which indicates current-squared values. In the use of this device for measuring the decrement of a transmitter, the condenser of the wave meter is set at the position of resonance which is indicated by the maximum deflection of the current meter. Next, the capacity of the condenser is adjusted until the deflection of the current instrument is reduced to one-half its value. Then the decrement plate is set at zero and clamped. When the condenser is again adjusted the decrement plate moves with it. Next, the condenser is adjusted continuously in one direction until the pointer of the current instrument passes from the position of half deflection to a maximum and back to half deflection. At this point the figure on the decrement plate opposite the index mark indicates a value of decrement, which is equal to the decrement of the wave meter plus that of the transmitter.

Measurement of Radio-frequency Resistance by Resistance-variation Method.—The measurement of radio-frequency resistance by the method of resistance variation has the advantages, compared with other methods, of accuracy and speed. Single measurements are accurate to about two per cent, and the average value of several measurements is accurate to about one per cent. The apparatus required consists of a vacuum-tube oscillator, a variable condenser C, a resistance box R_1 of the non-inductive type, a calibrated thermocouple galvanometer, and a coupling coil L. The diagram of connections is shown in Fig. 49. The output of the oscillator must remain constant to avoid inaccuracies in measurement. If possible, storage batteries of the lead-acid type should be used in order to obtain constant voltages. The condenser must be shielded and the shield connected to the ground to eliminate the effect of body capacity (page 637). The condenser should be of the air-dielectric type having negligible losses. At frequencies above 1,500 kilocycles the resistance box may have the effect of detuning the circuit, and hence the use of the straight-wire type of resistance is preferable at the higher frequencies. The resistance of the thermocouple should not be more than one-third to one-half of the circuit resistance. The coil must be kept away from any metal such as the condenser case in order to avoid an increase in the coil resistance due to the formation of induced eddy currents (page 11) in the metal.

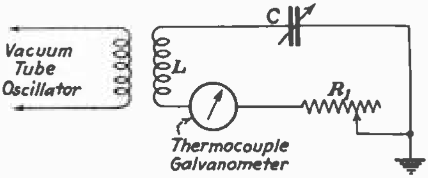


FIG. 49.—Measurement of radio-frequency resistance.

The first step in the procedure is to place the oscillator into operation at a given frequency. The circuit, with no resistance inserted, is tuned exactly to this frequency, the condition of resonance being indicated by the maximum deflection of the galvanometer. The value of the current I at this point is noted. Under these conditions the value of the current indicated by the galvanometer is

$$I = E \div R$$

where E is the voltage induced in the circuit in volts and R is the resistance of the circuit in ohms. Next, a resistance R_1 of a known value is inserted in the circuit, such that the galvanometer deflection is reduced to half its former value, and the new value of the current I_1 is noted. During this measurement the voltage E has the same value as before, and consequently

$$I_1 = E \div (R + R_1).$$

These two equations give a value for R of

$$R = R_1 \div \left(\frac{I}{I_1} - 1\right).$$

If the coupling between the circuits is tighter than necessary, too much power is taken from the oscillator. This may have the effect of changing the output of the oscillator and in turn the value of voltage induced in the measuring circuit. A measurement repeated at looser coupling will show a variation if the coupling for the first measurement was too tight.

Measurement of Series Resonance (see Terry, "Advanced Laboratory Practice in Electricity").—The relations between the current, the voltage, and the characteristics of an electrical circuit, for the condition of resonance in series, parallel, and coupled circuits have been described on page 82. In a measurement of series and parallel resonance, the apparatus used in most cases consists of a vacuum-tube oscillator, a resonant circuit of variable frequency, and a thermocouple galvanometer. The vacuum-tube oscillator should have a calibration curve which gives the frequency for any setting of the oscillation condenser. This apparatus is connected as in Fig. 50. The variable condenser C of the resonating circuit is set at its midpoint, and resonance is established by varying the frequency of the oscillator. The coupling should be adjusted to such a value that the reading on the thermal galvanometer is about 0.8 of the full-scale deflection. This is a condition of series resonance because the voltage producing the current in the resonating circuit is induced in the inductance L by mutual inductance; that is, it is in series with the circuit. The values for a family of resonance curves such as those shown in Fig. 51 are obtained by adjusting the oscillator for various frequencies on either side of the resonant frequency and reading on the galvanometer the current corresponding to each setting. The flattening of the curves in this figure is the result of introducing different values of resistance in the resonant circuit.

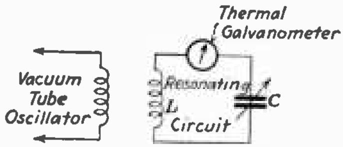


FIG. 50.—Measurement of series and parallel resonance.

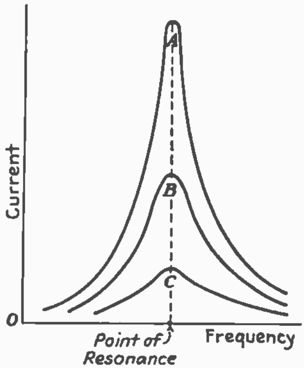


FIG. 51.—Resonance curves.

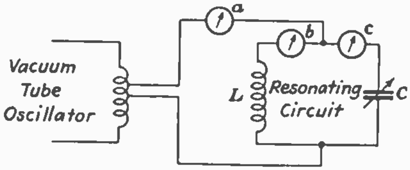


FIG. 52.—Oscillator connected for parallel resonance.

Measurement of Parallel Resonance.—In this measurement the apparatus is set up again as in Fig. 50 and the two circuits are adjusted for resonance at about the middle of their frequency range. Then the resonating circuit is placed in such a way that its coil L has no mutual inductance with the oscillator, and the resonant circuit is connected with the oscillator for parallel resonance as shown in Fig. 52. The energy required for the resonating circuit is obtained from a connection which is made across one turn of the coil of the oscillator. Three thermal galvanometers are required: (*a*) to measure the total current in the resonating circuit, (*b*) to measure the current in the coil, and (*c*) to measure the current in the condenser. The frequency of the oscillator is varied above and below the midpoint of its frequency range, and readings on the galvanometers are made for each setting of the frequency. It is to be noted that in this measurement for parallel resonance, the constants of the resonating circuit are fixed while the impressed frequency is varied. With this circuit it is possible also to obtain data for the condition of parallel resonance when the impressed frequency is constant and the frequency of the resonating circuit is varied.

Resonance in Coupled Circuits.—When two circuits, each of which has a resistance less than the critical value and is capable of independent oscillation, are coupled together, the combination has two natural frequencies. These two frequencies are different from either of the frequencies of each circuit by itself; one of them is above the larger of the individual frequencies, and the other is below the smaller of the individual frequencies. Such oscillations are called "normal nodes." In general, when two such circuits are set in oscillation, the combination oscillates according to both frequencies at once and two distinct frequencies f_1 and f_2 are present simultaneously in each circuit. The beats between these two frequencies result in amplitudes which vary alternately from their sum to their difference. Consequently, energy shifts from one circuit to the other at the frequency of the beats.

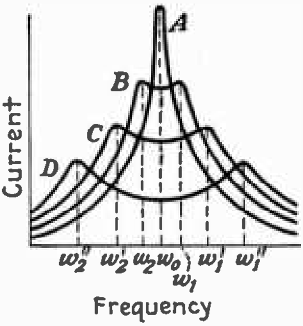


FIG. 53.—Curves of coupled resonant circuits.

The separation between the two resonance frequencies increases with the tightness of coupling. The resonance curves for such a combination are shown in Fig. 53, in which a curve of the current in one of the coupled circuits is drawn against frequency. The degree of coupling increases in the order *A* to *D*. The *coefficient of coupling* t may be calculated from the relation

$$t = \frac{f_1^2 - f_2^2}{f_1^2 + f_2^2}.$$

Measurement of Resonance in Coupled Circuits.—The apparatus required consists of a vacuum-tube oscillator, two identical resonance circuits which have a variable mutual inductance between them, and one thermocouple galvanometer. The set-up of the apparatus is indicated diagrammatically in Fig. 54.

The vacuum-tube oscillator is put into operation at a frequency in the middle of its range. Then the two resonance circuits are adjusted independently to resonance with this frequency. The condition of resonance is indicated by the reading of the thermocouple galvanometer. Then the two resonance circuits are so arranged that the coupling between them is loose, and they are brought into inductive relation with the oscillator. The galvanometer may be inserted in either of the resonance circuits. The coupling between the circuits and the oscillator is adjusted so that the reading of the galvanometer is at about eight-tenths of the full-scale range.

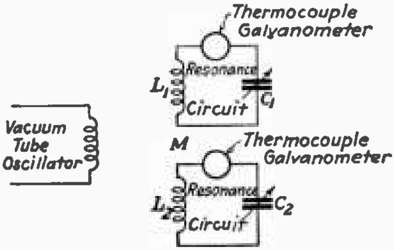


FIG. 54.—Measurement of resonance in coupled circuits.

As the frequency of the oscillator is varied, readings may be taken of the galvanometer indications to obtain curve *A* of Fig. 53. When this range of frequency has been covered, the coupling is tightened and the procedure is repeated to obtain the values for the curves *B*, *C*, and *D*.

Measurement of Amplification Constant of Vacuum Tubes.—The amplification constant u is defined as the ratio of the change in plate voltage to the change in grid voltage which causes an equal change in plate current. The circuit shown in Fig. 55 is due to Van der Bijl and is used in the application of a direct-current method for the measurement of the amplification constant. The apparatus required consists of the vacuum tube to be measured, the filament and plate batteries, a milliammeter *A*, a switch *S*, a battery *E* of about 20 volts, and the resistances r_1 and r_2. The unit r_1 consists of there rheostats; one has a resistance of 10 ohms, variable in steps of one ohm; the second has a resistance of 100 ohms, variable in 10-ohm steps; and the third, a resistance of 1,000 ohms, variable in 100-ohm steps. The setting of the dials of the rheostats will give the amplification

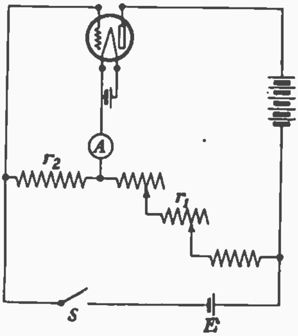


FIG. 55.—Circuit for measurement of amplification constant.

constant directly if the dials are graduated in tenths of the actual resistance. The resistance unit r_2 has a resistance of 10 ohms.

When the switch S is closed, the voltage applied to the grid is opposite in direction to the voltage applied to the plate. The applied grid voltage is proportional to resistance r_2, and the applied plate voltage is proportional to r_1. The effect on plate current of a voltage applied to the grid has u times the effect of the same voltage applied to the plate. Hence, if r_1 and r_2 are adjusted so that no change is indicated by the milliammeter A, then,

$$r_1 = ur_2, \text{ and } u = r_1 \div r_2.$$

Alternating current instead of the battery E may be used for this measurement with a few circuit modifications. A low-voltage source of alternating current at a frequency of 1,000 cycles per second is substituted for the battery E, and a pair of telephones for the meter A.

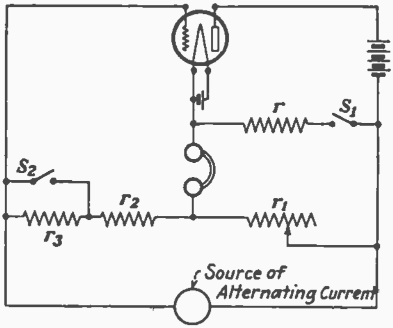


FIG. 56.—Circuit for measuring plate resistance.

Measurement of Plate Resistance.—The circuit shown in Fig. 56 may be used to measure both the plate resistance and the amplification constant. The unit r has a resistance of 10,000 ohms or more, depending on the type of vacuum tube used. The units r_1 and r_2 are similar to those shown in the previous measurement. The unit r_3 is equal in resistance to r_2. When the switch S_1 is closed and the switch S_2 is opened, the resistance r_1 is to be varied until a balance is obtained. This condition is indicated when silence is observed in the telephones. The plate resistance R_p is found from the equation

$$R_p = r\left(u\frac{2r_2}{r_1} - 1\right),$$

or, since $u = r_1 \div r_2$, $R_p = r$. In this case R_p, r_1, r_2, r_3, and r are in ohms and u is a ratio (amplification constant).

To measure the *amplification constant*, the switch S_1 is opened, the switch S_2 is closed, and r_1 is adjusted until there is no change of current in the plate circuit; that is, until there is silence in the telephones. At this setting the amplification u is equal to $r_1 \div r_2$.

Measurement of Vacuum.—The test for the presence of gas in a vacuum tube is based on the ionization of the gas. The circuit to be used is shown in

Fig. 57. The plate battery *B* may have a voltage of 200 volts or more if necessary to produce a high plate current. The electrons composing this current collide with the molecules of gas in the tube and ionize many of them. An ionized molecule of gas acts like a positive ion and is attracted to the grid, which is negative. This movement of positive ions is equivalent to a flow of current in the grid circuit from the grid to the filament on the outside of the tube. This flow of current is called a *reversed current* because it flows in a direction opposite to that of the current due to the movement of negative electrons to the grid. The strength of the reversed current is a measure of the rate at which positive ions are produced and consequently is also a measure of the amount of gas in the tube. The reversed current is indicated by the microammeter *A*. The value of the reversed current in a normal tube may not be more than a fraction of a microampere.

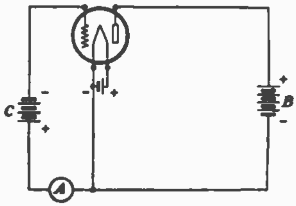


Fig. 57.—Circuit for measuring vacuum.

Measurement of Efficiency of Vacuum-tube Oscillator.—The apparatus may be set up as in Fig. 58 so that oscillations take place in the circuit *LRC*, the direct-current power being supplied by the battery. The blocking condenser C_1 is used to prevent the coil *L* from acting as a short-circuit across the tube. This coil *L* serves also to transfer the voltage across the plate turns of *L* to the plate. The value of *L* should be large compared to the capacity *C*. Another coil L_1 is used to prevent the alternating voltage between the plate and the filament from being short-circuited by the battery. The filament is connected to a point below the middle turn of *L* and is grounded. The grid-bias voltage for the tube is obtained by the use of the condenser C_2 and the resistance of the voltmeter V_2. The capacity of the condenser C_2 must be large enough to transfer voltage to the grid without any appreciable loss. The desired value of grid-bias voltage is obtained by selecting the proper size of the resistance which is shunted across the condenser C_2. For an oscillator of high power it is preferable to use a resistance of the grid-leak form instead of the voltmeter. The load resistance *R* and the capacity *C* are contained in a box with variable adjustment.

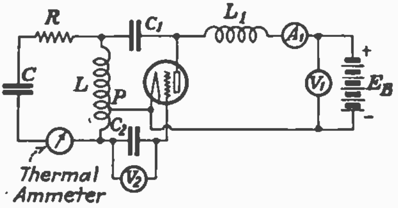


Fig. 58.—Circuit for measuring oscillator efficiency.

After a suitable value of the resistance load R has been selected, the ratio of the plate and grid turns is adjusted so that the reading of the thermal ammeter has a maximum value. The input power is obtained from the readings of the voltmeter V_1 and the ammeter A_1. The value of the output radio-frequency current is obtained from the reading of the thermal ammeter. Readings of the input voltage, the input current, the output radio-frequency current, and the grid-bias voltage are taken as the resistance load R is varied from zero to the largest value for which the thermal ammeter gives an indication. During these measurements it is necessary that the "supply" voltage be kept constant.

The next step is to compute the output power for these measurements. Then, with the resistance held constant at the value which gives the maximum output power, the supply voltage is varied over a wide range, and a second set of measurements are made of the input voltage, the input current, the output radio-frequency current, and the grid-bias voltage. It is necessary also to measure the filament voltage and the filament current so that the filament power may be calculated. The resistance of the voltmeter V_2 must be known.

The efficiency is taken as the output (watts) divided by the input to the plate circuit (watts) for each set of measurements. The *output power* in watts for each set of measurements is calculated from the relation I^2R where R is the resistance load in ohms and I is the current in amperes observed with the thermal ammeter. Likewise, the *input power* in watts for each set of measurements is calculated from the relation V_1I_p where V_1 is the plate voltage in volts and I_p the plate current in amperes. The grid-circuit loss is equal to $V_2^2 \div R_2$ where V_2 is the reading obtained on the grid voltmeter and R_2 is the resistance of that meter in ohms. For the first set of measurements, a curve may be drawn of efficiency against resistance load R; and for the second, of efficiency against the input of the plate circuit. Similarly a curve of grid-circuit loss may be drawn for each set of measurements.

Vacuum-tube Voltmeter.—A type of circuit commonly used as a vacuum-tube voltmeter is shown in Fig. 59. In this figure T is a vacuum tube, B is a 90-volt battery, C is a grid-biasing battery, and A is a *milliammeter*. The *alternating voltage to be measured* is impressed across the points marked 1 and 2. The value of the grid-bias voltage is such that the vacuum tube is operated at the lower bend of the static characteristic curve of plate current against grid voltage. For this condition of operation a given positive

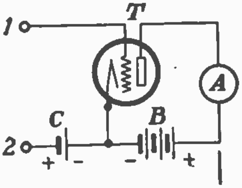


Fig. 59.—Circuit of vacuum-tube voltmeter.

change in grid voltage causes a greater variation in the plate current than an equal negative change in grid voltage; in other words, there is an increase in the average value of the plate current, and this increase may be observed on a direct-current milliammeter. It follows that if an alternating voltage is applied to the grid, the reading of the meter *A* is increased. This device may thus be used as an alternating-current voltmeter when there is a known relation between the indications of the milliammeter *A* and the effective value of an impressed alternating-current voltage.

The apparatus required is shown in Fig. 60 and consists of a suitable vacuum tube, a B battery, a C battery, a potentiometer which is used to vary the value of the voltage applied to the grid, and an alternating-current voltmeter. The alternating current used for calibration may be obtained from a 110-volt, 60-cycle line through a transformer having a secondary voltage of about 20 volts. The range of the milliammeter to be used as explained in the preceding paragraph should be such as to give full-scale deflection when the plate current reaches its saturation value.

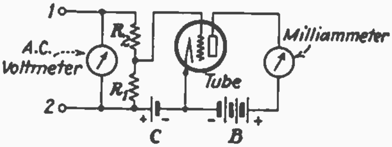


FIG. 60.—Calibration of vacuum-tube voltmeter.

After the vacuum tube has been put into operation, the grid-bias voltage is first adjusted so that the plate current reaches its maximum value, and then the grid-bias voltage is changed until the plate current becomes about one-tenth of its maximum value. This point on the scale of the milliammeter is used as the zero for the calibration curve. Next, the alternating-current voltage is applied across the points 1 and 2, and the resistances R_1 and R_2 are varied so that several readings of current are obtained over the scale range of the milliammeter. Readings are also taken of the indications of the alternating-current voltmeter. With these values a calibration curve may be drawn, plotting the alternating-current voltages against the readings of the milliammeter.

The vacuum-tube voltmeter gives indications which are independent of frequency if the relation between the changes in plate current and the squares of the effective values of the applied grid voltages is a straight line.

Calibration of Wave Meter by Comparison.—A wave meter is calibrated by setting it to be resonant (page 88) with a *standard* wave meter over a given range of wave lengths. At the point of resonance the wave length of the wave meter is equal to that of the standard. The comparison is made by tuning first the unknown wave meter and then the standard to a vacuum-tube oscillator. The condition of resonance is detected (1) by the *maximum deflection* of a "current-squared" indicator (page 111) of a wave meter; (2)

by the *click* method in connection with an oscillating vacuum-tube receiver; or (3) by the deflection of an *ammeter in the grid circuit* of an oscillating vacuum tube.

In the *maximum-deflection* method the apparatus required consists of a high-power vacuum-tube oscillator, the wave meter to be calibrated, and a standard wave meter. The first step in the calibration is to open the detector contact of the unknown wave meter as well as its buzzer (page 111) switch. Then the first coil is inserted and the condenser set at about 20 degrees. Next the oscillator is tuned approximately to the unknown wave meter and then this wave meter is adjusted for resonance with the oscillator. At this point the exact setting of the condenser of the wave meter is noted. Now the wave-meter is tuned off the point of resonance, and the standard wave meter is tuned to the oscillator. The setting of the condenser of the standard wave meter is then noted. The wave length of the standard wave meter at this setting is taken as the wave length of the wave meter to be calibrated. This procedure is repeated at steps of about 10 degrees over the condenser scale for each coil of the unknown wave meter. If one of the wave meters is provided with fixed condensers instead of the variable type, the oscillator is adjusted to resonance with it, and then the wave meter with the variable condenser is tuned to the oscillator. When the necessary data have been obtained a calibration curve is drawn by plotting wave lengths in meters against condenser settings in degrees.

In the *click method* an oscillating vacuum-tube receiver with telephones in
the plate circuit is used to detect the condition of resonance. The wave
meter used must have a low radio-frequency resistance and must be coupled
i very loosely to the tube circuit. When the condenser of the wave meter is
teurned to pass over the point of resonance, two clicks are heard in the
poilephones, one occurring below the resonance point and one above. The
occu t of resonance is taken as the mean of the setting at which the clicks
vacuu . These clicks are produced where the frequency of the oscillating
wave met -tube receiver is affected by the action of the circuit of the resonant
may be affecte If the coupling is not loose, the wave length of the oscillator
coupled circuit about the point that it follows the changes in frequency of the
clicks will be spaced farther ap of resonance. When this is the case, the
possible; but as the coupling is loose t, and accurate measurements are not
The circu should be adjusted to b ued the clicks will come closer together.
conden r scale for each coil and to pr ing the clicks near the middle of the
abou half a degree. duce a spacing between the clicks of

n the *grid-meter method* an oscillating
an meter in the grid circuit is used to detect vacuum-tube receiver with an
adv antages of this method are: (1) No indica the point of resonance. The
ing device for resonance is

needed in the wave meter; (2) the tuning is very sharp; (3) the coupling can be looser than that necessary in the click method; and (4) it can be used to calibrate wave meters of high resistance. In an oscillating-tube circuit the value of the grid current is reduced when the condition of resonance with a coupled circuit is established, as the condition of resonance occurs when the current reaches its lowest value. The apparatus required for this method

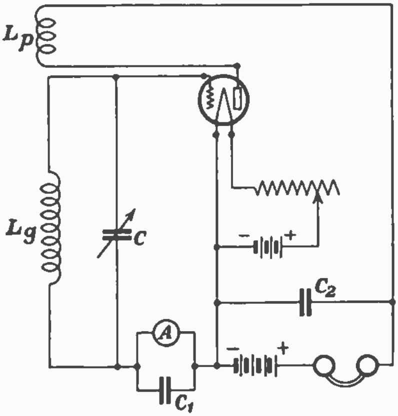


Fig. 61.—Circuit for calibration of wave meter.

consists of the wave meter to be calibrated and an oscillating vacuum-tub s
receiver which serves as the source of power. A diagram of the connection is
for such a receiver is shown in Fig. 61. This receiver has a tuned grid and rect
provided with a plate-coupling coil. The average value of the di which
current flowing in the grid circuit is indicated by a microammeter *A* rofarad.
is shunted by a by-pass condenser having a capacity of about 0.1 micr age and
The generation of oscillations is controlled b[illegible]ths. If the volt current is
the coupling between the plate and the griderminal of the tube, oscillations
reduced when the finger touches the grid p in the calibration is to adjust the
are present in the circuit. The first stepoint at which oscillation begins. At
receiver so that it is just beyond the pot at resonance is greatest. Then the
this setting the decrease in grid current and the point of resonance is located
wave meter is tuned to the oscillatortelephones. Next, the coupling is made
approximately by the clicks in thetuned to the oscillator until resonance is
looser and the wave meter is ding of the meter in the grid circuit. (Data
indicated by the minimum reaRadio Telegraphy and Telephony, U. S. Navy.)
from Robison's Manual o

SECTION XIII

PHOTO-ELECTRIC CELLS

Operation of Photo-electric Cells.—In recent years, various devices which are very sensitive to light have found application. One of these light-sensitive devices is the photo-electric cell which is sometimes called the "electric eye." The photo-electric cell depends for its operation on the principle that a current of electricity will flow through it only when sensitive parts of the device are illuminated. As illustrated in Figs. 1 and 2, the photo-electric cell consists essentially of an anode and a cathode, these being sealed into a suitable bulb from which the air has been removed to produce an almost perfect vacuum, or else the bulb has been filled with an inert gas like *argon* at a low pressure (usually 0.04 to 0.02 millimeter of

Fig. 1.—Typical photo-electric cell.

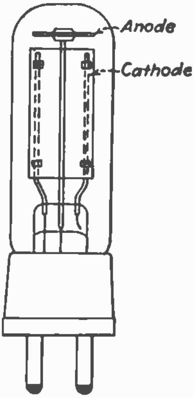


Fig. 2.—Arrangement of elements of photo-electric cell.

mercury). The effect of the argon is greatly to increase the flow of current due to the ions produced by the collision of the normal electrons with the gas molecules. The photo-electric cell operates very much like a two-element vacuum tube. In the most successful designs, the anode is a wire extending out from the bottom of the bulb into its central portion, the wire being "capped" in some designs by a small disk. The cathode is a material, usually caesium, which has the property of emitting large numbers of electrons when its surface is illuminated. The coating of caesium on the inside of the bulb is, in many cases, deposited on a "backing of metallic magnesium." After the electrons have been emitted from the cathode, their passage toward the anode may be hastened if a voltage of the right polarity and of suitable magnitude is applied between the cathode and the anode. A simple circuit including a photo-electric cell, an ammeter, and a battery is shown in Fig. 3. With these arrangements, a current flows through the cell and its circuit as shown, when its cathode is illuminated. A photo-electric cell must, obviously, have some provision for admitting light; and for this purpose, a small "window" is left in the magnesium backing.

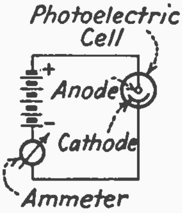


FIG. 3.—Simple photo-electric circuit.

The control of electric current by the action of light falling on a coating of caesium in a photo-electric cell may take place very rapidly. In fact, if a source of light is cut off from the cell several thousand times per second, the electric current will be affected the same number of times, following quite accurately the variation in light intensity.

It is possible to use a photo-electric device of this kind for the purpose of controlling an electric current with the very rapid variations of sound with respect to pitch and volume as in speech and musical instruments. If a very delicate telephone is made a part of the electric circuit including a photo-electric cell as described, the variations in sound communicated to the diaphragm of the telephone receiver can be made to produce corresponding changes in the intensity of a suitable source of electric light; and by means of a photo-electric cell, this light of varying intensity can be made to produce variations in the electric current in the part of the circuit in which the photo-electric cell is included, and then by the use of amplifying devices and loud-speakers the sounds can be reproduced from the electric current in very much increased volume.

Types of Photo-electric Cells.—There are two general types of photo-electric cells: (1) high-vacuum type and (2) gas filled; and each of these general groups has many kinds of special designs for use, particularly with different wave lengths of light. The three special kinds of tubes which are in greatest demand may be designated as follows: (1) VA cell is a vacuum type with a light-sensitive coating of caesium on a backing of metallic magnesium on the surface of the cathode cylinder; (2) VB cell, also of the vacuum type, with caesium as the sensitive material, but prepared in a different way from that used in the VA cell in order to obtain different characteristics; (3) GB cell which is of the gas-filled (argon) type but is otherwise similar to the VB cell.

As the pressure of an *argon-filled* cell is increased, the sensitivity of the cell is increased until the pressure is about 0.1 millimeter of mercury. If the pressure of the argon inside the cell is increased beyond this amount, the sensitivity gradually decreases. It should be observed, however, that the pressure of the argon giving the highest sensitivity is not always most desirable for the operation of the photo-electric cell because of the instability of its operation at this *critical value of pressure.*

There are many variable factors entering into the design of a photo-electric cell, these factors having important influences on the operating characteristics of the cell. The VA, VB, and GB photo-electric cells have their greatest sensitivity for visible light rays, that is, for the visible part of the spectrum. Other designs of photo-electric cells can be made to have their greatest sensitivity for ultra-violet rays, and still others for infra-red rays.

Sensitivity Curves.—The sensitivity of a photo-electric cell, that is, the amount of current passing through the cell per unit of light called a *lumen* (see "Industrial Electricity and Wiring," by Moyer and Wostrel, pages 241 and 264), depends on the voltage impressed between the cathode and the anode. Figure 4 shows this relation between sensitivity in micro-amperes per lumen to the impressed voltage between the cathode and the anode.

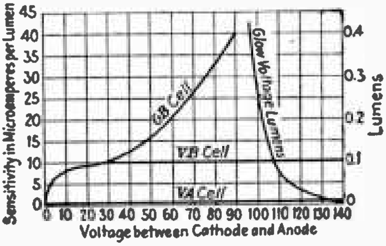


FIG. 4.—Typical sensitivity curves.

It will be observed in this figure that the operating characteristics of the VA cell are entirely different from those of the VB or the GB cells. The VB cell reaches almost complete saturation when the impressed voltage is about 30 volts. In other words, when the applied voltage is above 30 volts, no appreciable effect is produced on the amount of current passing through the cell for a given quantity of light falling upon the sensitive material. When the impressed voltage is less than 30 volts, there is apparently very little difference between the operation of the VB and the GB cells. The point of divergence of the two curves is the voltage at which the electrons leaving the light-sensitive surface of the gas-filled cell reach a high enough velocity to ionize (page 672) the gas through which they pass. This ionization of the gas produces a secondary flow of current through the photo-electric cell which is represented by the difference between the curves of the GB and VB cells when the impressed voltage is more than 30 volts. It will be observed that there is still another curve in Fig. 4 which is marked "glow voltage lumens." This curve indicates the conditions as regards impressed voltage and current flowing through the photo-electric cell at which a glow discharge occurs. The information given by this curve is valuable because it is essential that in all the designs of photo-electric cells the condition of glow discharge will never be produced in service, as the single occurrence of a glow discharge is likely permanently to alter the sensitivity of the cell.

It will be noticed that the VA cell passes relatively very little current per lumen when compared with the VB or the GB cells for the kind of light which is equivalent to that from an incandescent lamp. On the other hand, in certain color ranges, the VA cell is more sensitive than the VB cell, so that the principal application of the VA cell is in cases where colored light is used.

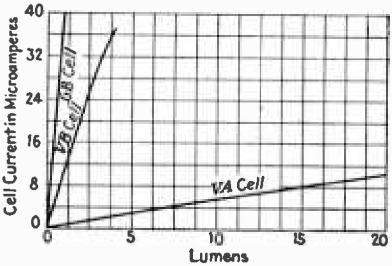


FIG. 5.—Illumination characteristics.

Illumination Characteristics. For the usual range of illumination, the current passing through a photo-electric cell of the types shown in Fig. 4 is directly proportional to the amount of illumination. The illumination characteristics for the VA, VB, and GB cells are shown in Fig. 5.

Selection of Photo-electric Cell.—The types of photo-electric cells, for example the VA, VB, and GB cells, are intended for different service requirements. The VA cell, although especially desirable for some applications where colored light is used, is less sensitive as shown in Fig. 4, than the other two types to the light from an incandescent lamp. The GB cell has advantages when very great sensitivity is necessary, especially where amplifiers are to be used, or when the glow voltage becomes an important factor.

Life of Photo-electric Cells.—Because of the complicated processes and the limited experience with the materials used in the manufacture of photo-electric cells, there are no very definite limits of cell life and constancy in operation. On the average, however, the well-constructed photo-electric cell has a useful life of about one year of practically continuous service under normal operating conditions. This statement does not apply, of course, in those applications where a photo-electric cell can be used satisfactorily only when it passes the amount of current corresponding to its *initial maximum sensitivity*, as measured in micro-amperes per lumen of an incandescent lamp. In such cases, the useful life of a photo-electric cell is very much less than it would be when some deterioration of sensitivity would not make the photo-electric cell unsuitable for further use. On the other hand, the amount of illumination to which a photo-electric cell is exposed has apparently no effect on the life of the cell. It should be noted, however, that exposure to any kind of light which causes the cell to attain a high temperature due to radiant heat will produce a reduction in the life of the cell. Photo-electric cells may generally be subjected to a temperature up to 150°F. without detrimental effects. Temperatures do not affect the sensitivity of a photo-electric cell unless the temperature is so high that the cell is damaged.

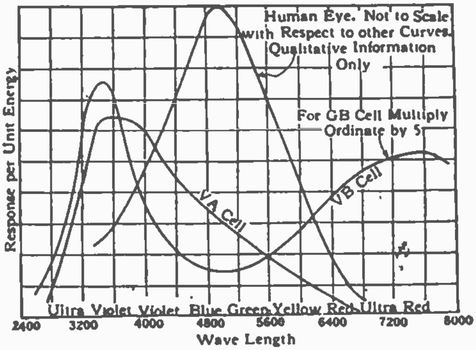


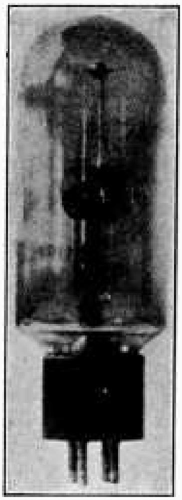
FIG. 6.—Influence of wave length of light on response of human eyes and cells.

The gas-filled type of photo-electric cell has usually a shorter life than the high-vacuum type. It is, therefore, desirable to use the high-vacuum type of photo-electric cell in every case where the somewhat greater sensitivity of the gas-filled cell is not necessary.

The influence of the wave length of light on the response of the various types of cells and of the human eye is shown in Fig. 6.

One type of *gas-filled cell* is intended for operation with an applied voltage which is high enough to ionize the gas and produce a glow discharge. The photo-electric cells for this kind of service, called *photo-glow tubes*, have a considerably higher gas pressure than the ordinary gas-filled photo-electric cell. The glow discharge from such a cell is sufficiently large (usually several milliamperes) to operate sturdy relays. The photo-glow tube is a half wave rectifier and, consequently, direct-current relays may be operated by the current passed through it. A typical photo-glow tube and its characteristic curves are shown in Fig. 7. Photo-glow tubes, as now constructed, have a life of less than 1,000 hours if operated for continuous glowing. In the present state of development, the life of the photo-glow tube is, therefore, relatively short and its application for the operation of relays is limited to services which are more or less intermittent, that is, to cases where the tube will not be required to glow continuously.

The principal difference between the photo-glow tube and the photo-electric cell is that the current passed through the photo-electric cell is proportional to the illumination as shown in Fig. 5, while the current passing through the photo-glow tube when once started is practically constant. It will be observed in Fig. 7 that the breakdown and break-off voltages are given by two sets of curves: (1) for alternating current; and (2) for direct current. The *breakdown voltage* is the value at which the glow starts, and the *break-off voltage* is the value at which the glow ceases. The information given by these two sets of curves is useful in many cases, as it shows the limits within which a glow discharge can be maintained in photo-electric cells during small changes in illumination.



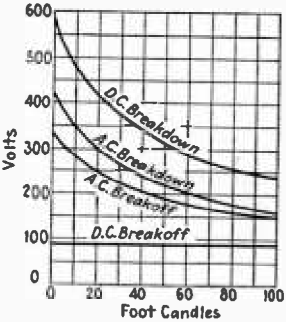


FIG. 7.—Photo-glow tube and its characteristic curves.

Photo-electric cells belong to the group of devices which has been studied for a number of years but has found practical applications only recently.

Selenium Cells.—One of the earliest light-senstive cells that was developed, but is now largely displaced, is the selenium cell which operates on the principle that the resistance of the metal selenium to the flow of electricity varies with the amount of illumination.

The selenium cell is a device in which the light-sensitive property of metal selenium is applied for the purpose of *operating a control relay*. These cells have entirely different properties from the so-called "photo-electric cell," in that the current output of the cell when a constant voltage is applied varies with the *square root of the illumination*, while in the photo-electric cell, the current output varies directly with changes in illumination. Cells of the selenium type are not commercially successful. Those that have appeared on the market are intended for very low voltages, have a very small current output, and are, therefore, not *generally* applicable for the control of the ordinary type of relay.

Selenium cells are usually constructed by depositing a strip of the metal selenium between the surfaces of two electrodes and then subjecting the cell thus constructed to a kind of heat treatment intended to produce the desired characteristics. The selenium cells have no real advantages over the present types of photo-electric cells but have the disadvantage, in addition to those already enumerated, that even when there is no appreciable illumination there will be a so-called "dark current" flowing between the electrodes and, therefore, through the cell. In other words, the selenium cell permits some current to pass through it when it is not illuminated; and, further, this dark current is not constant for different conditions but depends on the temperature of the cell and also somewhat on the method used in making it. In general, it may be stated that selenium cells are not so dependable in service as photo-electric cells and that they deteriorate more rapidly. The possible advantage of the selenium cell over the photo-electric type is that a single cell can be made to operate on an impressed voltage of 110 volts and will then pass enough current to operate a sturdy relay without an amplifier. In order to obtain, however, the passage of several milliamperes through a selenium cell to operate the usual type of relay, it is necessary to use a comparatively large cell which cannot be readily sealed in a high-vacuum bulb; and, unless the selenium cell is enclosed in a satisfactory vacuum, it deteriorates very rapidly.

Amplifying Vacuum Tubes for Photo-electric Cells.—The current which can be passed through a photo-electric cell is so small that it is measured in microamperes and can be used to operate only small and very sensitive relays or other similar instruments. In order to increase the power of a photo-electric cell, a method of amplification almost exactly the same as that applied in radio receiving sets has been devised to increase the power or, in other words, to amplify the effect obtainable with this type of cell. The photo-electric cell when supplemented with an amplifier unit, makes available currents of electricity which are measured in milliamperes instead of microamperes; and the outfit is so arranged that changes in illumination of the cell cause corresponding changes of the plate current in the amplifier. Several vacuum-tube amplifiers may also be used in "cascade" (in series) in various ways to secure a large amplification or increase in value of the original current passed through the photo-electric cell. In many cases, therefore, a single stage of amplification is sufficient for supplying the amount of current needed. In other cases, it is necessary to use two or even three stages of amplification (page 355) in order to obtain the necessary power.

Types of Multistage Amplifiers.—There are three general types of multistage amplifiers. These three general types can, however, be modified in a number of ways for special services. All the amplifiers used in connection with photo-electric cells belong to one of the types now in use, these being: (1) resistance-coupled amplifiers, (2) condenser-coupled amplifiers, and (3) transformer-coupled amplifiers.

Resistance-coupled Amplifiers.—A typical circuit in which the amplifier is connected by the method of resistance coupling is shown in Fig. 8. According to the arrangement of this circuit, when the photo-electric cell is not illuminated, the first stage has a negative grid-bias, meaning that the grid is negative with respect to the filament by an amount determined by the setting of the potentiometer P. The amount of grid-bias voltage or the negative charge on the grid will determine the amount of current flowing through the plate circuit of the amplifying vacuum tube. This flow of plate current will result in a voltage drop over the plate resistance R in the direction indicated by the signs. The grid-bias voltage in the second stage will then be equal to the difference between the voltage drop over the resistance R and the battery voltage between A and the negative end of the battery, with the voltage over the resistance R always the smaller. The second-stage plate current or output of the amplifier will then be determined by this grid-bias voltage.

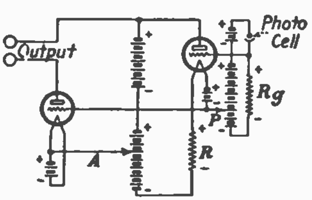


FIG. 8.—Resistance-coupled amplifier.

If a small amount of light falls on the photo-electric cell (Fig. 8), a current will flow from the positive terminal of the battery through the cell, and then through the grid resistance to the negative terminal of the battery. As a result of the current flow in the direction indicated, a voltage drop will occur across the resistance R_g, with the polarity as shown by the signs. This voltage drop will make the grid of the first tube of the amplifier more positive, and as a result more current will flow in the plate circuit and through the resistance *R*. The increased current flow through the resistance *R* will increase the voltage drop over the length of this resistance and make the grid of the second amplifying vacuum tube more positive, with a resulting higher output from the second stage of amplification.

This amplifier is most useful where it is absolutely essential to obtain the amplification of "pure" direct current. The number of stages which can be added to this circuit is limited, because, as successive stages are added, small variations in the first-stage tube characteristics are reproduced in increasing effect through the amplifier.

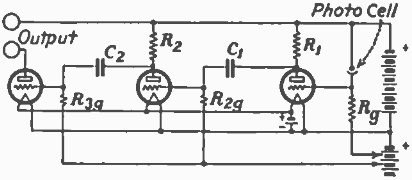


Fig. 9.—Condenser-coupled amplifier.

Condenser-coupled Amplifier.—The condenser-coupled amplifier circuit as shown in Fig. 9 is particularly valuable when amplification of very low frequencies is necessary. It is possible to adjust the circuit constants so that frequencies as low as two or three cycles per second can be correctly amplified.

The circuit is quite similar to that in Fig. 8 except that a condenser is used to prevent the effect of the direct-current flow in any one stage on the grid of the next succeeding stage. As a result, only impulses above a certain frequency are accurately transmitted to the grid of successive stages. This amplifier is much more stable than the one shown in Fig. 8 for the reason that small changes in the vacuum tubes and other minor variations are not transmitted through the amplifier unless they are of considerable frequency. The voltage amplification of a circuit of this type is from 4 to 100 per stage, depending largely on the amplifier used. The higher figure is for a screen-grid tube (page 305), in which case the circuit shown should be modified somewhat to suit the tube.

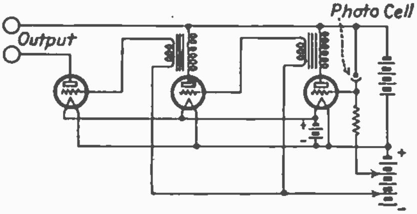


Fig. 10.—Transformer-coupled amplifier.

Transformer-coupled Amplifier.—The transformer-coupled amplifier circuit, shown in Fig. 10, does not differ greatly from that in Fig. 9, since a transformer is used to block the plate voltage of one stage from affecting the grid voltage of successive stages. Unlike the circuits in Figs. 8 and 9, however, the successive stages are insulated from each other instead of using a conducting medium between the plate circuit of one tube and the grid circuit of the following tube. The voltage amplification of this type of amplifier is from 20 to 200 per stage, depending on the amplifier used. The higher figure is for a screen-grid tube.

Many special forms of this type of amplifier can be designed. For instance, an amplifier can be designed to respond only to certain predetermined bands of frequencies such as from 800 to 1,200 cycles per second. With a proper design, amplifiers can be built to give essentially constant amplification over the range from 20 to 10,000 cycles per second. This limit can be extended still further by careful designing.

Forward and Reverse Circuits for Photo-electric Cells.—The vacuum-tube amplifier can be connected to a photo-electric cell so that its output current (page 304) either increases or decreases when the amount of illumination on the photo-electric cell is varied. The kind of circuit in which the output current of the amplifier increases with an increase of illumination of a photo-electric cell is called a *forward circuit;* the one in which the output current of the amplifier decreases when the illumination of the photo-electric cell increases is called a *reverse circuit.* One method of coupling the photo-electric cell to a vacuum-tube amplifier is by means of a grid resistance. Forward and reverse circuits in amplifiers will be discussed in the following paragraphs.

A vacuum-tube amplifier when supplied with direct current is the most sensitive amplifying device that is available. It has the further advantage that the output current of the amplifier per unit of illumination of the photo-electric cell is proportional to the product of the sensitivity of the photo-electric cell and the grid resistance. It is, therefore, possible to obtain almost any degree of sensitivity by using a very sensitive photo-electric cell and a high value of grid resistance. This highest value of grid resistance must be determined by its effect on the stability of the circuit in which it is to be used.

Unless very great sensitivity is actually required, it is usually desirable to avoid the use of the direct-current type of vacuum-tube amplifier and use instead the simpler type of amplifier operating with alternating current. The direct-current amplifier, if used in connection with alternating-current apparatus, must, of course, be supplied for its filament circuit with direct current from a rectifier or from a battery, although the current from a transformer of suitable secondary voltage can be used as a current supply for *heating* the filament. If, however, no appreciable hum or ripple is permissible in the output of the amplifier, the transformer method cannot be used for supplying current for heating the filament. Most applications of photo-electric cells will permit small amounts of hum or ripple in the output circuit, as most applications are for the operation of relays.

The forward circuit and the reverse circuit in such applications are very much alike. The forward circuit is the one more commonly used, except when the apparatus and the light source receive current at a somewhat varying voltage. Figure 11 shows a *typical forward circuit* in which the plate voltage plus the grid-bias voltage acts as the effective voltage for the photo-electric cell. When the photo-electric cell is dark, the grid of the vacuum-tube amplifier will be at a negative potential with respect to the filament as determined by the potentiometer *H* (page 121), as shown at *A* in Fig. 12. This is on the assumption that zero grid current is flowing through the grid resistance, which will be approximately the case if the vacuum-tube amplifier is properly manufactured and selected. When light falls on the photo-electric cell, a current flows from the positive terminal of the B battery through the milliammeter and relay to the anode or positive terminal of the photo-electric cell. From this point the flow is through the cell, the grid resistance, and then to the point *H* of the potentiometer and the negative end of the battery. The current flow produces a voltage drop over the grid resistance in such a direction as to cause the grid to become more positive with respect to the filament as indicated in Fig. 11 by the signs beside the grid resistance. Because of this change in the grid-bias voltage, at such a point as *B* in Fig. 12, an increased current will flow through the vacuum-tube amplifier.

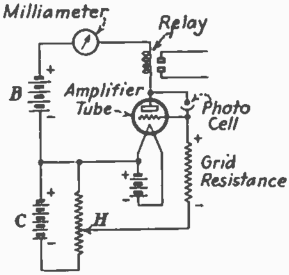


Fig. 11.—Typical direct-current forward circuit.

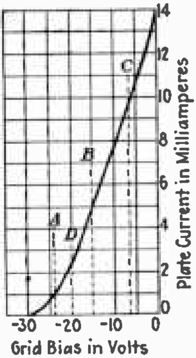


Fig. 12.—Characteristics of amplifier tube.

The current change in the output of the amplifier will be linear with respect to light under proper circuit conditions, since the response of the photo-electric cell varies directly with respect to the amount of light.

The characteristic curve of the amplifier tube shown in Fig. 12 explains this relation, except at the extremes of the grid-bias voltage. The amplifier should, therefore, be operated on the straight part of its characteristic curve and a grid resistance should be used having a resistance that does not change appreciably with a change of voltage.

In Fig. 13 is shown the *characteristic curve* of the circuit in Fig. 11 plotted with plate current of the amplifier tube as a function of units of light intensity (lumens) on the photo-electric cell for various initial current settings and illuminations. It will be noted that a point is reached as the illumination is increased at which the plate current seemingly saturates. As the point of zero grid current is passed in the positive direction, the current begins to flow from the circuit of the photo-electric cell to supply the positive grid current. A point is finally reached at which the increase in current passing through the photo-electric cell supplies the grid with current without an appreciable change in the plate current.

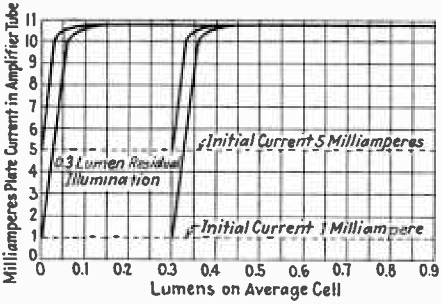


FIG. 13.—Response curve for forward circuit.

Figure 14 shows a *typical reverse circuit* supplied with voltage from batteries, although, as explained for the forward circuit above, a transformer can frequently be used for the filament supply. The operation of this circuit is only slightly different from the operation of the forward circuit. When the photo-electric cell is dark, the grid-bias voltage is obtained in the same manner as before, although less bias voltage is used to produce a current as indicated by the point *C* in Fig. 12. When the photo-electric cell is illuminated, a current flows from the midpoint of the potentiometer through the grid resistance, the photo-electric cell, and back to the negative side of the battery. The grid resistance will then have a voltage drop over it tending to make the grid more negative. The grid thus receives a higher negative potential, as at the point *D* in Fig. 12.

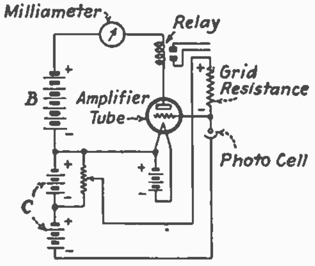


FIG. 14.—Typical direct-current reverse circuit

In Fig. 15 is shown the characteristic curve of the circuit in Fig. 14, plotted with the plate current of the amplifier tube as a function of the lumens (page 679) on the photo-electric cell. The plate current cannot be less than zero and, as is shown in Fig. 12, decreases to zero as the negative grid-bias voltage is increased.

Speed of Operation.—The speed of operation of the *photo-electric cell and an amplifier tube* in combination depends entirely on the size of the grid resistance in the circuit of the amplifier tube, since, individually, the amplifier tube and the photo-electric cell will respond to radio frequencies. The grid resistance and input capacity (page 304) of the amplifier tube result in a *time constant* depending on the input capacity of the particular tube and circuit and the grid resistance. The actual time delay may be about 0.001 second for an average circuit.

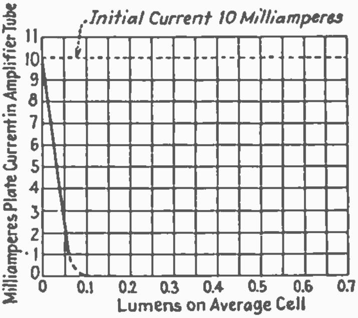


FIG. 15.—Response curve of reverse circuit.

Amplifier for Use with Alternating Current.—The vacuum-tube amplifier when used with alternating current is suitable for any relaying, indicating, or recording application in which sufficient sensitivity is obtained with its use. A factor to be remembered, however, is that the output of this circuit is *pulsating* direct current. Consequently, extremely rapid variations in light (short compared with one-half cycle) will not be faithfully amplified. This circuit is used in *smoke-recording devices* (page 700) to obtain a very simple design.

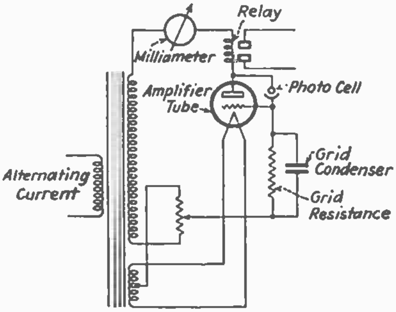


FIG. 16.—Alternating-current circuit of photo-electric cell and amplifier.

Figure 16 shows a typical forward circuit of this kind. Obviously, this circuit is similar to the circuit shown in Fig. 11. It is possible to operate the amplifier tube and photo-electric cell directly on alternating current, because both the amplifier tube and the photo-electric cell are half-wave *rectifiers*. The amplifier tube is operated so that when the alternating-current wave is such that the plate is positive, the grid is negative with respect to the filament. When the voltage is on the other half of the cycle, no current is passed, due to rectification, and it is immaterial what happens in the grid circuit, as long as desirable conditions of control and of grid-bias voltage are obtained on the positive half of the cycle. At the part of the cycle in which the amplifier is capable of passing current, the photo-electric cell also passes current creating a voltage drop over the grid resistance in a manner similar to that in a direct-current circuit.

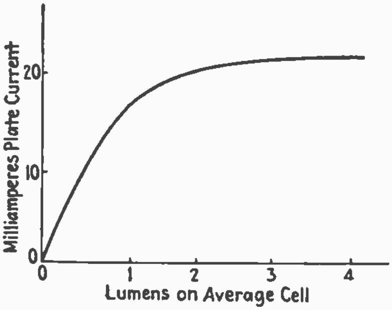


FIG. 17.—Response curve of circuit in Fig. 16.

The grid condenser serves the purpose of reducing the grid-bias voltage required to reduce the plate current to a given value when the photo-electric cell is dark. Without the grid condenser, the effective negative grid voltage is thrown out of phase with the plate voltage at high grid resistances, thus rendering the grid control ineffective. The out-of-phase condition, obtained when the grid condenser is absent, is caused by the input capacity of the tube acting in combination with the high grid resistance. The grid condenser brings the effective negative grid voltage into phase with the plate voltage, thus assuring the most effective use of the grid-bias voltage. The importance of the grid condenser is due to the fact that the "dark" current of the amplifier is unaffected if the grid resistance changes in service and lower grid-bias voltages are required.

In Fig. 17 is shown the characteristic curve of the circuit in Fig. 16. This characteristic curve is similar to the one shown in Fig. 13 for the direct-current forward circuit except that less sensitivity to changes in illumination is obtained.

A typical reverse circuit of this type is shown in Fig. 18. In theory of operation, it is similar to that in Figs. 14 and 16. It is similar to Fig. 14 since it is a reverse circuit, and similar to Fig. 16, since the circuit is for alternating-current operation. In Fig. 19 is shown the characteristic curve of the circuit in Fig. 18, with the output current plotted as a function of the illumination on the photo-electric cell. It will be noted that this circuit is somewhat more sensitive than that in Fig. 16.

Multi-cell Circuit.—Figure 20 shows a circuit identical with that of Fig. 11 except that a group of cells have been connected in series in place of the single cell. This circuit is valuable in applications requiring the *scanning of reflecting surfaces* for dark spots. When one cell is darkened, the result is the same as when darkening all the cells. This makes it possible to detect smaller spots than would be possible with a single large cell, unless a complicated mechanical scanning device is used.

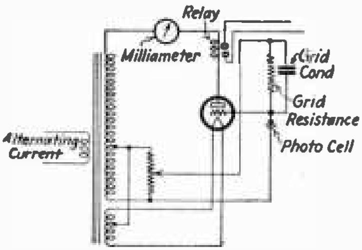


Fig. 18.—Reverse circuit for alternating-current operation.

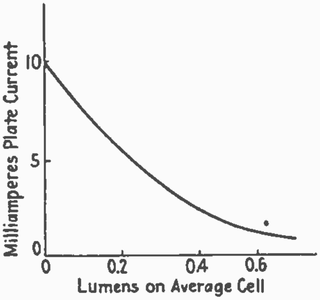


Fig. 19.—Response curve of circuit in Fig. 18.

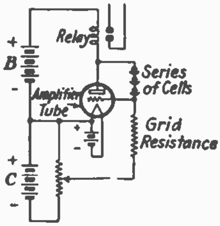


Fig. 20.—Circuit of photo-electric cells in series.

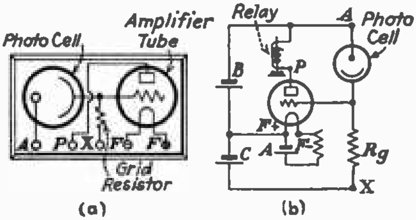


Fig. 21.—Amplifier panel.

The layout of a panel for amplifiers and its wiring diagram is shown in Fig. 21. Figure 22 shows a typical vacuum tube which is suitable for amplifying the current passing through photo-electric cells.

Characteristics of Amplifiers for Photo-electric Cells.—The characteristics of the amplifying tube shown in Fig. 23 are very desirable for use in connection with photo-electric cells. The reason for this is that the current is directly proportional to the grid-bias voltage in all but the left-hand part of each curve. This proportionality makes it easy to calibrate the apparatus for use in measuring devices where a graduated scale is desired for taking observations. The relation between the plate voltage and the plate current for the amplifier tube is shown in Fig. 23, the filament voltage being about six volts. As shown in Fig. 24, the plate current is not appreciably affected by other than abnormal changes in the filament voltage.

Stability is an important consideration in selecting amplifying vacuum tubes for photo-electric cells. In order to insure stability for an amplifier, it is usually necessary to keep the grid current at a rather low value.

Fig. 22.—Typical photo-electric cell and amplifier in combination.

The coupling of a photo-electric cell to an amplifying vacuum tube is usually accomplished most effectively by the use of a grid resistance in the grid circuit of the amplifier. The greatest amplification of the current passing through a photo-electric cell is obtained in this coupling device by applying the highest value of grid resistance which the characteristics of the amplifier will permit. In an *ideal* amplifier there should be no current in the grid circuit, if there is a very low vacuum in the bulb and no leakage of current. These ideal conditions cannot, however, be obtained in practice. The actual relation between the negative grid-bias voltage and the plate current of a poor and of a good amplifier are shown in Fig. 25. These curves represent the data obtained from two amplifier tubes of the same type when used for the same conditions, with a resistance of several megohms in the grid circuit. It will be noted that the good tube has a low negative grid current, while the poor tube has a relatively high negative grid current.

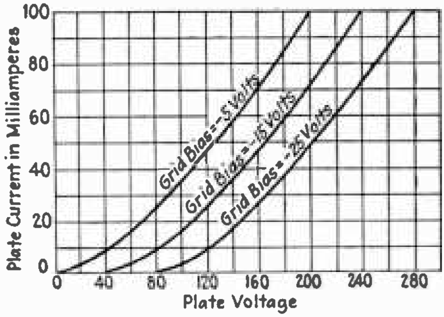


Fig. 23.—Characteristic curve of typical amplifier tube.

Tubes having the characteristics of the poor tube, as shown in Fig. 25, are not stable. For constant circuit conditions, the poor tube will give varying and undependable output of plate current due to temporary changes in the tube.

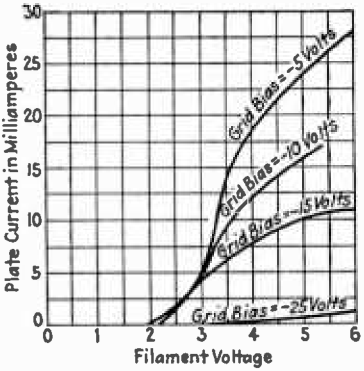


Fig. 24.—Variation of plate current of amplifier tube with filament voltage.

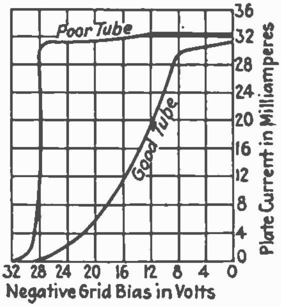


Fig. 25.—Characteristic curves of good and poor tubes.

Life of Amplifier Tubes.—An important factor in the selection of amplifier tubes is their life and constancy in service. It is desirable to use tubes which are specially designed, seasoned, and selected for this type of service.

The usual type of such tubes has a life of about 1,000 hours of continuous operation; but by careful designing and unusual precautions in manufacturing, the amplifier tubes for use with photo-electric cells are being made which have a life of about one year of continuous service. An amplifier tube which gives very good service in radio receiving sets may be quite unsatisfactory for use with photo-electric cells.

Applications of Amplifiers.—An application of amplifiers in combination with photo-electric cells has been made in devices for sorting and counting materials. These applications depend on the reflections of light from the surfaces of the materials and the reception of this reflected light on the sensitive surface of the photo-electric cell. The *amplifier* connected to the photo-electric cell is arranged to control automatic devices which sort materials according to the degree of their irregularities, and, similarly, the passage of opaque objects through the illumination which is reflected on the photo-electric cell can be used for the purpose of automatic counting. It is possible to match colors very accurately by the use of color filters used in conjunction with photo-electric cells and suitable amplifiers (page 691).

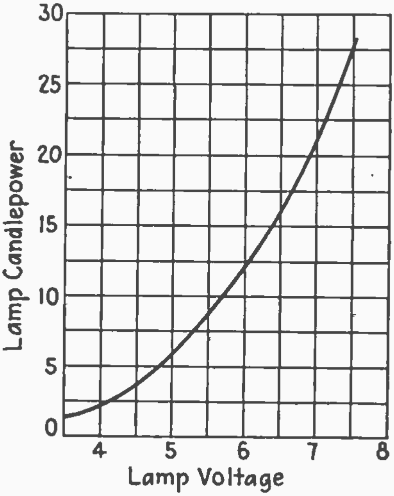


FIG. 26.—Candlepower of low-voltage Mazda lamp.

Light Sources for Photo-electric Cells and Similar Devices.—Two types of light sources may be required for use with photo-electric cells in various types of apparatus in which they may be used. One type of light source must be suitable for use in a projector. This form of lighting requires a concentrated filament. The other type of light source is used merely to illuminate the photo-electric cell or other light-sensitive device that is used. In any case, an excess of light over that required for the operation of the device is essential. One reason for this is that any type of incandescent or similarly constructed lamp has its candlepower reduced with use, and also because photo-electric cells decline gradually in sensitivity. Means must, therefore, be provided, preferably at the source of light available, to maintain operating conditions at an even standard during a considerable period of time. Incandescent lamps intended to operate at a voltage which is less than 110 volts are usually preferred, because they have smaller filaments than the 110-volt lamps. Since the candlepower of an incandescent lamp increases approximately as the *fourth power* of the voltage, it is considered advisable to operate such lamps at as high voltages as possible, with a maximum efficiency consistent with long life. Figure 26 shows the variations of the candlepower of a modern Mazda low-voltage lamp with voltage.

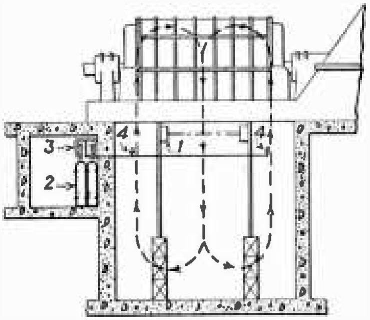
Grid Resistances for Light-sensitive Cells.—The design of resistances for use in the grid circuit of all kinds of light-sensitive devices of the vacuum-tube type is an important matter. Such resistances are intended, of course, to have the current pass through them, and, because of the voltage drop across the resistance, they provide a method of controlling the operation of the device with which they are connected. For example, such resistances may serve as "load resistors" for photo-electric cells and for amplifying vacuum tubes. For these purposes, it is necessary that such resistance have the following properties: (1) small temperature coefficient; (2) little change in resistance with changes in voltage; (3) long life in service.

Industrial Applications of Photo-electric Cells.—Photo-electric cells have found wide application for industrial and entertainment purposes. Among these may be mentioned the following: (1) "talking" motion pictures; (2) television; (3) counting objects passing a given point; (4) detecting and measuring the density of smoke.

Photo-electric Cells for On-and-off Action.—For the lighting of factories, shops, offices, and stores as well as also for the control of the lighting of electric signs, the photo-electric cell has found numerous applications because of its sensitiveness to daylight, the photo-electric cell operating to turn off lights at sunrise and to turn on lights at sunset or, at other times during the day, when the light intensity is low. The photo-electric cell can be adjusted to operate at any light intensity up to about 20 foot-candles (page 698). When the intensity of light falls below the desired minimum, the light-control switch is closed through the action of the photo-electric cell. One of the most numerous applications of the photo-electric cell in on-and-off action is for counting packages on a conveyor as they pass a certain point, it being arranged that a light beam when interrupted or cut-off from the photo-electric cell by a package operates the counting device. Vehicles, persons, or any object that is large enough to interrupt a small beam of light may thus be counted accurately up to a rate of about 300 per minute. A magnetic counting device operated by the current from a photo-electric cell and an amplifier, may be used to record the number of times that the beam of light is interrupted. When a suitable source of light is provided, the photo-electric cell may be placed at distances varying from a few inches to 10 or 15 feet away from the objects being counted.

Another class of applications of the photo-electric cell is of the kind which operates a suitable relay for ringing an alarm or lighting lamps when there is a break in the continuity of a strip of material, for opening garage or factory doors, and for temperature-control devices. Photo-electric cells may be used to operate signal lights to indicate the position of dangerous doors and the location of trucks and other vehicles in one-way passages or in dangerous locations.

Photo-electric Cells for Burglar and Fire Alarms.—The method of operating a relay by the agency of a photo-electric cell combined with an amplifier can also be arranged to operate burglar-alarm systems in dark rooms where there are safes and vaults. Light-sensitive cells may be placed inside a small safe or vault which is dark except when the door is opened. Devices of this kind have been designed in which the light for operating the photo-electric cell is of a kind not visible to the human eye. When a device of this kind is used, the person producing the alarm will not be aware of the existence of the device which he has set in operation. The photo-electric cell in this case should obviously be made extremely sensitive to light, so that it will operate with a small amount of illumination from a flash light.



1. Smoke Detector *3. Electric-Automatic-Manual Head*

2. Carbon Dioxide Cylinders *4. Discharge*

FIG. 27.—Smoke protector.

Photo-electric cells may also be used as very sensitive fire alarms. Their sensitivity to the slightest change in the intensity of light falling on them makes it easy to have a fire alarm operated from the flame of a very small fire. It is stated that even a puff of smoke from a cigarette is sufficient to set off a fire alarm of this kind and to open the valves in a sprinkler system. It is also used for the protection of power-plant equipment from fire or overheating. The type of equipment which is frequently protected in this way includes electric generators, transformers, and switch vaults. This apparatus is also suitable for the protection of industrial equipment where a fire is apt to spread quickly and cause damage in a short time, as, for example, in dipping tanks, booths for spraying lacquer, and similar apparatus. Figure 27 shows the application of a photo-electric smoke "protector" which operates for the protection of electric generators by the interruption of a ray of light by the smoke produced by a fire. In this case, the amplifier unit operates a relay which discharges carbon dioxide from pressure tanks located in the generator pit.

Photo-electric Cells for Sorting and Color Matching.—There are a number of interesting examples of the use of photo-electric cells for the measurement of different *intensities* and *qualities* of light. An entirely different application of photo-electric cells comes about in the use of these cells for sorting materials of various kinds, such as cigars, beans, and oranges, according to size and color. Any variation in the quality or quantity of light reflected from them may cause the photo-electric cell to operate a barrier or other device for removing or segregating all the objects that deviate from a fixed standard. In this application, any slight change in the amount of light reflected by the moving objects into the photo-electric cell can readily be made to stop a machine or conveyor. Electrical inspection of this kind is more rapid than is possible with similar work done with the human eye, and this method eliminates the "human factor" as indicated by fatigue or eye strain which tends to lower the accuracy and effectiveness of inspection work.

The sensitivity of the photo-electric cell, for example, is illustrated by the fact that it is used for automatically sorting tobacco leaves in cigar factories. In this application, the photo-electric cell matches colors very successfully and throws out of line all the tobacco leaves that are either too dark or too light. It is probable that the photo-electric cell can also be used to distinct advantage in the study of vibrations of running machinery. New uses and applications of photo-electric cells are continually developing, and it is safe to say that the present list of applications will be very much increased.

Photo-electric Cells for Sign Lighting.—An interesting application of the photo-electric cell is for controlling the incandescent lamps on electric signs. The lighting of electric signs is usually controlled by an automatically operated time switch controlled by a clock. The clock switch operates at certain predetermined times, the setting of the clock being independent of conditions of light or darkness on clear or cloudy days. The photo-electric cell when applied to this kind of service will operate according to light conditions or rather according to light intensity, whatever it may be. A device applying a photo-electric cell for sign illumination is shown in Fig. 28. This device as shown in the figure consists of a cylindrical metal tank about one foot in diameter upon which is placed a small periscope facing northwest. In the figure, the window in the periscope is pointed toward the right-hand side. Behind this window of the periscope is the photo-electric cell with its light-sensitive surface pointed toward the window so that it receives the unobstructed light from the sky.

The device can be adjusted to operate with almost any light intensity. The apparatus described here is arranged so that the incandescent lights of the electric sign are lighted when the illumination of the window of the periscope is less than ten foot-candles. A *foot-candle* is a unit of illumination which is defined as the average distributed light of one candle over a surface of one square foot from the source of light.

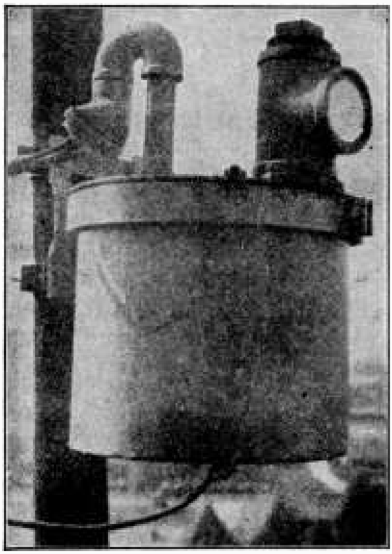


FIG. 28.—Sign-lighting equipment.

The photo-electric cell because of the very small current flow through it cannot, of course, of itself control the switches that are needed for lighting the electric sign. But this small current can be amplified by means of a vacuum tube having three or more elements, so that the amplified current is of sufficient strength to operate an electric *relay* device similar to those commonly used in telegraph and telephone service. The vacuum-tube relay and switches are located in the cylindrical metal tank shown in the figure. Although the device described here is said to operate when the illumination of the window of the periscope is ten foot-candles, it is just as easy to have it operate at any other light intensity by simply adjusting the relays in the cylindrical metal tank to operate at a different value of current. In some cases a time switch is connected in series with a photo-electric control device so as to turn off the incandescent lights in the electric sign at midnight or some other hour of the night when illumination of the sign is not desired. The same time switch can also be used to put the electric sign under the control of the photo-electric cell so that the electric sign will be illuminated at any time during the day when the amount of illumination at the window of the periscope becomes less than ten foot-candles, and also the photo-electric cell will shut off the lights of the electric sign when the illumination at the window exceeds ten foot-candles. On days when the sky is clear the starting time is, of course, later than on cloudy days. The complete device needs very little power for its operation, requiring less than ten watts continuously. It is, of course, possible to increase the power of the device for operating switches by almost any amount by providing additional relays. The accuracy of the device is such that it is sensitive to variations from any setting within one or two foot-candles. When the illumination at the window of the periscope is so low that it is below the setting of the unit, the photo-electric cell operates its relay and closes the switches required to light the lamps of the electric sign, and these lamps remain in operation until the illumination increases again to a value above the setting of the unit. With such flexibility of operation, the device may be installed in locations where the light intensity varies considerably.

Photo-electric Cells for Street and Interior Lighting.—The same type of device that is used for controlling the light of electric signs can be adapted with scarcely any modification to the control of street and highway lighting. At the present time such lights are turned on or off according to a fixed schedule which is not usually adjusted to allow for variations in illumination on clear and cloudy days. With the application of the photo-electric device, the lights on streets and highways would be turned on at the exact moment when the daylight intensity drops to a point where the light is not sufficient for safety and could be turned off when the daylight increases to a point where artificial light is not required. This device can be applied equally well for purposes of interior lighting, being especially adaptable to the requirements of schools, offices, storerooms, and for the operation of floodlights, of building exteriors, and for store-window illumination. A typical circuit diagram of a photo-electric device for these purposes is shown in Fig. 29.

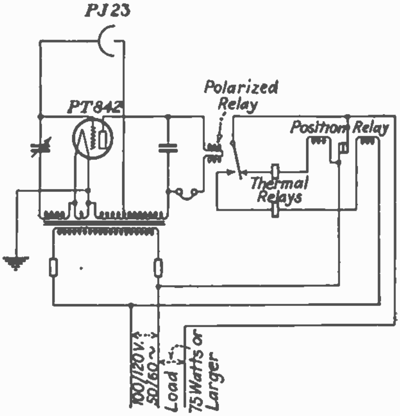


FIG. 29.—Photo-electric circuit for control of interior lighting.

Photo-electric Cells for Indicating Smoke Conditions in a Chimney and Fumes in Tunnels.—It is well understood that the color of the flue gases passing up the chimney of a power plant is to a considerable extent a gage of the skill of the firemen in obtaining satisfactory combustion. A smokeless chimney does not necessarily mean a satisfactory combustion condition; but, on the other hand, a chimney which emits flue gases which are very dark in color or smoky is almost invariably a sign of carelessness or otherwise improper operating conditions in the fireroom. The engineers of the Westinghouse Electric and Manufacturing Company have developed a device for mounting out of doors on the smokestacks which serves as a continuous indicator. The most important part of the device is a photo-electric cell which is mounted in a small casing at the end of a pipe which extends into the side of the chimney as shown in Fig. 30. On the opposite side of the chimney and directly in line with the pipe supporting the casing containing the photo-electric cell is another pipe of the same size extending through the wall of the chimney and on which there is a somewhat similar casing attached to the end on the outside. In this second casing is mounted an incandescent lamp so located that its brightest rays will pass first through the pipe nearest it, through the smoke in the chimney, through the pipe on the opposite side, finally reaching the light-sensitive surface of the photo-electric cell in the casing which was first described. The density of the smoke in a chimney will be indicated, of course, by the amount of light from the incandescent lamp on one side which registers on the light-sensitive surface of the photo-electric cell. The variations in smoke-density will, therefore, produce similar variations in the amount of current passing

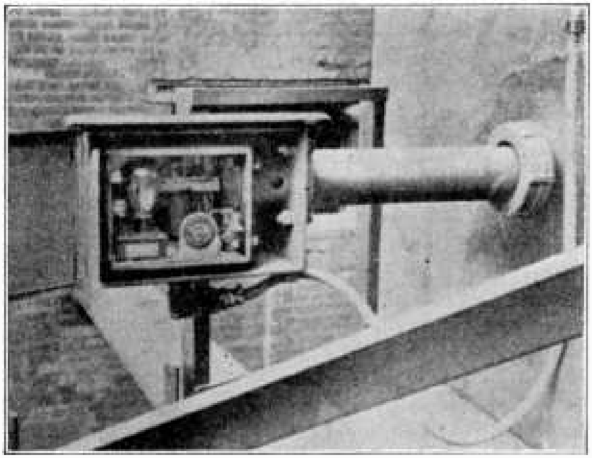


FIG. 30.—Smoke-recording device.

through the photo-electric cell, and by including suitable electric measuring instruments in the circuit of the photo-electric cell, an accurate record of the density of smoke in the chimney may be indicated or recorded if necessary at a distant point as, for example, in the fireroom or in a nearby office. Obviously, the information given by such an instrument tends to encourage intelligent and economical firing methods and should result in maintaining a relatively smokeless chimney.

One of the most interesting applications of the photo-electric cell is in the Holland Tunnel connecting New York City and Jersey City, to detect the relative amount of fumes in the air by the method of using the photo-electric cell to indicate the reduction in illumination from a light source as caused by dark-colored fumes in the air.

Photo-electric Cells for Train Control.—In Germany a method of train control has been devised which depends on the action of photo-electric cells. By this method, the photo-electric cell is arranged so that as the train passes the cell, the illumination from a carefully set light is shut off, and the photo-electric cell through a relay device operates the various switches.

Grid-glow Tube.—The so-called grid-glow tube consists in its important parts of a cylindrical aluminum cathode, a nickel anode, and a grid very much like the kind used in radio vacuum tubes, which is also made of nickel. The three electrodes, that is, the cathode, the anode, and the grid, are enclosed in a glass tube which after being evacuated of air is filled with *neon gas* at low pressure. Figure 31 shows a photograph and also details of a typical grid-glow tube.

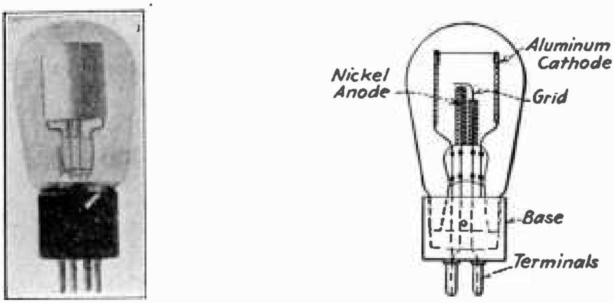


Fig. 31.—Typical grid-glow tube.

A unique feature of the grid-glow tube is that the discharge of electrons between the cathode and the anode may be controlled by means of a variable resistance or a variable condenser connected between the grid and the anode.

By varying this control device the electric charge can be made to leak off from the grid of the grid-glow tube, so that there will be a breakdown inside the tube and a glow discharge will pass a considerable amount of current. The grid-glow tube has particular advantages for use in alternating-current systems, as it includes the properties of (1) a *rectifier* and (2) an *amplifier*. The sensitivity of the grid-glow tube can be increased by connecting a variable resistance between the grid and the cathode.

Light Sensitiveness of Grid-glow Tube.—The ordinary photo-electric cell or the so-called "vacuum-tube" type is sensitive to all degrees of illumination; that is, it responds to the smallest amount of light which falls on the metal-coated surface of the cathode. The grid-glow tube, on the other hand, does not pass electric current through it for all degrees of light intensity. The light intensity may be so small that it will have no effect in permitting a flow of current through the tube. In fact, every grid-glow tube has a definite value of light intensity at which the flow of current through the tube begins. It is possible, however, to design a grid-glow tube so that it will have the reverse action of that stated above; that is, it will act so that the grid-glow tube must pass current through it until the light intensity falling on the metallic coating of its cathode reaches a certain value.

Comparison of Grid-glow with Vacuum Tube.—The control of the electric current passing through a three-element vacuum tube by means of an electrically charged grid is simple compared to the relatively complicated action of a grid-glow tube. For example, in the three-element vacuum tube, the current is carried through the tube in the space between the cathode *F* (filament) to the anode *A* (plate), as shown in Fig. 32, entirely by the flow of electrons which are emitted by the cathode (filament). In order to establish this flow of electrons, it is necessary to provide for the heating of the cathode; that is, a hot filament is a necessary requirement. The electrons emitted from the heated cathode are negative units of electricity. Now, it happens that when a grid *G* (Fig. 32) is placed between the heated cathode and the plate, and this grid is connected to a source of electricity in such a way that it becomes charged negatively, this negatively charged grid will interpose a barrier to the negatively charged electrons emitted by the heated cathode *F*, for the reason that two negative charges or two positive charges repel each other. This repulsion of the negative electrons from the negatively charged grid will, of course, tend to reduce the amount of current which would otherwise pass between the heated cathode and the plate of the vacuum tube.

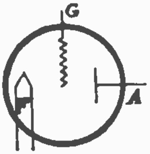


Fig. 32. Three-element vacuum tube.

The greater complexity of the grid-glow tube results from the fact that the current carried between the cathode and the anode is not by means of a flow of electrons alone but by approximately equal numbers of positive ions (page 279) and negative ions, the latter being, of course, designated as the electrons. Now, for example, if the space between the cathode *F* and the plate *A* in Fig. 32 is filled with a mixture of positive and negative ions, and then a negative charge is applied to the grid as explained in the case of the three-element vacuum tube (page 287), the amount that the current flowing through the grid-glow tube is decreased due to the repulsion of the negative ions from the negatively charged grid is compensated by the increase in the amount of current which will tend to flow because of the attraction of the positive ions to the negatively charged grid. The net effect, therefore, of the negatively charged grid in a grid-glow tube is, at least theoretically, zero. The control of current in a grid-glow tube cannot, then, be accomplished by adjusting the amount of negative charge of the grid, and a more complicated method must be used. Briefly, it is not possible by the application of any simple device to control the amount of current passing through a grid-glow tube after the flow of current has once started; but it is possible to control the voltage impressed on the circuit (including the cathode and the anode) at which the discharge of ions (and of current) begins. This *critical voltage*, at which the flow of current begins, is called the *breakdown voltage* or *sparking potential* of the tube. The voltage at which breakdown occurs may be varied over wide limits by means of a grid somewhat like those used in three-element vacuum tubes. The operation of a grid-glow tube can be controlled only by the method of using a grid circuit to vary the voltage at which breakdown occurs, meaning, also, the voltage at which the discharge of ions begins.

Principle of Glow Discharges.—For the reason that the operation of a grid-glow tube is so much more complicated than that of an ordinary three-element vacuum tube, some of the general theory of glow discharges must be discussed before its applications can be considered in detail. Diagrammatically, the anode *A* and the cathode *C* of a grid-glow tube are shown in Fig. 33. As shown, the anode and cathode are in an air-tight bulb containing an inert gas such as *neon* or *argon* at a low pressure. The distance between the anode and the cathode is *d*. If a voltage is applied to the terminals *A* and *C* of the tube with the current-limit resistance in series with this circuit, it will be found that at a certain critical value *E* of this voltage a discharge of ions will occur and a current will suddenly flow through the circuit. The value of the breakdown voltage varies with the distance *d* between the anode and the cathode and also with the gas pressure *P*. (The relation between breakdown voltage and distance between the electrodes *d* and the gas pressure *P* is usually known as *Paschen's law.*)

The irregularity of the variations of the breakdown voltage *E* with the distance between the cathode and the anode and the gas pressure *P* is shown graphically in Fig. 34. It is interesting to note in connection with this diagram that if the gas pressure in a tube of this kind is kept constant and the distance *d* between the anode and the cathode is varied, the point where the breakdown voltage is a minimum or has its lowest value is not when the distance between the anode and the cathode is smallest; in fact, the curve shows that when the spacing between the electrodes is very small, the breakdown voltage of the tube is very large. Although the curve, as shown in Fig. 34, is for a grid-glow tube with parallel electrodes (anode and cathode), it will be found that the general shape of the curve applies equally well to grid-glow tubes having concentric cylindrical electrodes. The discharge of ions between the anode and the cathode of a grid-glow tube is much more complicated than might be expected. In fact, the discharge passes through four different phases in its progress from the anode to the cathode. Immediately adjacent to the anode is a relatively long luminous portion of the discharge, marked "PC," which is called the "positive column." Next to this is a dark portion of the discharge marked "FDS" and called "Faraday dark space." Next is a luminous portion, not so bright, however, as the positive column, which is marked "NG" and is called "negative glow"; and then immediately adjacent to the cathode *C* is a very narrow portion, apparently completely covering the surface of the cathode. It is marked in the figure "CDS" and is called "cathode dark space" (also called "Crook's dark space"). In a fully developed glow discharge sometimes as much as 90 per cent of the total voltage drop across the tube may be in the very narrow portion of the discharge which is the cathode dark space.

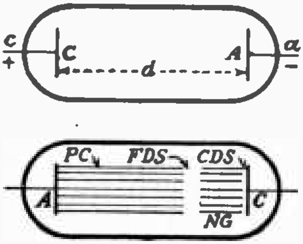


FIG. 33.—Diagram of two-element grid-glow tube.

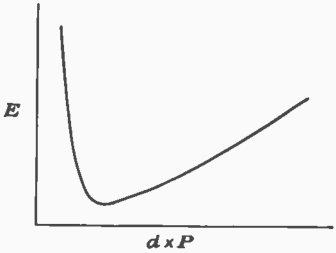


FIG. 34.—Paschen's law

As a grid-glow tube is actually constructed, the cathode and the anode are so close together that the positive column, Faraday dark space, and negative glow almost disappear, so that consideration of all parts of the ordinary glow discharge with the exception of the cathode dark space and the cathode glow may be eliminated without appreciable error.

Threshold Discharge.—The velocity of the negative ions (electrons) is about one hundred and fifty times as great as that of the positive ions (page 703) in the discharge from the cathode to the anode in a grid-glow tube. The anode or, in fact, any electrode, when located in the path of a discharge of ions, will, therefore, be struck by more than a hundred times as many negative ions (electrons) as by positive ions in a certain time. As a result of such a bombardment by ions in which the negative kind are by far the greater in number, the anode will become more and more negative with respect to the cathode until the attraction of the positive ions and the repulsion of the negative ions is such that they arrive at the anode in equal numbers. This condition is approximated in the grid-glow tube in the discharge which immediately precedes what is called the *complete glow*. This statement is somewhat at variance with the fundamental idea of the grid-glow tube, which is that a tube of this kind passes no current through it until the voltage equals the critical or breakdown voltage. The "complete-glow" discharge occurs at the same time that there is a voltage drop at the cathode of about 100 volts. This voltage drop is called the "cathode fall of potential" and varies somewhat with the kind of gas with which the tube is filled. It should be noted that an appreciable time is required for the establishment of the complete-glow discharge. The reason for this is that the gas occupying the space between the cathode and the anode normally contains less than a hundred ions, including both positive and negative. From this small number, many millions of ions must be developed in order that there may be a complete-glow discharge in the space. During the development period, the current passing through the tube is gradually increasing, the voltage drop across the tube is changing, and the distribution of ions between the anode and the cathode as well as the relative number of positive and negative ions is changing.

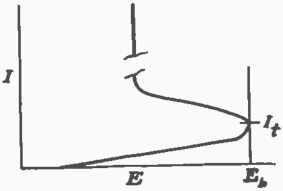


FIG. 35.—Volt-ampere characteristic of glow discharge.

Voltage-current Characteristic of Grid-glow Tube.—The variation of the amount of current passing through a grid-glow tube as the voltage drop E across the tube is changed is shown in Fig. 35. It will be observed that the current I starts to flow at small values of the impressed voltage E and increases with a "stable" characteristic up to a critical value of the current marked I_t. This critical value of current is called the "threshold current," corresponding to the maximum value of the impressed voltage marked E_b, which is the breakdown voltage, meaning that this is the value of the direct-current voltage that is needed to cause the breakdown in the usual manner.

If the impressed voltage E is increased above the value E_b (breakdown voltage), there will be, as shown by the curve, an increase of current accompanied by a decrease of voltage, and the discharge between the anode and the cathode becomes definitely unstable. Under this condition, with an applied voltage considerably less than E_b, the discharge and consequently also the current will increase indefinitely until it becomes a complete glow, which, in some cases, may even develop into a brilliant arc light. For practical applications of grid-glow tubes, the threshold current I_t will not exceed a few microamperes. This small amount of current is the discharge necessary to maintain a critical value of ionization in the *most sensitive part* of the discharge path. If a means is provided, therefore, for removing a portion of the ionization effect from this most sensitive part of the discharge path, a very accurate means of controlling the breakdown voltage will be obtained. The *grid* of a grid-glow tube is the electrode which is used to accomplish the control of the breakdown voltage.

FIG. 36.—Three-element grid-glow tube.

Three-element Grid-glow Tube.—The type of grid-glow tube which has found considerable application consists of three elements: (1) the anode, (2) the cathode, and (3) the grid, as shown in Figs. 36 and 37. It will be noted that in this tube the elements are spaced closely together and that the anode and cathode are cylindrical. The space between the anode and the grid is short in comparison with the distance between the grid and cathode. The bulb of the tube is filled with neon gas at a pressure of a few millimeters of mercury. The gas pressure must be such that the breakdown voltage for the short space between the anode and the grid is much higher than for the longer space between the grid and the cathode.

Values of Impressed Voltage in Standard Grid-glow Tubes.—In the so-called standard grid-glow tubes, a voltage of about 1,000 volts must be available; and for the operation of the tube provision should be made for regulating the voltage between this value and about 400 volts. For controlling the impressed voltage on the grid-glow tube, a grid-bias type of voltage control, as shown in Fig. 38, may be used. As shown in this figure, a direct current at 1,000 volts is impressed between the anode *A* and the cathode *C*. The grid *G* is connected to some point on the potentiometer *R* (page 39). If the potentiometer is adjusted so that the voltage *N* between *G* and *C* is less than 400 volts, no breakdown will occur in the space between the grid and the cathode, and the remaining 600 volts is not sufficient to produce a breakdown voltage in the region between the anode and the grid. If, however, the resistance tap of the potentiometer is moved toward the left so that the voltage between the cathode and the grid becomes somewhat greater than 400 volts, a discharge will occur between the grid and the cathode, and this discharge will be very quickly transferred also to the anode so that the tube will then have developed a complete glow discharge.

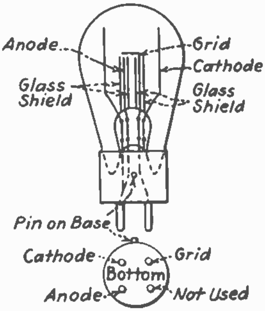


FIG. 37.—Side and bottom views of grid-glow tube.

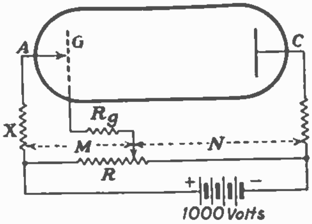


FIG. 38.—Grid-bias control of grid-glow tube.

Since the threshold current I_t, meaning the maximum value of current for the grid-glow tube at which there is a stable characteristic, is only a few microamperes, the discharge between the grid *G* and the cathode *C* must obviously be limited also to correspondingly small values of current.

A practical example of the method of controlling a grid-glow tube by the use of a grid and a potentiometer may be illustrated by the following data: If it is assumed that the current passing through a grid-glow tube is 2 microamperes and the voltage drop between the cathode and the grid is 300 volts, then the resistance R_g will be about 50 megohms, and this amount of resistance must be placed in series with the grid. This resistance will enable a current of 2 microamperes from the grid to start a current of from 10 to 50 milliamperes in the circuit from the anode to the cathode. This example serves to show how a grid-glow tube may be used.

Application of Photo-electric Cell as the Anode.—It is shown in the preceding example that a resistance of several megohms and a grid current of 2 microamperes serve as a means of control. It is, therefore, possible to substitute a photo-electric cell in the anode-to-grid portion of the potentiometer, marked *M* in Fig. 38. With the change in the circuit caused by increasing the amount of light falling on the photo-electric cell, the grid voltage will be shifted more and more toward the anode until the critical grid-to-cathode voltage (400 volts) is reached, at which time, as previously explained, the threshold discharge starts. If the resistance of a photo-electric cell is sufficiently low to allow the threshold current to pass, the discharge transfers to the anode and the breakdown voltage of the tube is obtained.

Self-biasing Grid-glow Tube.—The previous explanations of the operation of a grid-glow tube have depended on the fact that a grid-bias voltage was obtained either from a battery or from a potentiometer for the purpose of controlling the breakdown voltage by means of a grid located between the anode and the cathode.

The neon gas initially in a grid-glow tube contains probably less than 100 ions, and these ions are moved by the action of the electrical field toward the electrodes, the negative ions moving toward the anode, and the positive ions toward the cathode. The positive ions, being relatively heavy compared with the negative ions, move at a slower speed toward the cathode at the same time that the negative electrons move toward the anode. In their movement toward the anode, the negative ions collide repeatedly with the atoms of the neon gas and ionize them, producing after each collision one more negative ion and one more positive ion. The resulting negative ions then in turn acquire additional energy from the electric field and ionize more of the inert gas by impact. This process continues to build up positive ions at the cathode with the emission of just enough negative ions so that the discharge current I_t will have the proper value to attain the direct-current breakdown voltage across the tube.

Resistance in Series with Grid-glow Tube.—If the resistance in series with a grid-glow tube, as, for example, the one marked *X* in Fig. 38 is not sufficiently large to limit the current to the critical value I_t, as in Fig. 35, the current will increase and the voltage across the grid-glow tube will decrease until $I = (E - E_t) \div X$. In this equation I is the current flowing through the grid-glow tube in amperes, E is the voltage applied to the tube in volts, E_t is the voltage drop across the grid-glow tube, and X is the resistance in series with the grid-glow tube in ohms. When the grid of a grid-glow tube is disconnected entirely from both the anode and the cathode and a suitable voltage is impressed between the anode and the cathode, the threshold current will immediately begin to develop, the negative ions going toward the anode and the positive ions going toward the cathode. The grid is thus exposed to all the negative ions. While the positive ions going toward the grid are only those generated in the comparatively small space between the anode and the grid, the number of negative ions is about one thousand times as large as the number of positive ions. It is, therefore, not surprising that the grid under these circumstances has a voltage almost the same as that of the cathode, so that practically all of the impressed voltage (about 800 in this case) is shifted to the space between the anode and the grid, where about 1,000 volts are required for the breakdown voltage.

There is always some leakage of current from the grid to the anode, and if this leakage is increased by the method of introducing a high resistance between the grid and the anode, there will be a reduction of the charge on the grid and an increase in the amount of current passing between the cathode and the grid. As soon as this grid-to-cathode current reaches the value of I_t, the grid-to-cathode discharge becomes self-supporting and the discharge will be transferred also to the anode, producing, then, a complete glow discharge. It is therefore possible to dispense with the potentiometer shown in Fig. 38 and to use in many cases a simple circuit like the one shown in Fig. 39. The variable resistance R in the latter figure may be a photo-electric cell.

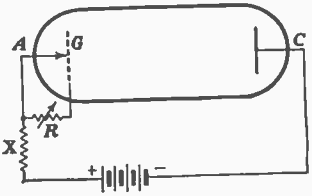


FIG. 39.—Grid-bias control without potentiometer.

Summary of Operating Conditions of Grid-glow Tube.—The following summary may be made of the fundamental operations of a grid-glow tube: (1) The discharge always tends to develop in the region of the grid toward the cathode; (2) the discharge increases in intensity until a critical value is reached called the *threshold* current. At this point, the voltage across the discharge is called the *breakdown* voltage; (3) over a considerable range on either side of the threshold current I_t there exists for every value of current a certain minimum voltage which must exist between the anode and the grid in order that the discharge shall be transferred also to the anode and thus make a complete glow discharge.

Grid-glow Tube for Alternating Current.—The previous paragraphs describing the action of grid-glow tubes referred particularly to their use with direct current, but they are also suitable for use with alternating current. The characteristic property of the grid-glow tube is that its glow or discharge persists when once started until the applied voltage is reduced below a certain value. Because of this fact, the grid-glow tube when used with *alternating current*, establishes its glow or discharge, and also breaks down or extinguishes its glow or discharge, completely during every cycle of the alternating current. If, at any time, the condition of the grid is changed to such an extent that the grid-glow tube does not operate, it will break down on the next succeeding cycle and the current flow through the tube will be interrupted, meaning that the current is not able to start again. In the normal operation of a grid-glow tube, however, a complete reversible on-and-off operation is possible with alternating current.

A grid-glow tube may be made entirely symmetrical, meaning that both the cathode and the anode are of the same size, with the grid located at equal distances from each of them. In a grid-glow tube of this construction, the current will pass through it with no more difficulty in one direction of the alternating current than in the other. In the usual construction of a grid-glow tube, with the anode at the center, this central electrode (anode) is usually very much smaller than the outer electrode (cathode). In this construction, the grid-glow tube cannot pass current equally well in both directions, and it becomes a *rectifier* tube. In general, the statement holds that the current passing through a grid-glow tube (not referring now to the relative value of current in either of the directions of a cycle of alternating current) is proportional to the amount of surface of the electrode which is negative. Thus, when the outer electrode (usually the cathode) is the negative electrode, a large current flows through the grid-glow tube, but when the inner electrode (usually the anode), which is generally small in size, is the negative electrode, a very small current passes through the tube.

The outstanding characteristic of a grid-glow tube is that the *grid is effective only in starting a glow* or arc discharge, or it may prevent a glow or discharge from starting; but, on the other hand, the *grid cannot be made to extinguish a glow* or arc discharge. It has also no control over the glow or arc discharge after it is started. For the further discussion of the theory of operation of grid-glow tubes, it will be necessary to explain more in detail what is meant by a *control grid* in such a tube. A grid in a grid-glow tube is an electrode which controls a glow or arc discharge in such a way that it carries very little current itself. In this connection, it may be desirable to refer again to the use of a grid-glow tube for use with direct current. Now, if the grid of a grid-glow tube used with direct current takes current in about the same amount as the current to be interrupted, the so-called "grid electrode" of the tube does not really act as a grid according to the definition just given but is really only another path through the grid-glow tube for the passage of the glow or arc discharge. This fact may be made clearer by supposing that a so-called grid electrode of a grid-glow tube is immersed in a glow discharge and that its voltage with respect to the cathode or the anode is then varied. In that case, there is only one value of voltage for which the current to the grid is zero. This is the voltage which causes positive ions and negative ions (electrons) to arrive at the grid in equal numbers. If, then, the grid is made more negative, time is required to reach this critical value. More positive ions and fewer negative ions (electrons) arrive at the grid, and produce, of course, a grid current in amount corresponding to the greater number of positive ions. The region around the grid will then contain an excess of positive ions, meaning that there is a positive space-charge layer around the grid. As the current continues to flow through the grid-glow tube, the space-charge layer around the grid increases in thickness until the drop of voltage in this layer plus the drop in voltage in the grid resistance (provided there is one) brings the outer boundary of the space-charge layer to the same voltage as the glow or arc discharge. When the polarity of the grid is reversed, that is, after it is made positive, the resulting conditions are essentially the same. The only effect then of varying the voltage of the grid is to increase its effective size because of the space-charge layer which surrounds it.

In the ordinary conditions of operation of grid-glow tubes, the space-charge layers are very thin and make, therefore, a negligible change in the dimensions of the grid. The thickness of the space-charge layer increases as the intensity of the discharge decreases, because the current must consist of positive ions, or of negative ions (electrons) obtained from a greater volume. At the very low intensities of space charge such as *precede* a glow discharge, the space-charge layers of the grid become quite appreciable in thickness so as effectively to increase the dimensions of the grid to such an extent that the cathode and the anode of the grid-glow tube are so effectively isolated from each other that further development of the discharge is prevented. On the other hand, by bringing a spark coil near the grid-glow tube and thus increasing the ionization in the tube, the thickness of the space-charge layer of the grid may be decreased to such an extent that the glow or arc discharge will again pass between the cathode and the anode. The same effect can be produced also by increasing the flow of grid current. By reducing the amount of the grid resistance (if there is one) so that the grid current is increased the ionization density of the tube is increased.

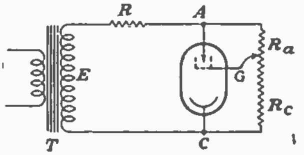


FIG. 40.—Circuit of alternating-current grid-glow tube.

Typical Circuit of Grid-glow Tube Used with Alternating Current.—A simple circuit in which a grid-glow tube can be applied effectively for operation with alternating-current devices is shown diagrammatically in Fig. 40. This circuit includes a transformer T, a current-limiting resistance R, an anode A, a grid G, a cathode C, and variable resistances R_a and R_c. The variable resistances are connected, respectively, from the grid to the anode and from the grid to the cathode, as shown in the figure. If the variable resistances R_a and R_c are comparatively small in value so that the current flowing through them *in series* is large compared to the threshold or preignition current of the discharge, they may be regarded simply as potentiometers intended for varying the grid voltage. The output voltage of the transformer is marked E. The operation of this circuit is relatively simple. For example, the output voltage E may be 600 volts, and the variable resistance R_a may be large compared with R_c. These resistances when taken together, as constituting a potentiometer, divide the voltage in proportion to their ohmic resistances. With this arrangement, the resistance R_a, being relatively large compared with the other resistance R_c, attains a high voltage, and this voltage as shown in Fig. 40 is impressed across the grid-to-anode circuit. Now, if this latter circuit is designed to withstand that voltage without a breakdown, no glow or arc discharge will occur. If the variable resistance R_a is, however, gradually decreased, the voltage drop in the grid-to-anode circuit is reduced and consequently the grid-to-cathode voltage is increased. At a critical value of the latter voltage, a discharge starts abruptly between the grid and the cathode and appears to develop instantly into the usual kind of glow discharge, but actually there is a time lag of several microseconds. The discharge of the grid-glow tube does not stop at the value of the threshold current, because the variable resistance R_a is not sufficiently large to limit the current to that value. An intense discharge of this kind between the grid and the cathode is transferred almost immediately to the grid-to-anode circuit, and a complete "relay action" is performed, meaning that a very small change in the voltage of the resistance R_a produces a correspondingly small change in the voltage drop in the grid-to-anode circuit and produces also a change in the *plate* current from zero to several milliamperes, or possibly even to several amperes in the case of grid-glow tubes which operate with a *hot cathode.*

The operation of this grid-glow tube circuit implies that the combined resistances of the potentiometer R_a and R_e are of such values that the current flowing through the potentiometer circuit is larger than the threshold current. A numerical example may make this clear. If the threshold current I_t is 1 microampere and the current flowing through the potentiometer resistances R_a and R_c is 2 microamperes, then the sum of the potentiometer resistances, that is, $R_a + R_c$, is $440 \div 2 \times 10^{-6}$ or 220×10^{6} ohms.

Analysis of Operation of Grid-glow Tubes.—The analysis of the operation of a grid-glow tube for sensitive circuit conditions cannot be stated simply. In every circuit there will be some resistances and distributed capacity (page 86). In many cases the principal effect of resistances and distributed capacities is to shift the phase of the grid voltage with respect to that of the cathode-to-anode circuit. The effects of the shift of phase of the grid voltage may be explained by reference to the curve marked "1" in

Fig. 41 showing for an experimental grid-glow tube of the *cold cathode* type the relation between grid-to-cathode voltage and grid-to-cathode current, when this current is limited to relatively small values. It has already been explained that the breakdown of the tube and the glow discharge occur first between the grid and the cathode part of the circuit, and, for this reason, the data of the curve are of considerable importance. The circuit shown in Fig. 40 may be used to illustrate the curves, except that no transformer will be used, and E is assumed to be a variable direct-current voltage, for the reason that the voltages of the circuit may be varied more easily with a direct than with an alternating current. Each value of direct-current voltage E is, of course, comparable to a corresponding point on the wave of a 60-cycle alternating current. All reference in the following paragraphs to voltages may be considered as either direct-current values or instantaneous values on the wave of a 60-cycle alternating current. The resistances R_a and R_c of this circuit have very high values. It will be noted from the curves in Fig. 41 that the breakdown voltage between the grid and the cathode occurs at 400 volts. Now, if the resistance R_a were of small instead of large value, say a few thousand instead of several million ohms, the discharge would at once develop into a glow discharge, as it is generally defined. On account of the high value of the resistance R_a, the grid current (from grid to cathode) does not exceed a few microamperes. If, now, the grid current is increased by reducing the resistance R_a and the voltage drop from the grid to the cathode is measured, curve 1 in Fig. 41 will be obtained. An examination of this curve shows that as the grid current (grid to cathode) is increased, there is at first a decrease in the voltage until the grid current is 20 microamperes. Beyond this value of current, the voltage drop increases as the current increases until the original breakdown value of 400 volts is obtained, and then, again, the voltage decreases rapidly toward the normal characteristic of the grid-glow tube. This grid current (grid to cathode) or threshold current, as it is often called, is very sensitive to the conditions within the tube, such as the spacing of the cathode and anode with respect to the grid. The shape of the grid, the kind of service, the quality of the gas, and the gas pressure

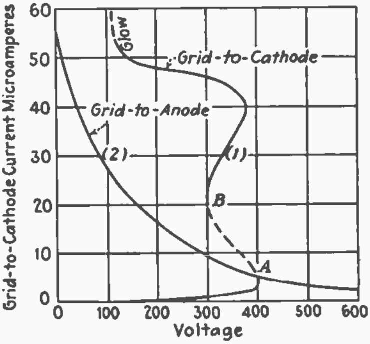


FIG. 41.—Effects of shifting phase.

affect the shape of curve 1 in Fig. 41 to the extent that it frequently contains bends or even discontinuity. The grid current in the region between the points marked A and B has a direct-current component with a superimposed alternating-current component which is small in comparison to the direct current; the alternating current, however, changes continually both in amplitude and frequency. The frequency range of this alternating current extends from the audio-frequency region and continues through to the radio frequencies.

Transfer Voltage of Grid-glow Tube.—For each value of grid current (grid-cathode) there is a definite value of voltage required between the grid and the anode in order that the discharge occurring first between the grid and the cathode may be transferred to the grid-to-anode circuit. These voltages between the anode and the grid in order to accomplish complete discharge are shown by the curve marked "2" in Fig. 41. Data given by the curves 1 and 2 in Fig. 41 are preferably plotted on the same sheet, so that they can be studied together.

The use of these two curves in combination may be explained in connection with a simple circuit including a photo-electric cell in Fig. 42. As shown here, the photo-electric cell takes the place of a variable resistance, the resistance varying with the exposure of the cell to different degrees of illumination. The photo-electric cell is connected into the circuit between the grid G and the anode A. A variable condenser O is connected similarly between the grid and the cathode for the purpose of adjusting the sensitivity of the circuit. When the photo-electric cell PC is illuminated, the effect of the light is to reduce its resistance and also, consequently, the voltage drop across its terminals. With constant impressed voltage on the circuit, the effect of reducing the voltage drop across the terminals of the photo-electric cell is to increase the voltage drop across the condenser O, that is, in the grid-to-cathode circuit. Changing the resistance of the photo-electric cell when operating in a circuit similar to the one in Fig. 42 not only changes the amount of the current in the grid-to-cathode circuit but also causes a *shifting of the phase* relations of the voltages, the voltage E_0 across the condenser lagging less behind the applied voltage because of this change in resistance in the photo-electric cell, and the voltage drop E_{pc} across the photo-electric cell leading the applied voltage by a correspondingly larger angle. (The phase relations of alternating currents with explanations of *lagging* and *leading* voltages are explained on page 10.)

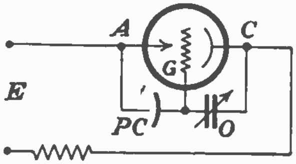


FIG. 42.—Simple circuit of grid-glow tube with photo-electric cell.

Under certain conditions when dealing with an alternating-current voltage there will be the following sequence. When starting with a high resistance. as, for example, that of the photo-electric cell in Fig. 42, and then gradually reducing this resistance by varying the illumination on the cell: (1) The voltage drop across the condenser *O* becomes equal to the critical value and a discharge starts between the grid and the cathode; the voltage drop across the photo-electric cell being then equal to the transfer voltage, the discharge goes from the grid to the anode and complete discharge is effected. (2) When the resistance of the photo-electric cell has been considerably reduced, the phase relations of the voltages become such that at the instant when the voltage drop across the condenser is of a value to cause breakdown, the voltage drop across the photo-electric cell is not great enough to transfer the discharge. The result is that the grid-glow tube will fail to operate under this set of conditions. (3) When the resistance of the photo-electric cell is very greatly reduced, the current in the initial discharge from the grid to the cathode becomes so large that practically no voltage is required for the transfer, and then the grid-glow tube again operates. The points of non-operation of the grid-glow tube represent discontinuities in the operating characteristic of the tube and are called *transition points* or *dead spots.* Only one transition point would be accounted for by the previous explanation. When, however, the peculiar shapes of the curves in Fig. 41 are considered, it will be observed that there may be several transition points over the same range, unless the circuit is carefully designed to avoid irregularities.

The instantaneous value of the voltage in the grid-to-anode circuit of Fig. 42 which is required to obtain a transfer voltage bears a definite relation to the threshold current, that is, the current in the grid-to-cathode circuit. In the circuit just explained, the amount of voltage available for transfer is the voltage drop across the photo-electric cell.

If the photo-electric cell is likely to be subjected to intense illumination so that its resistance becomes comparatively low, a permanent resistance should be connected in series with the photo-electric cell, this resistance measuring from five to ten megohms. Such a permanently connected resistance will insure that sufficient transfer voltage will always be available to complete the cycle of operations. In the latest designs of grid-glow tubes, the transfer voltages have been greatly reduced and the threshold-current characteristic has been improved so that very little trouble is experienced from transition points or dead spots.

Methods of Varying Grid Conditions of Grid-glow Tubes.—The types of circuits using grid-glow tubes may be divided into two kinds according to the manner in which the condition of the grid is varied. The first method of grid control consists essentially in varying the value of the grid voltage and maintaining *constant phase relations*. The second method is almost exactly the reverse of the first, as, by this method, the *phase of the grid voltage is varied* and the grid voltage remains approximately constant in magnitude. Theoretically, these two classifications can be justified, although in practice there are very few circuits which could be classified as belonging entirely in one group, nearly all cases being a combination of the two. It is only for convenience of analysis that the two kinds of grid control are considered separately. In either case, the object is to find the point of control on the voltage wave at which the current begins to flow.

The phase relations of the voltage wave *A* between the cathode and the anode, and the voltage wave *B* between the cathode and the grid, are shown in Fig. 43. As shown in the figure, the voltage of curve *A* leads the voltage of curve *B* by approximately 90 degrees. Now, if the voltage between the cathode and the anode as shown by curve *A* is kept constant in magnitude and the grid voltage as represented by curve *B* is increased in magnitude, a critical value will be reached at which the grid-glow tube will begin to operate. This critical point on the voltage wave *A* is about the lowest voltage at which the grid-glow tube will operate; and any further increase in the grid-voltage curve *B* will not increase the average output current. After being once established, the current flows for the rest of the half cycle, as represented in the figure by the shaded area. When the current is integrated over the whole cycle, it will be found that it is the maximum value for any condition for particular values of current in the grid-anode circuit. The curve in Fig. 43*b* shows the relation between the grid voltage and the grid-anode current. Now, if the grid-voltage is retarded until, for example,

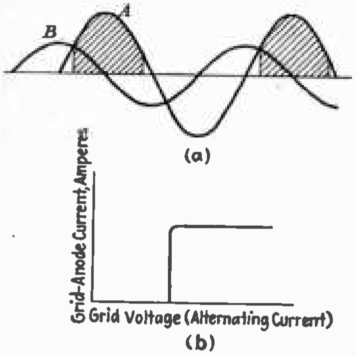


FIG. 43.—Phase relations in grid-glow tube with voltages out of phase.

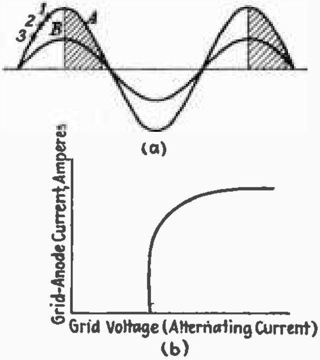


FIG. 44.—Phase relations in grid-glow tube with voltages in phase.

it is in phase with the anode-to-cathode voltage, the tube will break down first at the peak of the voltage wave and the current will continue to flow for approximately one-fourth of a cycle, as shown in Fig. 44*a*. If the grid voltage is still further increased, the starting point on the wave *A* occurs earlier, as shown by the points 1, 2, 3, and so forth, corresponding to successive increases in the grid-to-cathode voltage. The grid-anode current for this condition is therefore similar to Fig. 44*b* and is characterized by a sudden increase in the amount of current followed by a *gradual* increase as the grid voltage is increased. From these examples, it will be seen that if the grid voltage lags behind the grid-to-anode voltage by 90 degrees, the breakdown in the tube will first occur at a point near the end of the cycle. If the grid voltage is increased, the breakdown point will occur earlier, but it can never reach the peak of the voltage wave in the cycle, so that the current obtainable is small and the tube capacity is not efficiently used. Characteristic of this condition is the fact that the current starts from practically zero and approaches a maximum value. A continuous increase in the current in many cases may be obtained by using *phase control* (page 716) instead of *grid-voltage control*.

A convenient method of varying the starting point of the discharge over nearly a complete half cycle is illustrated by the circuit shown in Fig. 45. In this case, the current passing through the grid-glow tube may be controlled from practically zero to a maximum value; and at the maximum value of current, the tube will be used most efficiently. If the variable resistance *R* is a photo-electric cell, the circuit is suitable for application in a light meter as well as in a relay. Another valuable feature is that in this circuit the grid-glow tube breaks down during each cycle and the illumination on the photo-electric cell merely advances or retards, according to its intensity, the breakdown point, indicating that a grid-glow tube in a circuit of this kind has remarkable constancy.

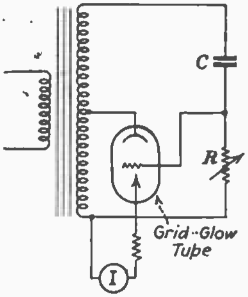


Fig. 45.—Circuit for varying starting point of discharge.

Grid-glow Tube Applications.—In the application of grid-glow tubes, it was mentioned that the current flow through the tube could be *varied* by means of a resistance, or capacity, or both. If a pair of contacts are placed in series with a grid resistance and provision is made for making and breaking the current which would not exceed a few microamperes, then by the application of a suitable *relay* with its coil placed in the main output circuit of the grid-glow tube, the relay will be able to handle currents which would be measured in amperes instead of microamperes.

The grid-glow tube can be used effectively for the automatic control of oil burners used in connection with house-heating boilers. A control device of this kind will be effective in preventing a series of "puff-backs" or even more serious explosions in the fire box of the heater. Dangers from these causes may be due to (1) intermittent electric ignition when starting the burner or (2) the occasional failure of the flame while the burner is operating.

The grid-glow tube for oil-burner operation has advantages over the more commonly used thermostatic devices which are operated by the heat of the flame or of the flue gases. The thermostatic devices are relatively slow in operation, while the grid-glow tube when used for this purpose operates instantly. The grid-glow tube is not operated by the heat of the flame of the burner but operates by changes in electrical conductivity, the conductivity of the tube being zero when there is no flame.

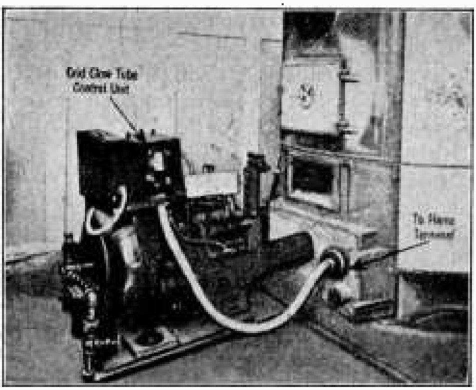


Fig. 46.—Grid-glow tube for controlling oil burner.

Figure 46 shows the application of the grid-glow tube to a control unit on an oil-burner installation.

Grid-glow Tubes as Amplifiers.—When used as amplifiers in connection with photo-electric cells, grid-glow tubes are essentially "relaying" tubes, meaning that the current passing through the tube begins at a certain definite amount of illumination on the cell and the current going through the tube stops again when the illumination becomes less than that value. The current flowing through the grid-glow tube need not be related, of course, to the amount of illumination on the photo-electric cell. This current through the grid-glow tube is usually constant, while the illumination on the photo-electric cell must be made to vary with the conditions to be observed. The grid-glow tube combined with a photo-electric cell is a somewhat simpler and cheaper device than the amplifying vacuum tube, for the reason that it requires only a small amount of auxiliary equipment. Probably the greatest advantage of the vacuum-tube amplifier is the proportionality of its output current to the grid-control voltage. The vacuum-tube amplifier when supplied with direct current is the most sensitive means of amplification now available. Further, when the vacuum-tube amplifier is supplied with alternating current and is made self-rectifying, it will retain the proportional relation of output current to the amount of illumination on the photo-electric cell. For this reason, the photo-electric cell and the vacuum-tube amplifier in combination are more suitable for giving calibrated indications and records, and also for high sensitivity, than the alternate combination of the photo-electric cell with the grid-glow tube.

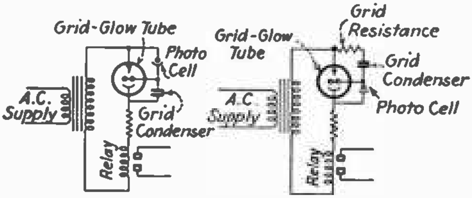
Photo-electric Cell and Grid-glow Tube in Combination.—One means of amplifying the current of a small photo-electric cell is by using a grid-glow tube to pass a quantity of current depending on the voltage of the grid with respect to the anode. If the grid in a grid-glow tube is sufficiently "negative" with respect to the anode, no current will be allowed to flow from anode to cathode, and the grid-glow tube may serve, therefore, as a very sensitive relay, which can be controlled by the photo-electric cell. This combination of the grid-glow tube with a photo-electric cell is particularly valuable for applications in which the change of light is relatively great and abrupt such as counting, relaying, and automatic control of various kinds. The combination is also inexpensive and simple as compared with some other types of amplifiers.

There are two general types of circuits for this combination, as for other amplifiers, called (1) forward and (2) reverse circuits. The circuit in which the output current increases with an increase of light is known as a *forward circuit* and the one in which the opposite is true is known as a *reverse circuit*. Both types of circuits require a current-limiting resistance in the anode-to-cathode circuit to prevent the current from passing into an arc discharge. A *vacuum* type of photo-electric cell is used with this combination, since the voltage is high enough in many cases to cause a *gas-filled* cell to glow and be ruined. This combination of photo-electric cell and grid-glow tube when used on alternating current passes direct current. Hence a "lag-loop" relay or direct-current relay with a condenser in parallel is needed.

Forward Circuit for Alternating Current.—This type of circuit has characteristics similar to those of the combination of photo-electric cell and amplifying vacuum tube in that the output current is a function of illumination on the cell within certain limits.

A photo-electric cell and a condenser may be used as an *impedance potentiometer* as indicated in Fig. 47*a*. Since the effective resistance of the photo-electric cell is subject to change with various values of illumination, the voltage of the grid is determined by the illumination on the cell.

The *characteristic curve* of the circuit including a vacuum-type photo-electric cell, a grid-glow tube, a grid condenser, and a current-limiting resistance is shown in Fig. 48. The sensitivity or slope of the curve is approximately proportional to the cell sensitivity and inversely proportional to the capacity of the grid condenser and the resistance of the current-limiting device. The output current "saturates" with a continued increase in illumination. This is due to the fact that the control exerted on the grid is such as to cause the grid-glow tube to break down and pass current during various parts of the illumination change of the cell. The slope of the curve in Fig. 48 can be made of almost any steepness by changing the circuit constants, one of which is the current-limiting resistance. The maximum current must never be greater than the current-carrying capacity of the grid-glow tube. The point of saturation is determined by the anode-to-cathode voltage and the current-limiting resistance.



(a)-Forward Circuit (b)-Reverse Circuit

FIG. 47.—Photo-electric cell controlling grid-glow tube (forward and reverse circuits).

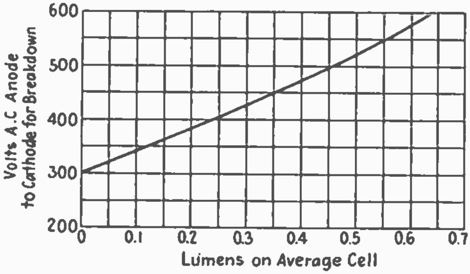


FIG. 48.—Characteristic curve of photo-electric cell and grid-glow tube in combination (forward circuit).

The method of operation is to select values of alternating-current voltage, current-limiting resistance, and grid-condenser capacity, and then operate by varying the illumination. The normal anode-to-cathode voltage is 440.

The Reverse Circuit for Alternating Current.—This type of circuit gives a *discontinuous* characteristic. In other words, as the light is varied slowly, a point is reached where the glow tube either passes a definite current or passes no current, depending on a very small change in light on the photo-electric cell. The output current is not proportional to the light on the cell as is the case with the forward circuit, and for both the forward and reverse circuits of the combination of an amplifier vacuum tube and a photo-electric cell. The sensitivity of this circuit is about proportional to the sensitivity of the photo-electric cell and is inversely proportional to grid-condenser capacity.

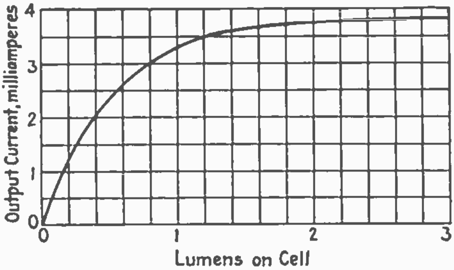


FIG. 49.—Characteristic curve of photo-electric cell and grid-glow tube in combination (reverse circuit).

A typical circuit of this type is shown in Fig. 47*b*. The potentiometer, controlled by the photo-electric cell, has merely been reversed so as to produce the opposite type of control from that discussed under the forward circuit. A typical characteristic curve of this circuit is shown in Fig. 49.

Speed of Operation.—The speed of the combination of a photo-electric cell and a grid-glow tube on alternating current is limited only by the time required for the voltage to reach the proper half of the cycle, or is less than one cycle. Relays can be used which will close in two or three cycles after being energized.

Direct-current Operation of the Photo-electric Cell and Grid-glow Tube. A forward circuit for using the photo-electric cell and a grid-glow tube on direct-current is shown in Fig. 50. It should be noted, however, that with direct-current the action of the grid-glow tube is non-reversible. It is necessary that the voltage from anode to cathode be reduced below the fixed break-off value of approximately 180 volts before the flow of current is stopped, even if the cell illumination is restored to the value existing before breakdown. The fact that "locking" is thus obtained is often of considerable value in detecting transients of very short duration in the light. The reverse circuit differs only in that the photo-electric cell and grid resistance are interchanged.

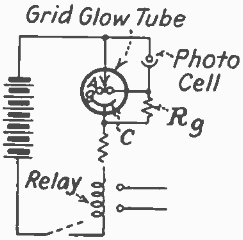


FIG. 50.—Forward direct-current circuit (non-reversible operation).

Optical Systems. Light-source Units.—There is a great variety of light sources and light-source units required for the many widely differing applications of photo-electric cells. The light-source units can be divided into two general groups, however, which may be classified as (1) lens type and (2) reflector type.

There are several advantages and disadvantages for each of the two types of light-source units. There are, of course, certain specific requirements for each application. One requirement common to all is that light-source units must be easily adjusted and must maintain their adjustment over long periods of time. This factor is of prime importance regardless of other considerations.

The main advantage of the *lens type of light-source* unit is its simplicity and permanency. A lens can be cleaned merely by wiping it, and no matter how dirty it gets it can always be put back in service quickly. A reflector, on the other hand, is not easily cleaned properly, due to its polished surface which is easily damaged. The *reflector type* has the advantage of collecting more of the light emitted from a light source than the lens and will in many cases give a more efficient optical system, especially in projectors.

The greatest possible efficiency for the lens type of light-source unit is obtained when a double-convex lens is used with a focal length as small as possible for a given diameter. Theoretically, a lens of this type can be made with a focal length as small as about one-half the diameter. Practically, this is never realized, since such a lens would be approximately a sphere. If such a lens were available, its usefulness would not be very great because of spherical aberration. The best lens which can be made will pick up about 60 to 70 degrees solid angle of light from the light source. The reflector, on the other hand, can pick up considerably more. A reflector can be made to pick up about 180 degrees solid angle of light or about 100 per cent more light than with a lens.

Another point of great importance in the design of a light-source unit is the size of beam which must be obtained. The lens is the only suitable method of obtaining a very small beam of light, although it can sometimes be used in conjunction with a reflector to advantage. The reflector type of light-source unit is more suitable, however, if the light beam need not be less than several inches in diameter. The lens optical system is necessary when spots of light a fraction of an inch in diameter must be obtained.

Taking the above points into consideration, it is easily seen that a reflector type of light-source unit is most suitable for applications in which the beam of light can be of relatively large diameter, where the greatest amount of light possible must be had, and where extreme constancy of light output is not of prime importance. Among the many applications of this nature are counting, relaying, etc.

The lens is most suitable for use in applications such as smoke recording, sorting, grading, matching, etc., where constancy of light output is essential, since the devices are calibrated, and where in many cases only small concentrated beams of light are required.

Sometimes the light-source unit can be a simple lamp, with no optical system, when the spacing between the light source and light-sensitive device is small enough to operate directly from an unfocused light. This device can be worked satisfactorily on operations such as counting sheets of paper and some kinds of automatic control. All that is necessary is for the material causing operation to obscure the filament of the lamp so that no light reaches the light-sensitive device. Success will depend greatly on the distance of the material from the light source.

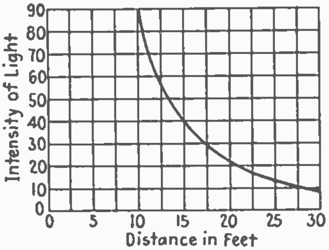


Fig. 51.—Typical curve of light intensity.

Another requirement in the design of a light-source unit is that the spot of light at the light-sensitive device be of such a size as to make it practical to collect the greater portion of the light and project it on the photo-electric cell with a lens. Small filament lamps, usually of low voltage, make this possible. Lamps of the standard 110-volt rating are usually not suitable for this service because of their large filaments which, when used with an optical system, give a spot at the light-sensitive unit of unsuitable size. The lamps are usually of 6- to 10-volt rating. The lamps of the low-voltage rating also use less power with consequently less heat to dissipate than lamps of higher rating.

A typical curve of light intensity is shown in Fig. 51. It should be pointed out that the illumination on the lens is inversely proportional to the square of the distance of the light-source unit from the light-sensitive device. So long as (at the distances considered) the spot of light at the light-sensitive device is larger than the lens or cell window, the effect on the cell will be inversely proportional to the distance that the two units are apart.

Automatic Sliding Door.—An automatic sliding door, that opens and closes without conscious human effort, has been perfected in the laboratories of the General Electric Company at Schenectady. A person walks toward the door and when he gets within the proper distance it opens and lets him pass, closing only when his passage has been completed. Hotel waiters and others who carry burdens in their arms need no longer struggle to hold the door when such an installation has been made.

A ray of light is focused past the door threshold on a photo-electric cell. This ray, when interrupted by the body of a person approaching the doorway, sets a hydraulic door opener to work. The hydraulic device is somewhat similar to that used in subway cars for actuating the doors.

The cell is connected so that it controls, through a three-tube amplifier, an automatic relay, which in turn starts a small motor which operates the hydraulic device. A lever then forces the door open and holds it for a period of time adjustable to the varying conditions under which the door may be used.

Photo-electric Spectrophotometer.—This instrument is designed for the accurate analysis of emitted, transmitted, or reflected radiation (light and other waves). Its sensitivity is such that it may be used to measure the relative intensity of individual lines in the spectrum at an accuracy which is within 0.1 per cent. All measurements are made electrically, so that errors resulting from visual observation are eliminated.

The field of application of this instrument is not limited to the visible spectrum, for it can be used to make direct quantitative measurements in the regions of both the ultra-violet and the infra-red regions. For measurements in different regions of the spectrum, different light sources and photoelectric cells are employed, as well as different types of spectrometers; but the method of operation is the same, regardless of the spectral region in which the analysis is being made.

Regardless of the kind of material to be examined, whether gaseous, liquid, or solid, whether transparent, translucent, or opaque, the essential parts are (1) a carrier for the sample; (2) a light source operated by a storage battery; (3) a spectrometer to segregate the lines or bands of the desired wave lengths; (4) a case containing the photo-electric cell, electrical circuits, amplifiers, and control panel; (5) a galvanometer; and (6) a Wheatstone bridge, usually one of the Kohlrausch type.

Figure 52 shows the arrangement designed for making color analyses of transparent substances in the visible spectrum. It consists essentially of (*A*) a modified Bausch & Lomb constant-deviation spectrometer to which a light source has been attached; (*B*) a case containing the photo-electric devices, on the outside of which is provided an enclosed slide for the material to be examined; (*C*) a Leeds and Northrup bridge; and (*D*) a Leeds and Northrup galvanometer.

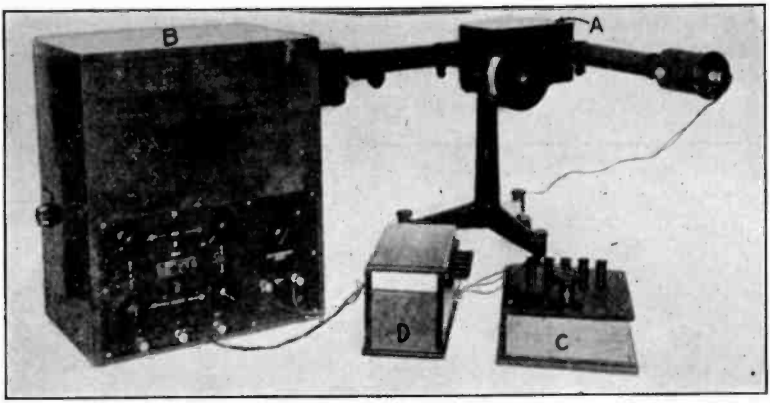


Fig. 52.—Photo-electric spectrophotometer for transparent substances. (*American Photoelectric Corporation, New York City.*)

Figure 53 shows the arrangement designed for making color analyses of opaque substances in the visible spectrum. It consists of (*A*) a modified

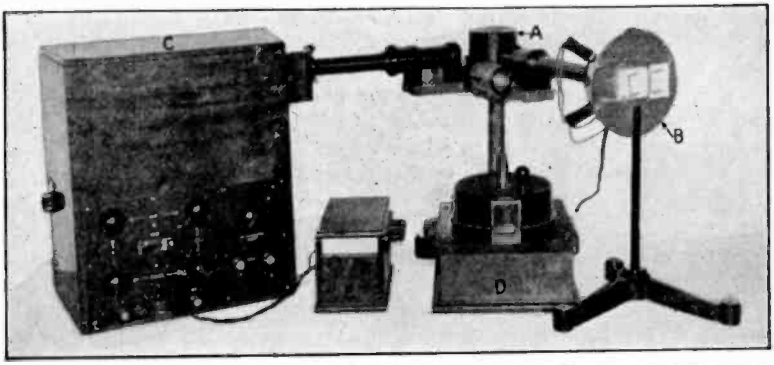


Fig. 53.—Photo-electric spectrophotometer for opaque substances. (*American Photoelectric Corporation, New York City.*)

Hilger constant-deviation spectrometer; (*B*) an opaque illuminator; (*C*) a case containing the photo-electric devices; (*D*) a Kohlrausch bridge; and (*E*) the same type of galvanometer as shown in Fig. 52.

Figure 54 shows the arrangement designed for the determination of the relative energy distribution in the ultra-violet region of the spectrum. It consists of (*A*) a modified Hilger quartz spectrometer; (*B*) a case containing the photo-electric devices; (*C*) a Kohlrausch bridge; and (*D*) a galvanometer. It is understood that for work in the ultra-violet region, whether with transparent or opaque substances, a light source such as a quartz-mercury arc is employed which is rich in ultra-violet rays and that all parts of the instrument through which light passes are of quartz.

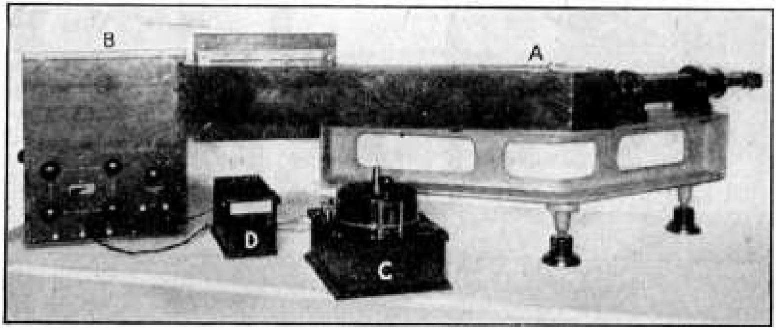


FIG. 54.—Photo-electric spectrophotometer for transparent or opaque substances. (*American Photoelectric Corporation, New York City.*)

To make a reading on any material at any desired wave length, it is necessary only to balance an electrical circuit by turning a dial similar to those on radio sets, and then, after interposing the material under examination, again to balance the circuit by turning another dial on which is read directly in per cent the proportion of the total light of that particular wave length which is transmitted or reflected by the material. A sufficient number of readings at different wave lengths are made to enable one to plot an accurate curve of intensity against wave length over any desired range of the spectrum.

Sample carriers and light sources are so constructed, and spectrometers are so modified, that the instrument may be operated in a lighted room, which increases the facility and speed with which determinations can be made. In this connection, it should be noted that the light source is of the low-voltage and low-current type, which eliminates many difficulties encountered in color analyzers where the light source consumes 500 watts or more. For example, for measurements of transmitted waves the light source in this instrument consumes only 15 watts, and for reflection measurements less than 100 watts.

All determinations are independent of the color and intensity of the light source. It is not necessary for the electrical circuit to be kept constant throughout a series of readings in order to insure the accuracy of the measurements, because the measurements are independent of gradual variations either in the light source or in the photo-electric cell. Since the determinations are independent of empirical values of standards, the results may be expressed in any convenient terms such as total reflection (or spectral centroid). Readings may also be secured directly in terms of eye sensitivity or in terms of any theoretical or real color standards.

In the field of physical research this instrument offers a means for securing fundamental data on the characteristics of radiant energy and on the structure of matter. For example, by the accurate measurement of the relative intensity of individual lines in the spectrum, it may be employed for the differentiation of isotopes. With some modifications it can be used for the measurement of sound.

This instrument has already been used in many industries, such as those engaged in the manufacture or use of dyes, paints, textiles, paper, animal and vegetable oils and fats, petroleum products, glass, and moving pictures, where accurate determination of color is of importance. It is beginning to find applications in other industries where color can be used as a critical index to the accurate control of production when its measurement can be made quickly and exactly.

A modification of this instrument may be used as a *pyrometer* for the precise measurement of the temperature of steels or other materials during heat treatment, it being possible to detect a change in temperature as little as 1°C. by this means.

Opacimeter.—This instrument is designed for the accurate measurement of the opacity of transparent or translucent materials such as glass, parchment, and paper. Its accuracy is within 0.5 per cent, and an experienced user can secure check readings within 0.2 per cent. The construction of the instrument and its method of operation are such that determinations of opacity are independent of the color and surface-reflection characteristics of the sample. The device is illustrated in Fig. 55. The operation of the opacimeter is based on the same principles as those embodied in the photo-electric spectrophotometer.

All measurements are made electrically so that errors inherent to visual observation are wholly eliminated and the instrument can be operated either in daylight or under artificial illumination, thus increasing the facility and speed with which determinations can be made. Measurements are independent of (*a*) the voltage applied to illuminating lamps; (*b*) the composition of the color emitted by the illuminating lamps; (*c*) the relative spectral absorption of the reflector; (*d*) the color-sensitivity curve of the photo-electric tube; (*e*) the grid-voltage, plate-current characteristics of the amplifying tubes; (*f*) the gradual deterioration from age and use of the batteries supplying the energy required in the A, B, and C circuits and by the illuminating lamps.

When determining the opacities of different papers, or similar materials, in order to secure results that will be directly comparable over long periods, it is necessary that all samples tested are either quite dry or have been stored under identical conditions of temperature and humidity. The research that resulted in the development of this instrument proved conclusively that the opacity factors of papers varied with fluctuations of the absolute humidity of the atmosphere in which they had been stored. The opacity factor of any material as determined by this instrument is not a direct function of its transmission.

FIG. 55.—Opacimeter. (*American Photoelectric Corporation, New York City.*)

Opacities are measured directly in per cent on a scale established by each sample on which black (no illumination) equals 0 per cent and the illuminated sample when "backed" by a magnesium carbonate block equals 100 per cent. The 100 per cent adjustment calibrates the instrument on that proportion of the total light incident to the sample which is reflected by the material itself plus that reflected back through the sample from the magnesium carbonate block. The direct percentage reading is that part of the total which is reflected by the material alone. The opacities of most commercial papers as determined by this method usually are between 50 and 90 per cent. For first-class quality of paper for books and magazines an opacity factor of at least 80 per cent is desirable. The opacities of most commercial clear, uncolored glasses, which transmit from 85 to 90 per cent of the light in the visible incident spectrum, are usually from 2 to 8 per cent, depending on the thickness and absorption characteristics of the samples.

For particular purposes the instrument may be calibrated to scales other than the standard above described. Thus, for example, significant data can be secured with this instrument that make possible the evaluation of different papers or combinations of various papers with different inks. The measurement of the opacities of different papers on scales where 100 per cent equals the total light reflected by the materials themselves plus that reflected back through the samples by many thicknesses of the same materials will quickly determine their relative values for books, magazines, and similar uses. Similar measurements with the samples when backed by many thicknesses of the same materials printed with different inks will disclose the relative values of different combinations by determining the differences in illumination between different areas, namely those backed only by the materials themselves and those backed by some particular ink.

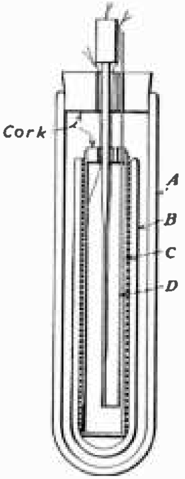


Fig. 56.—Photo-electric thermostat.

Low-temperature Thermostat.—(*Journal Franklin Institute*, March, 1929.) This device is comparatively simple in construction but is capable of maintaining the temperature constant to within 0.001°C. at any point from the boiling point of liquid air to ordinary room temperatures. The thermostat bath is of pentane contained in a cylindrical copper vessel *C* in Fig. 56. A heating unit of 40-ohms resistance is wound around the outside of this vessel and the whole is placed inside a small Pyrex Dewar flask *B*, and the Pyrex flask is placed in a bath of liquid air contained in a larger Dewar flask *A*.

Thermal equilibrium is maintained to a fair degree by the heavy copper walls of the thermostat, since it is of such dimensions that no point within it is more than 1.5 centimeters from the walls. Sometimes a hand stirrer *D* is used, but more often a heavy copper tube (not shown) of a diameter of about half that of the thermostat is employed to further minimize temperature gradients. Obviously only the latter can be used below about 140°C., at which point pentane begins to solidify.

Temperature regulation is accomplished in the following way: A copper-constantan thermocouple is soldered to the inside of the copper container about one-third of the way down from the top. The voltage from this is opposed with that from a potentiometer which can be set to correspond to the desired temperature. The thermocouple and potentiometer are connected in series with a high-sensitivity galvanometer. When the temperature of the thermostat differs from that corresponding to the voltage set on the potentiometer there is a galvanometer deflection, which regulates the heating of the resistance coil.

An image of the filament of a 100-watt lamp is focused by a lens on the galvanometer mirror which reflects this onto a *photo-electric cell* about 0.5 meter away. The cell is of the potassium-hydride type. It is enclosed in a black box which has a square hole with sharp edges so placed that the hole is in front of, but smaller than, the "window" in the photo-electric cell. When the image of the filament falls on the cell box, it produces a sharp line of light about 1 millimeter wide. The zero point of the galvanometer is so adjusted that the edge of this line of light falls exactly on the edge of the square hole over the window of the photo-electric cell. When the temperature drops below that required, the line of light moves about 0.2 millimeter so that it falls on the window of the cell, causing the latter to operate a relay which shunts a resistance and thus increases the heat input into the thermostat. Conversely, when the temperature becomes too high the line of light moves off the cell, the relay is released, and the heat input is reduced. In this manner the temperature of the walls of the thermostat is regulated to about a thousandth of a degree.

The photo-electric cell circuit is shown in Fig. 57. All the batteries are insulated against grounds by paraffined blocks, and the cell, radio tubes, and grid leaks are enclosed in a lead-covered moisture-proof box. This, together with sheets of metal under the batteries, is grounded. When this is not done the operation of the cell causes the galvanometer to behave erratically.

The thermostat heating circuit in Fig. 57 is designed so that the voltage drop across the heating coil and the shunt resistance, as well as the current through them, may be adjusted. This is accomplished by placing directly across the 110-volt, direct-current line a 65-ohm variable resistance and connecting one lead of the heater to the movable contact and the other to one end of the resistance. The resistance shunted by the relay must be variable in order that the change in heat with the operation of the photo-electric cell can be adjusted to give the best temperature regulation.

To cool the thermostat, the cork in the top of the outer Dewar flask is raised and liquid air is blown in until its level is above that of the copper container, which projects above the Dewar flask, which holds it. In this way the thermostat is quickly cooled and is ready for use as soon as the slight excess of liquid air evaporates.

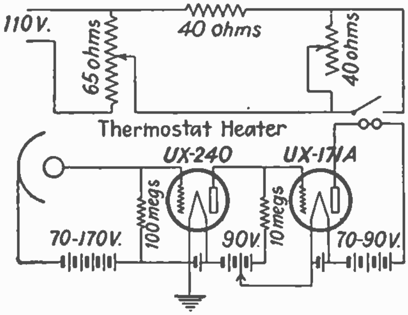


Photo Electric Cell Circuit

Fig. 57.—Thermostat circuit including photo-electric cell.

The advantages of this type of low-temperature thermostat are: (1) Temperature is maintained constant to 0.001°C. indefinitely with proper stirring; (2) small quantities of liquid air are used; including the liquid air for cooling down, only about two liters are used in a day; (3) only 15 to 60 minutes are required to change from one temperature to another and to reestablish equilibrium; (4) safety, since the inflammable pentane is encased in a copper container.

SECTION XIV

TELEVISION

Telephotography.—The principle by which pictures are transmitted electrically was explained, although vaguely, about fifty years ago. This early work received little attention but renewed interest was established with the development of radio in recent years. New types of radio-vacuum tubes which have been recently devised are useful in radio photography, these being the vacuum-tube amplifier and the photo-electric cell. *Radio photography* has now become an accomplished fact, whereas the practical realization of actual *television* (seeing moving objects at a distance) still involves some difficulties in its practical application. Rapid progress has been made, however, in the development of a practical technique in telephotography by methods of dealing with static and fading which presented almost insuperable difficulties when pictures were to be transmitted over long distances.

Static and Fading.—Two distinct methods of communication have been developed to be used with radio equipment, these being (1) by modulation (page 170) and (2) by interruption (page 169). The first of these methods is usually associated with the radio broadcasting; and the second with radio telegraphy. Both of these methods may be adapted to radio photography, and each will have its distinct field. The effective range of a broadcasting station is very much shorter than that of a radio telegraph station of the same power, but within its range the radio broadcasting equipment gives excellent service. Freedom from disturbances due to *static* and *fading* may be accomplished by having a large number of transmitting stations interlinked by a wire system. This method of obtaining freedom from such troublesome disturbances has been characterized as the application of "brute force" instead of scientific research. On the other hand, it is argued that this method of approach has really developed radio to its present standing as an industry. In the usual methods of radio communication relatively long wave lengths are employed. Compared with the more or less standardized wave lengths, short radio waves have been shown to have a special suitableness for certain kinds of service, and for these services they are more sensitive, and communication can be made more economical than with the more standardized equipment. The most striking illustrations of these characteristics of the short waves are shown by the feats of amateurs in communicating with stations on the other side of the earth by means of small home-made transmitting and receiving sets. Although this short-wave method of communication has been limited to telegraphy by means of dots and dashes, it is likely that the short waves will be eventually used for the transmission of pictures, facsimile of letters, printed pages, motion pictures, and other radio photography by television.

The essential problems of television have been worked out by studying the methods of transmitting half-tone pictures by radio. The underlying principle which makes this possible is the use of a system of signalling in which the results are independent of the signal strength. If, for example, the signal or other impulse to be transmitted is strong enough to be recorded at all, it gives the same intensity in the record whether the transmitting signal is relatively strong or weak. Obviously, this method makes television independent of the effects of *fading*. If the signals or other impulses to be transmitted are stronger than the prevailing static, it is possible to eliminate the effects of static by introducing a "threshold" value of signal strength in the receiving set, so that nothing is received unless the signal strength exceeds this value.

Half-tone Radio Photography.—By the methods of radio photography half-tone effects are produced by resolving the picture to be transmitted into five or more separate colors or "shades" of color, such as, white, light gray, medium gray, dark gray, and black. In the application of suitable methods in the use of transmitting and receiving equipment, these colors and shades of colors are automatically analyzed for transmission and are then reassembled for reproduction in a picture. For transmitting light intensities as represented by these colors and shades of colors, various methods for the use of radio waves have been devised. One of the most satisfactory methods uses five wave lengths, one wave length for each color or shade. Another method, in some respects much simpler, uses only one wave length for such transmission. The picture shown in Fig. 1 was transmitted by a method using a single wave length for all colors and shades.

The radio transmitting equipment required in the application of the first of these methods, that is, when five wave lengths are used for as many colors or shades, is designed so that at every moment the color or shade of color that comes nearest to the one of the five having individual wave lengths will be automatically selected and transmitted. The transmission will, of course, be in a group of five wave lengths corresponding to the colors and shades of colors. The receiving set is likewise designed to select in very much the same way the corresponding colors and shades which are transmitted. This process may appear to be complicated but it is not nearly so much as it may seem, as the device by which the different colors and shades are selected naturally results from the synchronous operation of the transmitting and the receiving machines. The black color in a picture which is being transmitted is produced by the exposure of sensitized paper to the "recording" spot of light during four successive revolutions of the spot of light. The light-gray color is produced by a single exposure during one of the four revolutions and no other exposure during the three succeeding revolutions. The overlapping exposure is progressive and is a continuous process.

FIG. 1.—Picture transmitted by multi-shade television.

Television.—The methods of radio telephotography are fairly well worked out and reasonably successful. The realization of actual television seems to depend mainly on increasing the speed of the devices already in use for radio telephotography. In both processes essentially the same equipment is required. The devices concerned are (1) the photo-electric cell, (2) the vacuum-tube amplifier, and (3) the antennas for transmission and reception. Fortunately the photo-electric cell and the vacuum-tube amplifier depend for their operation on the flow of electrons, which is very rapid; but the use of radio waves in transmission from the antennas by radiation and its reception by means of antenna imposes certain speed limitations on account of the limited scale of the available wave lengths. The practical solution of television depends probably, more than on anything else, on the application of the most suitable wave length for transmission. For example, radio telephotography may be very successfully performed in two minutes for a picture 2 by 4 inches when the wave length is 12,000 meters (25 kilocycles per second). Now if a wave length of 12 meters could be used instead of 12,000 meters, corresponding to a wave frequency of 25,000 kilocycles per second instead of 25 kilocycles per second, and if the photo-electric cell and the vacuum-tube amplifier as well as also the light-control device can keep up with this speed, then the radio wave will do its part and transmit in 1/1,000 part of two minutes (about ⅛ second) a picture of the same size and quality. It is thus possible to transmit a picture in a space of time which is about that required for good motion picture operation (about 1/16 second per picture).

Television Projector.—The size of picture described in the preceding paragraph (2 by 4 inches) will not, however, meet the requirements of successful television. The public will want television pictures shown in nearly life size on a large screen; and in this specification is the fundamental difficulty. A television projector including a suitable source of light, a lens, and a drum carrying a number of mirrors is shown in Fig. 2. In the operation of this projector a "spot" of light is focused on the screen used for showing the pictures when the drum is stationary. This spot of light is the "brush" that makes the picture. Now when the drum revolves, the spot of light passes across the screen. Since each of the mirrors on the drum is set at a different angle, as the drum revolves a different mirror (at a different angle) comes into line, and the spot of light passes rapidly up and down over the screen on tracks, each being adjacent to the first one, the process continuing until the whole screen is covered. If a picture is to be made in this way by

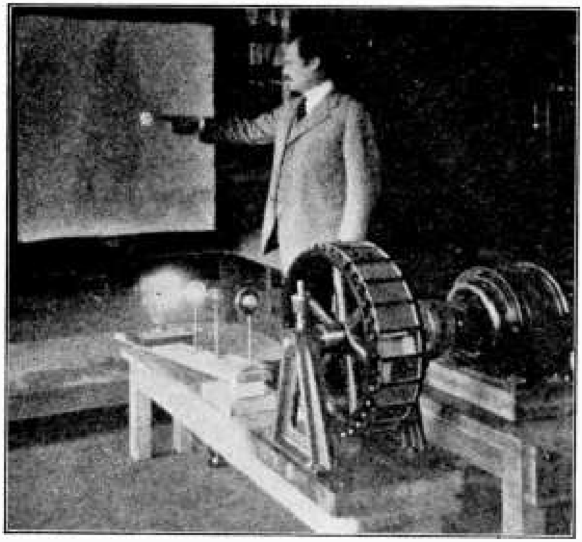


FIG. 2.—Experimental television projector.

the spot of light, there must be about 10,000 separate strokes of the brush (spot of light) per second. This means that the spot of light must pass over the screen in 100 parallel paths, making 100 separate impressions of light in each path. If now the process of picture reproduction is repeated over and over again sixteen times in a second it means that 160,000 independent movements of the brush (spot of light) are made in each second. Such a speed of operation may at first seem inconceivable, and yet 100 separate impressions of the brush will not give a satisfactory picture. Actually the speed requirements for television are about 300,000 independent movements of the brush in a second.

Besides the high speeds of operation that have been explained, television requires a quality of light of such brilliancy that it will illuminate the screen effectively when it remains in one spot on the screen only 1/300,000 second. The problem of light intensity is really one of the greatest difficulties in the application of this system. No matter how the optical system of the projector is designed, it is impossible even with the use of the most brilliant arc light to illuminate a large screen sufficiently with a single spot of light. The obvious procedure is, therefore, to increase the number of spots of light. In a typical television projector, 7 spots of light are used for illumination instead of 1, with the result that seven times seven or forty-nine times as much illumination is obtained on the screen. The reason why the gain in illumination is in proportion to the square of the number of light spots is that the drum has 24 mirrors; and in one revolution of the drum, 1 spot of light passes over the screen twenty-four times. Now when 7 *sources* of light and also 7 *spots* of light are used, there is a total of 168 "light-spot" paths on the screen to be illuminated during one revolution of the drum.

The gain in using 7 sources of light in multiple is twofold: (1) a direct increase of 7:1 in illumination and (2) the speed at which each light beam must travel on the screen is reduced at the rate of 7:1, for the reason that each spot of light has only 24 paths to cover instead of 168. While the spot of light itself may travel at any conceivable speed, there are limitations to the speed at which the drum carrying the mirrors can be operated. The higher speed of the spot of light can, therefore, be attained only by making the mirrors smaller; and mirrors which are only one-seventh as large as those originally designed will reflect only one-seventh as much light. The brilliancy of the spot of light would be, therefore, only one-seventh of that obtained with the multiple-beam system which gives 7 spots of light, seven times as bright, or forty-nine times as much total light for illumination.

There is also another advantage of the multiple-light arrangement, for the reason that each light beam will move only one-seventh as fast as with a single beam and will, therefore, give only 43,000 instead of 300,000 separate impressions per second. A modulation speed (page 170) of 43,000 impressions per second is relatively high for the present types of radio equipment, and it is several times as high as present broadcasting practice.

Another point of view in regard to multiple-light beams is also significant of its advantages. It is easy to design a television system to produce, for example, 43,000 picture impressions per second, but by the ordinary means the images so obtained will be so crude as to be of very little practical value. It has been already stated that for satisfactory radio-picture operation, an operating speed of 300,000 picture units per second is necessary to give good results. This speeding up of the process will, of course, add to the difficulties already present in securing, by the ordinary means, 43,000 impressions per second. In fact the difficulties increase by the square of the speed of operation. If a television picture is to be projected on a fairly large screen so that a good image is obtained, the speed of the process must be increased seven times, and in so doing the dimensions of the picture must be reduced the same amount so that only one forty-ninth as much light is available for illumination. It is, therefore, inadvisable again to increase the speed of the mechanical process of making a single image, and the better solution seems to be to produce a number of pictures simultaneously on the same screen and interlace them optically so that the combined effect gives the impression of a good picture. In the operation of this method of "scanning" the screen with 7 beams of light working in parallel simultaneously, as the drum revolves, the 7 spots of light trace 7 lines on the screen at the same time and then pass over an adjacent track of 7 lines until the whole screen is covered. When the drum carrying the mirrors is stationary, the 7 spots of light are seen on the screen as a cluster as shown in Fig. 2. A complete television system requires the independent control of the 7 light spots; and for this purpose 7 photo-electric cells are located in a cluster in the transmitting equipment. For the control of a multiplex radio system having 7 channels, a *Hammond multiplex system* can be used with 7 intermediate carrier waves (page 486) which are "scrambled" and sent out by a single transmitter and then "unscrambled" at the receiving station so that each photo-electric cell controls one of the 7 light beams. In a practical demonstration of the "scanning" method at a theater in Schenectady, N. Y., E. F. W. Alexanderson presented live-size pictures on a large screen in a theater. The performers appeared before the television camera in a studio which was one mile distant. The light impulses showing the performers were first converted into electric impulses by means of photo-electric cells and then these electric impulses were sent out by the transmitting equipment to be picked up by the television antenna at the theater. After the amplification the electric impulses became sound impulses for the operation of the usual type of loud-speakers. Microphones in the distant studio were placed near the performers and picked up their speech and song, these instruments converting the sound impulses into electrical impulses which were carried by a wire to a short-wave transmitter which radiated into the air the corresponding radio waves.

At the theater where the pictures were shown, the receiving antenna picked up the radio waves from the air and transmitted them on the lead-in wire to the television receiving set which was operated in connection with a small monitor called a *telopticon,* from which the light impulses are transferred to a "light valve" based on an invention of Dr. Karolus of Germany, which operates directly and accurately to permit the passage of light in correspondence to the electric impulses received from the television transmitter. This light valve is a part of an intricate system of lenses and for its operation receives light from a high-intensity arc lamp of a type similar to those used for the projection of motion pictures. The electric currents from the television receiver and monitor are passed through a combined rectifier and amplifier before they are transformed into light impulses in the light valve. In this method the light impulses are passed on through lenses to a disk corresponding in size, number of holes, and rate of rotation to the disk of the camera used for taking the television picture. Additional lenses pass the light forward to the screen where these light impulses at the rate of 40,000 per second become the living, active image of the person or thing being shown. The arc lamp with its lens system and the Karolus light valve are all included in the piece of apparatus called the television projector which is shown in outline in Fig. 3. In the arrangement of the

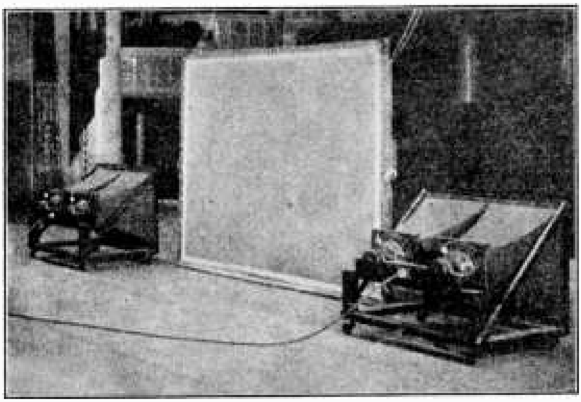


Fig. 3.—Receiving equipment for sound and television.

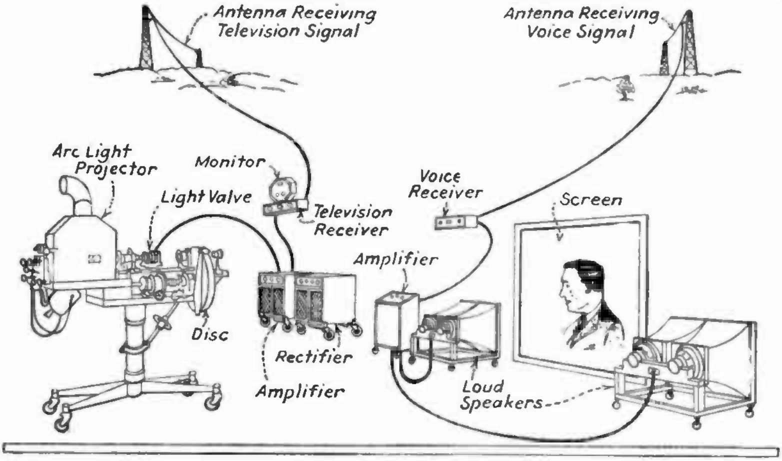


FIG. 4.—Screen and loud-speakers on theater stage.

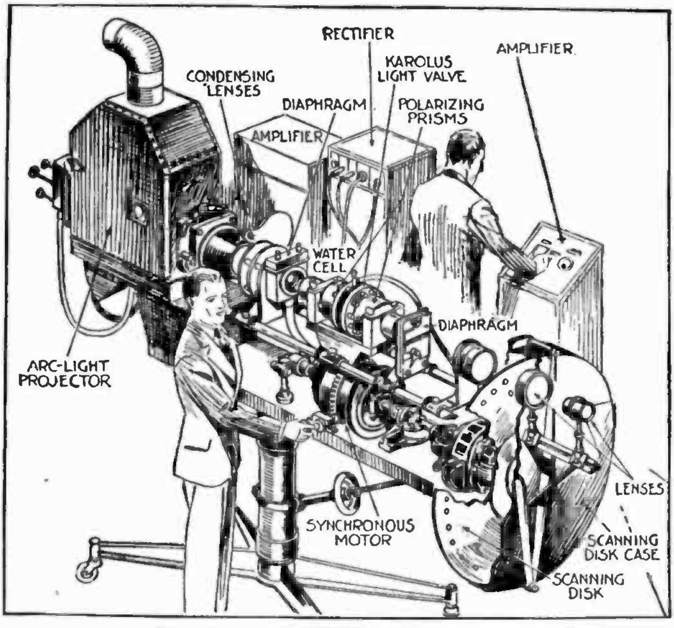


FIG. 5.—Typical television projector.

television projector and its screen on a theater stage as shown in Fig. 4 the space between them is usually between 15 and 20 feet for producing a 6-foot image on the screen. Figures 3, 4, 5, 6, and 7 show in some detail

Fig. 6.—Orchestra directed by television.

the television-projecting apparatus, the scanning-disk booth, and the picture of an orchestra in the theatre being directed by a person at a distance by the method of showing his image on the television screen.

The remarkable achievement which was demonstrated by the showing at the Schenectady theater was the increased size of the television picture which was so much larger than any which had been shown before. Previous demonstrations had shown television pictures only a few inches square, while the Schenectady pictures measured in some cases 6 by 6 feet. The other accomplishments demonstrated at this time were that a bright enough illumination light could be obtained so that the 6-foot images could be seen by a large audience and that a lens system and a method of controlling this bright light had been devised. Instead of the pinkly glowing neon tube used by other experimenters, Alexanderson uses a very brilliant arc lamp which supplies a steady and very strong light. He is able to do this by the use of the Karolus light valve or light-shutter device which can be operated at an enormous speed. By means of this light valve it is possible to interrupt with sufficient rapidity the flow of light from the arc lamp through the holes in the scanning disk in the receiving set. The light valve is in turn controlled by the television impulses at the receiver.

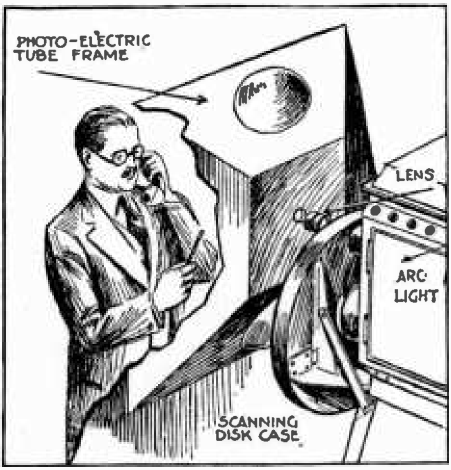


FIG. 7.—Scanning booth.

The *Karolus light valve* contains nitrobenzol and is placed between two prisms which polarize the light so that it vibrates in one plane only. Polarized light is needed because the Karolus light valve can be operated only with such light. As originally designed and constructed, this light valve was delicate and extremely short-lived, but it has been perfected to the extent that it can be used for continuous operation in connection with a high-intensity arc light.

Figure 7 shows a performer in front of the scanning-disk booth in the position in which he might be directing an orchestra in a distant concert hall. Attached to this case is the mechanism of the scanning-disk apparatus. As the scanning disk rotates, the light and dark portions of the horizontal section of the image will translate it by means of a photo-electric cell into corresponding electrical impulses. These impulses are sent as radio waves to the receiving apparatus where they are amplified and transformed back into light impulses or vibrations. The scanning disk has 48 holes and rotates at 20 revolutions per second.

Television Combined with Telephone Conversation.—The Bell Telephone Laboratories in New York City have demonstrated with suitable apparatus that it is possible to combine television with ordinary telephone service, so that it is possible for both parties to a telephone conversation to see as well as hear each other.

Television for Guiding Airplanes in Fog.—The principles and equipment successfully applied by Alexanderson for the practical use of television have been adapted by John Hayes Hammond, Jr. of Gloucester, Mass., for use in aviation with the particular object of making airplane landings safe in foggy weather. It is generally recognized that the present methods of making landings in a thick fog are probably the most difficult and dangerous circumstances in airplane operation. If television apparatus can be successfully and simply applied to airplanes so that it can be used to facilitate the safe landing of airplanes in dense fog, a great deal will have been accomplished in making air navigation relatively safe. In this application of the methods of television as developed by Alexanderson, he has combined a method used in the United States Navy to duplicate at a distance the position of the "loop" used to take radio-compass bearings. For the application of this method, the airplane is equipped with a small radio transmitter which sends out continuous radio waves. These radio waves are picked up by three radio-compass stations, suitably spaced around the outside edge of the landing field. At one side of the landing field there is a television transmitting station, and in this station the special transmitting and receiving apparatus is installed. This equipment consists of a conventional type of television transmitter in which the lenses are pointed straight down. This apparatus constitutes the television scanning unit (Fig. 7) and under this unit is located a miniature reproduction of the entire landing field, every detail of the field and surrounding obstructions being reproduced in small size but in exact proportions. By concentrating a brilliant arc lamp on this miniature representation of the flying field it is possible to obtain the best possible conditions for television transmission. The spot representing the airplane in its location over the flying field may be a small disk set at the focal point of the lens in the television transmitter. The shadow of this disk representing the airplane will then appear on the image as scanned by the television transmitter.

Although it is stated that this device is an application of the Alexanderson television methods and that the Karolus light valve is used, it is probably impossible to use an arc light to secure the necessary brilliant illumination, for the reason that space and weight are so limited in an airplane. A nitrogen-filled incandescent lamp will probably give a sufficient amount of illumination for the small screen that is required in the airplane. In the application of this invention to airplanes, it is possible for the aviator when landing in a fog or darkness to see spread out before him in an extension of his instrument board a bright image showing every detail of the landing field which he is approaching. The image of a disk or similar object will indicate on his screen the location of his airplane with respect to the hangars, runway, and obstructions on the landing field; and as the airplane moves about in the vicinity of the landing field, the spot (disk) representing the airplane will move across the miniature map to duplicate the movement of the airplane. If the pilot of the airplane sees the spot representing the airplane heading toward some obstruction on the field, he can immediately correct the movement of the airplane by the operation of the controls so as to change the course. Immediately after this change of course the spot will show by its movement on the screen whatever change in the course of the airplane has been accomplished. If this device can be successfully applied, it will be possible for an aviator to fly his airplane in fog or the darkness of night and see the landing field below as brightly lighted on his screen as the field is in clear daylight.

Television in Color.—The development of color television has been greatly simplified by the fact that as far as the eye is concerned, any color may be represented by the proper mixture of just three fundamental colors, these being red, green, and blue. This fact was utilized in the development of color photography, and all that has been accomplished in that field has served for the improvement of color television. In the applications of color television, three sets of photo-electric cells are used instead of one cell that is commonly needed for telephotography in "black and white." Each set of photo-electric cells is provided with filters of colored gelatin. One set has filters of an orange-red color to make the cells see things as the red-sensitive nerves of the eye see them. Another set of cells has yellow-green filters to give the green optical sensations. The third set of cells has greenish-blue filters which give the optical sensations of blue color. The scanning disk required and the source of light are very much the same as those used in monochromatic telephotography, the only difference being in the arrangement and the multiplicity of the photo-electric cells, as there are three series of television sensations or signals (one for each set of cells) instead of one in the monochromatic work.

In the operation of a typical system of television in color, 24 photo-electric cells are used. Of this number, 2 cells are provided with the so-called "blue" filters, 8 with "green" filters, and 14 with "red" filters. The number of each kind of photo-electric cell is determined by the relative sensitiveness of the photo-electric cells to different colors in order that photo-electric sensations of about equal value in the three colors may be obtained. These photo-electric cells are placed in three separate banks, one bank in front of and above the position of the scanned object, one bank diagonally to the right, and another bank diagonally to the left, so that the cells receive light from both sides of the object and also from above. Each bank has, of course, a proportionate number of cells of the three different colors. Large sheets of rough glass are set up some distance in front of the banks of cells, so that the light reflected from the object to the cells is diffused. Electric currents are produced in the photo-electric cells by the light which is reflected from the object and then passes through the color filters. Three sets of amplifiers instead of one, however, are required, as one set is needed for each color. There must also be three communication channels in place of one.

At the receiving end of the color-transmission system, the three sets of electric radio waves for the respective colors must be received and viewed together, on a screen and in superposition. Several methods of reception of color television may be used. For displaying the transmitted image to a large audience, the method of reception may be essentially the same as for monochromatic television. The surface of a scanning disk similar to that used at the sending end is used, and the light from the receiving lamp is suitably focused by means of lenses. In order to combine the light of three lamps, they are placed at some distance behind the scanning disk, and two semitransparent mirrors are set up at right angles to each other but each at 45 degrees to the line of sight. One lamp is then viewed directly through both mirrors, and one lamp is seen by reflection from each. To obtain suitable lamps to provide the red, green, and blue light has required considerable study. There is no difficulty about the red light because the neon glow lamp which has been used previously in television can be transformed into a suitable light of this color by interposing a red filter. For the blue and green lights no other source is nearly so efficient as the neon lamp, but fairly good results are obtained by the use of argon lamps for this purpose. Unfortunately, however, argon lamps are not nearly so bright as neon lamps, and special types of these lamps are needed to give exceptional brilliancy.

Satisfactory telephotography in colors is much more difficult to accomplish than the monochromatic kind. Errors of quality which would pass unnoticed in an image of only one color may be fatal to true color reproduction where three such images are superimposed and viewed simultaneously. If the light from the object is not distributed equally to all the cells, the object will appear as if illuminated by lights of different colors shining on it from different directions.

One of the significant features of color television is, however, that it does not require completely new apparatus. The same light sources, driving motors, scanning disks, synchronizing systems, and the same types of circuits as well as methods of amplification are used as in the monochromatic system. The only new features are the type and arrangements of the photo-electric cells in the transmitting equipment and the type and arrangements of neon and argon lamps at the receiving end.

The development of a special type of photo-electric cell for color television is an important accomplishment. The new type uses sodium on its sensitized surface, the process requiring the use of sulphur vapor and oxygen instead of the former use of hydrogen. The response of the new cell to color instead of stopping in the blue-green region continues all the way to the deep red. Because the former potassium cells were responsive only to the blue end of the spectrum, objects of a gelatinous color appeared darker than they should be. This disadvantage applied particularly to persons of dark and tan complexion. When the new cells are used in the old type of telephotographic apparatus, and with yellow filters (similar to those used in photographing landscapes), this defect is corrected, and the images assume their correct values of light and shade no matter what the color of the subject or the complexion of the sitter.

SECTION XV

INDUSTRIAL APPLICATIONS OF VACUUM TUBES

Weighing and Measuring with Radio Currents.—Methods of determining weight and thickness with unusual precision depend on the use of vacuum tubes applied in very much the same way as in the ordinary radio receiver. Applications for this purpose may be illustrated by the use of a variable condenser which is a part of the radio receiving set. The sensitivity of the variable condenser in the receiver to changes in the relation to each other of the movable plates may easily be shown by placing a piece of tissue paper between two of the plates and observing the effect on reception. For example, if the dials of the receiving set have been adjusted so that the receiving set is tuned for the reception of the radio waves from a distant broadcasting station and then a piece of very thin paper is placed between the plates of a variable condenser in the set, the reception from the broadcasting station which had been tuned in will fade, and if there is another distant station operating at about the same wave length, the receiving set may be observed to be tuned to it. The reason for this is that paper has a much higher dielectric constant (page 55) than air, and, consequently, when a piece of paper is inserted between the plates of the condenser, its capacity is so much increased that the radio receiving set may be tuned to a broadcasting station transmitting on a somewhat higher wave length.

A regenerative receiving set tuned by the zero-beat method has been found to be very satisfactory for this kind of measurement, as very slight variations in the thickness of the paper between the condenser plates has a marked effect on the tuning of the set. In its essential parts, a radio receiver for this kind of service consists of an oscillator vacuum tube (page 387) and a tuned resonant circuit (page 403). The resonant circuit includes, preferably, both indicating and recording ammeters. This circuit may be tuned by altering the capacity of either of two condensers. One of these is a precision variable condenser which is used to bring the tuned circuit into resonance with the oscillator tube when the materials being measured are of widely varying dielectric strength. The other condenser is of the fixed type shown at the ends of the arms of the instrument in Fig. 1. A strip of the material to be measured is passed between the plates of the fixed condenser when measurements are to be made. Any variation in the thickness or the weight of the material in the strip which passes between the plates of the fixed condenser will cause a variation of the capacity of the condenser and, consequently, also a variation of the natural period of the tuned circuit. As the result of the variations of capacity and natural period of the tuned circuit, there will be corresponding variations in the radio-frequency current flowing through the indicating ammeter which is arranged to show such variations. Now, if a strip of some material as, for example, a sheet of paper is passing between the plates of the fixed condenser, and the variable condenser is set to bring the tuned circuit to a "point" just off the resonance peak, then, any variation in the capacity of the fixed condenser, as the result of a variation in thickness or weight (and of the dielectric constant) of the paper, will produce a change in the circuit of the oscillator vacuum tube. The pointer of the indicating ammeter will then swing away from its central position in a direction depending on whether there is an increase or decrease in the thickness or weight of the material of which the moving strip is made. A circuit diagram of this device is shown in Fig. 2.

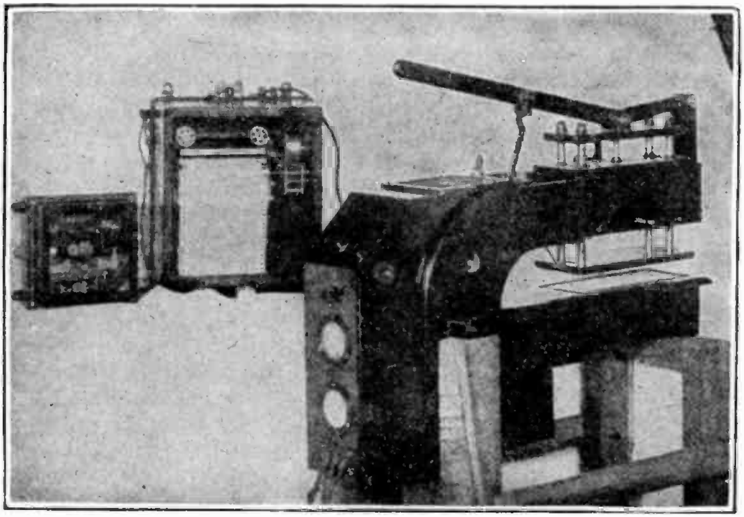


FIG. 1.—Condenser for measuring thickness of paper.

In the use of the experimental apparatus which was first tried to demonstrate the practicability of this device, it was found that the temperature of the room in which it was used had a considerable effect in changing the relative position of the metal parts of which the device was made, so that changes in temperature were recorded as if there were changes in thickness or weight of the material being measured.

The temperature difficulties are avoided by using a massive cast-iron frame for the fixed condenser and providing columns made of invar steel for supporting the plates of this condenser. By properly arranging the cast-iron parts and those of invar steel, the variations in capacity effects due to temperature changes have been minimized to such an extent that they have no appreciable effect on the operation of the instrument.

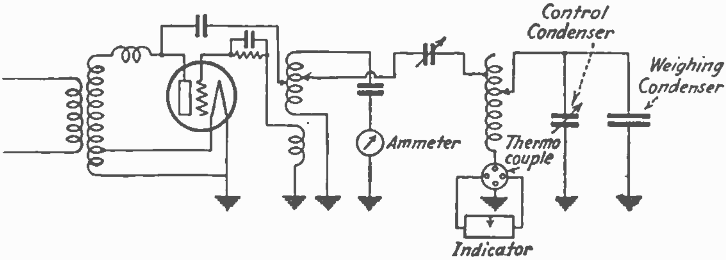


Fig. 2.—Circuit of radio measuring device.

Radio Apparatus for Moisture Control.—A radio device using vacuum tubes has been developed for the very accurate control of moisture in the manufacture of products which are made in sheets. The apparatus used for this purpose has the same general arrangement of circuits as the device already explained for the accurate measurement of thickness or weight of sheets of materials in the process of manufacture. For example, in the manufacture of paper, the moisture content of the sheets in the last stages of manufacture is important. Application is made of the variation of the capacity of a fixed condenser in the same way that the capacity varies with the thickness or weight of strips or sheets of paper passing between the plates. An apparatus of this kind is a *precision hygrometer*. In this instrument, the measurements are made by an indirect method; that is, the change of moisture capacity of the material itself as it varies with moisture content is not measured. On the other hand, all the measurements are made of the moisture content of a ribbon of cellulose acetate which is stretched across the surface of the moving sheet in which the amount of moisture is to be determined. This ribbon of cellulose acetate, when passed over, but not quite touched, by the surface of the sheet of material being manufactured, is very sensitive to changes in the moisture of the manufactured sheet.

In the precision hygrometer operated by radio circuits, the moisture content of sheets of the manufactured product is used to vary the tuning of the secondary radio circuit in such a way that the current in the circuit produces corresponding deflections, right or left, of the pointer of the indicating ammeter. In the operation of this device, a narrow ribbon of cellulose acetate, which is very sensitive to the presence of moisture, is placed very close to the sheet of manufactured product but is shielded on all other sides so that it is exposed only to the variations of moisture in the moving sheet passing near it. When the sensitive ribbon of cellulose acetate is placed in this way, its moisture content is directly responsive to that of the paper and to nothing else. Now, the effect of moisture on the cellulose-acetate ribbon is to change its length which becomes slightly greater when the amount of moisture is increased. In the device described, the sensitive cellulose-acetate ribbon is fixed at one end and is attached at the other end to the movable plate of a fixed condenser which is connected into the secondary circuit of two transformer-coupled circuits. Changes in the moisture of the sheet of the manufactured product as it passes along over the shielded cellulose-acetate ribbon cause changes of length in the ribbon, which cause corresponding changes in the tuning of the condenser, in the same way that the movement of the knob of a variable condenser changes its tuning. These changes of tuning by alterations of the length of the ribbon produce variations of the current in the secondary circuit in which the sensitive indicating ammeter is included. It is obvious, therefore, that moisture variations in the sensitive ribbon will affect the amount of current in the secondary circuit and, therefore, the indications of the pointer of the meter.

A variable type of condenser which is used for purposes of adjustment is in parallel with the fixed condenser, as described, and is used to control the amount of moisture in the product to be manufactured. This variable condenser is used to set the mid-scale reading of the instrument at the particular value of moisture content in the manufactured product that it is desired to hold. The sensitiveness of the instrument, that is, the number of increments of deflection of the pointer of the indicating meter for 1 per cent of change in moisture of the manufactured product, can be adjusted by changing the air gap of the fixed condenser. It will be understood that these two adjustments are necessary in the setting up of the instrument or in the necessary changes which may be made to adapt it to different operating conditions as they relate to changes of product or to changes in specifications for moisture content. For example, the moisture content which is preferable for news print is much higher than for other grades of paper. Provision may be made so that the variations of the indicating ammeter are shown on a chart as a continuous record.

The most important advantage of using, as a guide, the continuous record rather than an indicating instrument is that any changes made by the operator of a machine may be based on the trend, as well as the present value, of the moisture content. The paper might be "on the dry side" but showing a progressive rise of moisture, and the operator might rightly conclude that it would become normal shortly if let alone. He is working much less in the dark than if he knows only the condition of the paper at the moment. The instrument is provided with electrical contacts that are closed by the pointer of the indicating ammeter whenever the moisture becomes too high or too low, and connected so that they will open an electrically actuated steam valve by a measured amount when the low-moisture contact is made, and close it by such an amount when the moisture content is too high.

Chemical Control and Measurements.—The so-called *Braun vacuum tube* (cathode-ray *oscillograph*, page 38) may be used to photograph the order of a process or reaction which the human eye cannot follow. This tube serves also to provide a constant check of the form of the audio-frequency current required in many measurements of solutions and gases. The neon tube has been applied also in a stroboscopic method to supply and check the frequencies required in measurements of conductivity and of dielectric constants. Audio-frequency oscillators using vacuum tubes of the radio type will provide the alternating voltage for measurements of the conductivity and the dielectric constant of gases and liquids. In measurement of conductivity and capacity, a visual method may be used instead of the audible one by amplifying and rectifying the bridge currents (page 609) so that they may be observed on a direct-current milliammeter. A vacuum-tube oscillator provided with a split grid coil which surrounds a measuring vessel may be used in viscosity measurements of solutions and oils which are so opaque that the drop of a steel ball in them is not visible. The coil is arranged so that a click is obtained in the telephone receivers as the ball passes each section of the coil.

The vacuum-tube voltmeter is useful when measurements of electromotive force are required in methods of analysis, in solubility measurements, and in determining acidity values. Acidity measurements are used in processes which involve fermentation, electroplating, tanning, soap making, and water supplies.

The advantages of a vacuum-tube circuit in the measurement of small currents are utilized in connection with the photo-electric cell for chemical analysis and control. Measurements of acidity may also be made by a method which involves the change in color in a class of organic subjects known as *indicators*. There are two general kinds of indicators: (1) the type which involves a change in the transmission of light of one spectral band or color and (2) the type which involves a similar change in colors, with change in acidity. Visual precision is exceeded about ten times by the photo-electric cell method with one stage of amplification and an indicating milliammeter. This colorimetric method may be used for the analysis of certain metals which have colored compounds such as nickel, cobalt iron, manganese, copper, tungsten, carbon, and aluminum. It may be used also to observe and control processes which involve nitration, bromination, chlorination, and titration. By this means it is possible to have a continual check of the hardness of water or its content of chlorine.

A photo-electric cell together with a vacuum tube may be arranged in a circuit which is capable of measuring colors. The connections and apparatus as shown in Fig. 3 consist of the resistance *R* (50 megohms), the photo-electric cell *PC*, vacuum tube *T*, and the milliammeter *MA*. The voltage drop across the resistance *R* is proportional to the photo-electric current and hence to the light intensity (page 680). The reading of the milliammeter then is proportional to the color value which is being measured. It is possible also to measure the voltage drop across the resistance *R* by means of a vacuum-tube voltmeter. This apparatus may be used for the control of processes by replacing the milliammeter with a relay, acting on a current-supply circuit which provides power to the apparatus which is to be controlled.

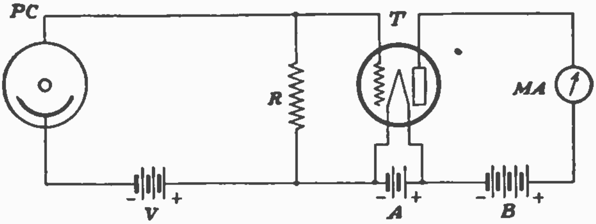


FIG. 3.—Circuit for measuring color values.

Electric-heater Control Device.—An electric control device applying vacuum tubes intended to control the operation of a circuit by the use of extremely small currents and to energize an electrical control circuit from a single source of alternating current has been designed for use with electric heaters. The device is particularly applicable to temperature-control systems in which the current through an electrical heater is increased or decreased by the opening or closing of an electrical circuit through a temperature-responsive device such as a mercury column and its electrode. To prevent sparking between the mercury and the electrode, which would cause the deterioration of the contact and reduce the accuracy of its operation, the current carried by the circuit through the mercury column and the inductance of the circuit must be small.

When this device is used for regulating an electrical heater, the thermostat carries only a very small current which is limited by a high resistance connected in the grid circuit of the tube. In another application, the variable-impedance connection for controlling the grid-bias voltage comprises a second vacuum tube the impedance of which is controlled by means of electromagnetic waves received from a distant radio transmitting station.

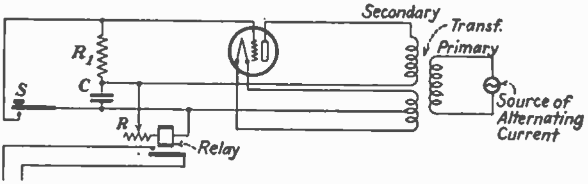


Fig. 4.—Typical electric control device.

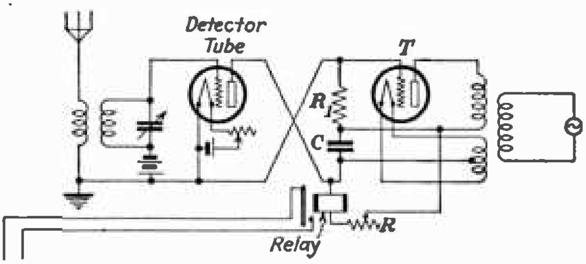


Fig. 5.—Control device applied to electromagnetic receiver.

This application may be employed in any case in which it is desired to operate the control circuit from a low-energy electrical source.

A diagram of the electrical control device of this kind is shown in Fig. 4. A diagram of the control device applied to a receiver of electromagnetic waves is shown in Fig. 5. A diagram of the control device applied to a thermostat is shown in Fig. 6.

The control circuit shown in Fig. 4 includes a three-electrode vacuum tube. The primary winding of the transformer is connected to a source of alternating current, one portion of the secondary winding being connected to the filament of the vacuum tube. One terminal of the secondary winding of the transformer is connected to the plate of the tube, while the other terminal is connected through a variable resistance R and the winding of a relay to the center or midpoint of the filament winding. A condenser C of large capacity is connected between the midpoint of the filament winding and the terminal of the transformer winding which is connected to the resistance R. This terminal of the transformer winding is also connected to a resistance R_1 of several megohms, the other terminal of this resistance being connected to the grid. The poles of the switch S are connected to the grid and the midpoint of the transformer winding, respectively.

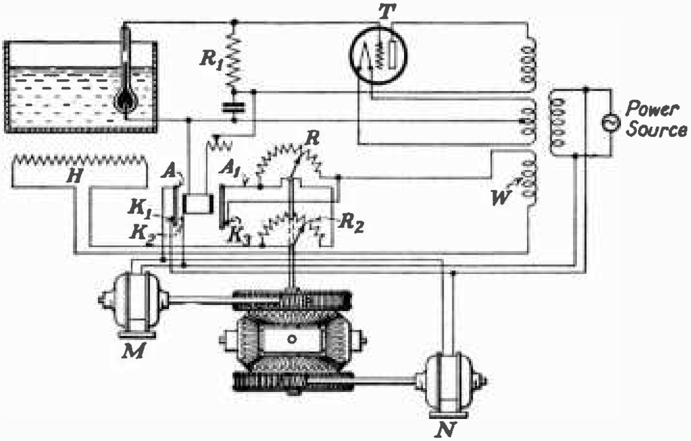


FIG. 6.—Control device applied to thermostat.

In operation, the alternating voltage supplied through the transformer winding to the plate of the tube causes rectified current to flow in a positive direction from the filament through the filament winding, the winding of the relay resistance R, the secondary winding of the transformer, and back to the plate. The condenser C serves to shunt a large portion of the alternating-current component of the rectified current flowing in the plate circuit. The voltage drop across the resistance R and the relay winding is impressed on the grid through the resistance R_1 for supplying a negative grid-bias voltage to the grid, thereby limiting the current flowing in the plate circuit and through the winding of the relay. The current through this relay winding is adjusted by means of the resistance R to such a value that it is normally insufficient to operate the relay. When the switch is closed, however, a low-resistance connection is provided between the grid and the filament, thus changing the grid-bias voltage from a negative value to practically zero. Due to this change in the grid-bias voltage, the current flowing through the plate circuit is increased to a value sufficient to cause the operation of the relay. By employing a resistance R_1 of large value, the current flowing through the contacts of the switch may be exceedingly small, for example, as little as a few microamperes; and since the impedance of the circuit through which this current flows has only a negligible reactance component, practically no sparking or heating occurs at the switch contacts. The high resistance of R_1 also prevents the relay winding from being short-circuited by closing the switch.

The control device shown in Fig. 4 may be adapted to numerous practical applications by substituting other variable-impedance connections for the switch. In Fig. 5 the input circuit of the device is shown connected to the plate circuit of a detector vacuum tube and is adapted to be operated by *electromagnetic waves* which reach the antenna and are transmitted to the grid of the detector tube through the tuned circuit. The other circuit elements are the same as those in Fig. 4.

The current flowing in the plate circuit and the resistance measured between the plate and the filament of a vacuum tube vary with the voltage drop between the grid and the filament. When the grid is grid-biased by a negative voltage of sufficient magnitude with respect to the filament, the current I_p for a given value of plate voltage may be reduced to practically zero, or to a low value I_{p1}. If an alternating voltage having a peak voltage approximately equal to the grid-biasing voltage is now impressed on the grid circuit, the plate current I_p will vary in accordance with the frequency of the alternating voltage from zero to a value I_{ph}. The values of the direct-current resistance r_p, measured between the plate and filament of the tube corresponding to the values of I_{p1} and I_{ph}, respectively, may be designated as r_{ph}, and r_{p1}, representing high and low values, respectively, of the resistance. The variations in r_p, corresponding to changes in I_p, from zero to I_{ph}, will be from infinity to some finite value of several thousand ohms.

The effect of impressing the alternating voltage on the grid of the detector tube suitably grid-biased, as indicated above, is to change its plate resistance from a value r_{ph} to a value which changes in accordance with the frequency of the impressed voltage from r_{ph} to r_{p1}. The value of r_{p1} is sufficiently low that the magnitude of the negative grid-bias voltage of the vacuum tube R is considerably reduced for half the time that the alternating voltage is impressed on the grid of the detector tube, thus increasing the root-mean-square (page 10) value of the plate current in the tube T. Since the relay is unable to respond to the rapid change in current due to variations of the grid-bias voltage of the vacuum tube T, it remains in the operating position during the whole period that the alternating voltage is applied to the grid of the detector tube.

In Fig. 6 the control circuit is shown applied to a thermostat for regulating an electric heater. The control circuit proper is the same as that of Fig. 4. The arrangement employed to vary the voltage applied to the grid of vacuum tube *T* consists of a mercury thermometer having one electrode in contact with the mercury and an upper electrode with which the mercury column makes contact when the temperature is sufficiently high. The thermometer is immersed in a bath of the liquid to be controlled in temperature, the liquid being heated by the electric heater *H*. The contacts of the relay in the plate circuit of the vacuum tube serve to short-circuit the rheostat *R* and to operate either of the motors *M* or *N*, these motors serving simultaneously to revolve the contact arms of rheostats *R* and R_2 through a differential gear.

In operation, when the temperature of the bath is sufficiently high to bring the mercury column in contact with the upper electrode, the grid-bias voltage of the vacuum tube is changed from a negative potential to practically the potential of the filament. The plate current is consequently increased sufficiently to cause the operation of the relay, thus opening the connection between the armature *A* and the contact K_1, at the same time closing the connection between the armature *A* and the contact K_2. The connection between the armature A_1 and the contact K_3 is then opened. For this condition the heating circuit may be traced from the upper terminal of the transformer winding *W* through the resistance of rheostat *R*, the contact arm of this rheostat, the resistance of rheostat R_2 and its contact arm, the electric heater *H*, and thence to the lower terminal of the winding *W*. Starting from the upper terminal of the power source, a circuit may be traced through the motor *N*, the armature *A*, the contact K_2, and back to the lower terminal of the power source, the motor *M* being short-circuited through the armature *A* and the contact K_2. When the motor *N* is in operation the arms of the rheostats are revolved in a counterclockwise direction, thus increasing the resistance in series with the heater and reducing the current. This operation is continuous until the temperature of the bath decreases sufficiently to break the contact between the mercury column and the upper electrode, thus restoring the negative grid-bias voltage to the grid of the vacuum tube and causing the armatures *A* and A_1 of the relay to be restored to the position shown. As a result, the rheostat *R* and the motor *N* are short-circuited, and the motor *M* is operated, thus causing the clockwise rotation of the arms of the rheostats and reducing the effective resistance in the heating circuits. A curve showing values of the heating current plotted against the time shows a slowly decreasing current followed by an abrupt increase, then a slowly increasing current followed by an abrupt decrease. When the system is in equilibrium, the periods of increasing and decreasing current are approximately equal. When not in equilibrium, however, one of these periods is longer than the other so that the system is gradually brought to the equilibrium condition.

Temperature Control for Electric Furnaces.—A thyratron (page 317) operated with an alternating voltage on its anode may be used as the basis of a method of controlling the temperature of an electric furnace. Figure 7 shows a method of maintaining a constant temperature by means of a thyratron tube. The temperature-sensitive element is an alternating-current Wheatstone bridge (page 113), consisting of four resistances, one of which, the so-called *resistance thermometer*, is placed in the furnace in which the temperature is to be controlled. Normal temperature corresponds to a balance of the bridge, that is, when there is no alternating-current voltage between the points *a* and *b*, the temperature being adjusted to any desired value by varying the resistance of one of the fixed arms of the bridge. A rise of temperature above the normal value unbalances the bridge, and this unbalanced voltage, after being increased by a transformer, is applied to the grid of the thyratron tube, in such a way that the grid is made negative during the half cycle when the anode is positive. This change has the effect, of stopping the flow of current through the thyratron tube and allows the relay to open and interrupt the heating current. Similarly, when the temperature is below the normal value this device produces an unbalance of opposite phase, causing the thyratron tube to operate and hold the relay closed. By this means it is easy to maintain the temperature of a large furnace constant within 10° at 800°C. The 10° variations are caused mainly by the lag in temperature of the thermometer and the furnace heating coils. because of their heat capacity. This lag can be minimized in many ways, One of the simplest methods, and the most accurate, is to connect the furnace winding directly in series with the thyratron tube and obtain continous modulation of the heating current by "phase control" (page 318).

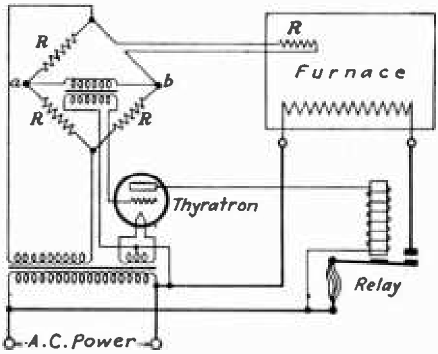


Fig. 7.—Temperature control for furnace.

Voltage Regulation of Alternating-current Generators.—A thyratron tube when operated with an alternating voltage on its anode may be used as the basis of a method of voltage regulation of alternating-current generators. A circuit for controlling the voltage of an alternating-current generator by means of a thyratron tube is shown in Fig. 8. The voltage-sensitive element is a bridge of dissimilar resistances or impedances, of which one diagonal pair may be wire resistances that follow Ohm's law, but the other pair are resistances that deviate from Ohm's law in either their instantaneous or their average value. A simple form of such a resistance is a tungsten-filament lamp, of which the equilibrium current varies as the square root of the voltage. Since the resistances follow different laws, it is evident that the midpoints *a* and *b* can be at the same potential for only one value of terminal voltage. This defines the normal voltage. At this voltage the thyratron tubes are so nearly balanced that they are in a neutral position in regard to starting and consequently operate only about half of the time. Their action, when they operate, is to supply more current to the field of the generator than could flow from the exciter through the resistance R, thus increasing the voltage. Any deviation of generator voltage from the normal value unbalances the bridge; that is, it produces a voltage between *a* and *b*, which is increased by a transformer and applied to the grids of the thyratron tubes. The transformer is connected in such a way that an increase of the generator voltage makes the grids negative during the half cycle when the respective anodes are positive, thus preventing the thyratron tube from operating and decreasing the field current of the generator; while a reduction of the generator voltage below the normal value gives a positive charge of the grid and continous operation of the thyratron tubes, thus strengthening the field of the generator and increasing the voltage. The absence of mechanical inertia makes this method of voltage regulation remarkably free from rapid variations of the voltage with sudden changes of load. Excessive voltage variations due to the electrical inertia of the generator field may be reduced to any desired degree by increasing the resistance of the field circuit, assuming the use of true non-ohmic resistance, without temperature lag.

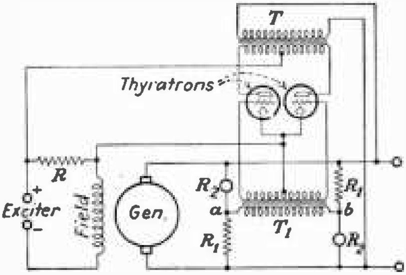


FIG. 8.—Circuit for regulating voltage of generator.

Figure 9 gives two recording voltmeter records showing the performance of two small alternators, of 10- and 15-kilowatts capacity, respectively, which are regulated in this way. The left-hand portion of each record was taken with the regulator attached; the right-hand portion without regulation. The full rated load of the generators was thrown on and off at the points indicated, the voltage varying less than one-quarter of one per cent from no load to full load. The action of the regulator is so rapid that the needle of the voltmeter did not move when the rated full load was put on the generators. The resistances R_2 in these tests were standard Mazda lamps (page 695), which were operated at half of the rated voltage.

A similar test was made with a 100-kilowatt, three-phase alternator, by the method of regulating one of the phases. In this case the thyratron tubes acted on the field of the exciter. The regulation was satisfactory, but the characteristic time lag between the exciter and the alternator voltage was shown by an instantaneous "overshooting" of the voltmeter when the load was taken on or off.

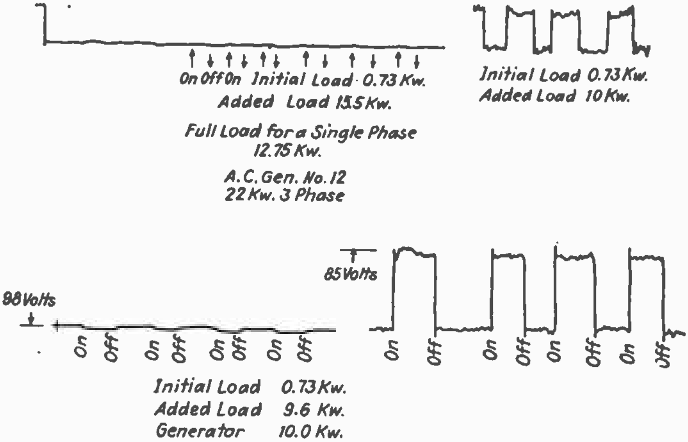


FIG. 9.—Voltmeter records of alternators regulated by thyratron circuit.

Telemetering.—Automatic performance has been applied extensively during recent years to the generation, transmission, and distribution of electrical energy. *Automatic supervisory equipments* provide the operator with visual indications of apparatus positions and means for controlling power apparatus located at remote points.

Channels Available for the Transmission of Readings.—In the design of a telemetering equipment it is necessary to study the channel limitations and to design the terminal equipments accordingly. For economic reasons it is desirable to have as many readings as possible transmitted through a given channel. There are three important types of channels: (1) multi-conductor cables, (2) wire construction, and (3) transmission lines. The first two (cable and wire construction) are essentially metallic connections, although in some instances it is the practice to install insulating transformers to protect terminal equipments from high electrostatically or electromagnetically induced voltages. The third type of channel, the transmission line, requires the use of additional terminal equipment and radio coupling devices.

Terminal Equipments.—Two successful types of terminal equipments are the rectified-current type and the vacuum-tube type, as described in *Journal A.I.E.E.*, March, 1929.

Rectified-current Type of Telemeter.—When it is desired to transmit readings of alternating-current amperes and volts, the simple device shown in Fig. 10, consisting of an instrument transformer, a rectifier, a transmission channel, and a milliammeter, may be used. Transmission by direct current instead of alternating current eliminates trouble due to pilot-wire inductance and capacity.

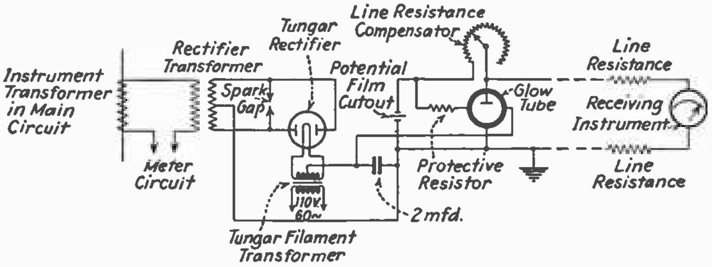


FIG. 10.—Rectified-current telemeter.

The rectifier transformer used in obtaining the voltage readings is a transformer operated from the secondary coil of the main current transformer. The secondary winding is tapped at the middle to obtain full-wave rectification of the power taken from the rectifier transformer.

The "burden" that each rectifier transformer imposes on the instrument transformer is approximately 10 volt-amperes; except that for the current transformer the burden is nearly doubled when the protective spark gap operates. Thus, there is very little chance for overloading the instrument transformers with this equipment.

The full-wave rectifier in the secondary winding of the rectifier transformer is of the hot-cathode type. The rectifier and the metering circuit are arranged as follows: The two terminal secondary windings of the rectifier transformer are connected to the anodes of the rectifier. The alternating current of the rectifier passes from the cathode of the rectifier through a pilot wire, a milliammeter at the receiving station, and another pilot wire, back to the midpoint of the secondary winding of the rectifier transformer.

The combined resistance of the line, receiver, compensating resistance, and the protective resistance of 2,500 ohms is 5,000 ohms. The receiver is a standard direct-current indicating or recording instrument. It is calibrated in terms of the unit being measured.

Vacuum-tube Type of Telemeter.—The apparatus employed is shown in Fig. 11. A small condenser is attached to the instrument whose reading is to be telemetered. This condenser is connected to an oscillator tube so that the frequency of the latter varies according to the meter position.

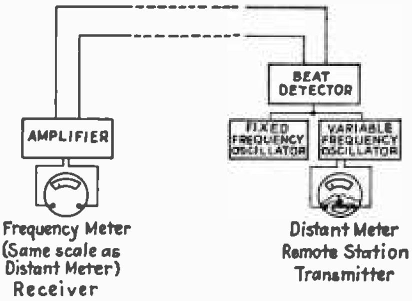


FIG. 11.—Vacuum-tube telemeter.

A second oscillator tube, operating at a frequency close to that of the first oscillator tube, has a fixed condenser and, therefore, furnishes a constant frequency. A beat frequency (page 408) is set up by these two oscillator tubes, which is detected by means of a third vacuum tube. This beat frequency is relatively low and varies in accordance with the instrument deflection.

The beat or telemetering frequency is transmitted over the connecting line to the receiving station, where it operates a direct-reading frequency meter, which may be directly energized by the income signal, or an amplifier may be provided, the method depending on the nature of the line, its impedance, and on the permissible energy level.

The frequency meter is furnished with a scale which corresponds exactly to that of the distant instrument and it indicates at all times the position of the remote instrument. The indications of the receiving instrument depend on the frequency only, and, provided it receives more than the minimum power necessary to operate it, is not affected by changes in the signal strength. Thus any changes in the impedance or leakage resistance of the line do not affect the accuracy of the meter.

The instrument readings may be transmitted by carrier waves, over special conductors, telephone lines, or high-voltage power lines. The transmitting and receiving apparatus necessary for this purpose is similar to telephone communication equipment.

A schematic diagram of the general arrangement for *carrier-current telemetering* is shown in Fig. 12. The beat-frequency output of the oscillator circuit, instead of the output of a microphone-speaking circuit, is applied in the regular way to the modulator (page 477). The carrier-current generator consists of the usual arrangement of a master oscillator (page 474) and a power amplifier (page 39). Thus there is sent out over the channel a carrier wave of constant frequency modulated by audio-frequency waves which vary with the magnitude of the quantity being telemetered. At the receiving end, the carrier is "demodulated" and the audio-frequency signal is amplified. The amplified signal is then taken to the frequency meter which reproduces the position of the pointer of the distant instrument. The signal strength (provided it has sufficient strength to energize the apparatus) has no effect on the accuracy of the indications.

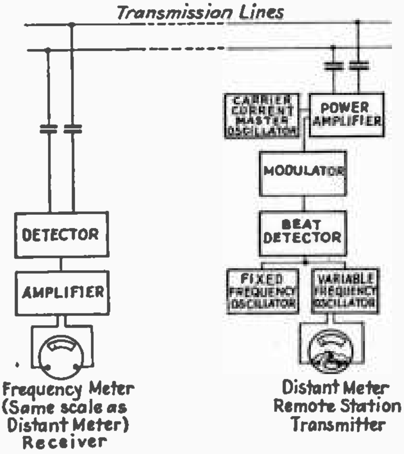


Fig. 12.—Carrier-current telemeter.

The vacuum-tube type of apparatus is readily applicable to such special problems as the totalizing of load indications at various points on a network, graphic recording, and integrating.

Electrical Prospecting.—Electrical methods of prospecting have assumed considerable importance in the past few years. These methods are of value in the study and development of mining property, particularly in districts where the geology is complex or has not been determined sufficiently to assist in locating minerals.

Inductive Method.—All the electrical methods depend on the effects of electrical currents produced in the earth. They detect the presence of ore or other similar material because such substances usually are better electrical conductors than the surrounding envelope. In any case, the material to be located must have a conductivity which is greater or less than that of the envelope. Ratios of conductivity greater than 100:1 are necessary for good indications.

The inductive method depends on two operating conditions: First, a flow of current is introduced in the subsurface conductive body due to electromagnetic induction by the use of an alternating electromagnetic field on the surface of the ground; and, second, a radio direction-finding device is used for taking directional readings and locating the conductor.

The magnetic field is obtained from a flow of alternating current in a closed vertical coil connected to a high-frequency energizing device. This device utilizes storage batteries for the supply of power and consists of a frequency changer to convert the direct current from the batteries to a low-frequency alternating current, and an oscillator using vacuum tubes to raise the frequency of the current to about 40,000 cycles. The high-frequency current which flows in the vertical coil produces a high-frequency electromagnetic field which in turn induces a flow of current in the sub-surface conducting body.

Secondary Field.—The field produced by the current in the subsurface conductor is known as the secondary field to distinguish it from the primary field produced by the energizer. The most satisfactory method of studying the secondary field utilizes a detecting device which consists of a direction-finding loop and a receiver containing a vacuum-tube detector, stages for amplification and compensation, and head phones. This method is similar to that used by shore radio stations for determining the position of ships at sea (page 789). When the wave front is undistorted, the signal obtained has a maximum value when the plane of the loop points toward the axis of the field. The signal obtained has a minimum value when the plane of the loop is at right angles to the line between the loop and the axis of the field.

The direction-finding loop is mounted upon a transit so that the angle toward the conducting body may be measured. This angle is called the *dip.* The position of minimum signal strength is determined by rotating the coil.

In operating, the direction-finding loop is acted upon by both the primary and secondary fields. The energizing coil is located in the vertical plane and hence its effect upon the direction-finding loop is such that the signal obtained has a maximum value when the loop is vertical. The effect of the secondary field surrounding the conducting body is such that a maximum signal is obtained when the direction-finding loop points toward the conducting body. As a result of these two actions, the signal obtained is a maximum when the direction-finding coil is pointing in the direction determined by the resultant of the two fields. When the direction-finding loop is practically above the conducting body, a vertical angle is obtained because both the primary and secondary fields induce a maximum signal in the loop when the loop is in a vertical plane. When the loop is moved away from the vertical position the value of the dip angle is changed.

Effect of Phase Difference.—When high frequencies are used, it sometimes happens that the primary and secondary fields are not in phase as they reach the receiver. Under these conditions it is not possible to obtain a position at which a zero signal is observed. In this case the frequency of the energizer should be changed until correct phase relations are again obtained.

This variation in the phase relation between the primary and secondary fields may be caused by several conditions. One of these conditions depends upon the average depth of the conducting body as compared to the distance between the energizer and the receiver. Another condition is due to the difference in the velocity with which the wave is propagated through the air and through the earth. That portion of the primary field which reaches the receiver must travel in the air, and that portion of the primary field which energizes the conducting body, and also the useful portion of the secondary field, must travel through the earth. Measurements show that the average value of the velocity through the earth is about one-fourth of that through the air.

Phase differences also may be caused by distortion of the wave front. The effect of such distortion is that the observed depth reading is less than the true depth. If several readings are taken on each side of the vertical position, the distortion may be calculated and the true location of the conducting body may be obtained.

Another operating difficulty is caused by the distortion of the primary wave front at the receiver. It is clear that the velocity of propagation of this wave in the air is different from that in earth. The effect of such distortion varies with the height of the receiver from the ground. As a result of this distortion a so-called "phantom dip" is obtained. This is the angle between the direction-finding loop and the vertical when no secondary field is present. The direction-finding loop gives a vertical reading only when there is no distortion of the wave front, when the energizing coil is vertical, and when no conducting body is present. Proper converging lines are not usually obtained from phantom-dip observations. Phantom dip may also be caused by improper alignment of the energizer and the direction-finding loop. The distortion of the wave front increases with the distance between the energizer and the direction-finding loop.

Determining the Conductor Location.—A plan view of the conducting body may be made by locating a number of points at which vertical indications are obtained. It should be noted that converging dips will be observed on either side of such vertical indications.

The depth of the conducting material is obtained by taking a series of readings across the conducting body and noting the angles. When the positions and angles are plotted, a drawing similar to that shown in Fig. 13 is obtained. The method of constructing this drawing is as follows: The line *A* is extended until it meets the vertical at the point *a*. A line *ax* is drawn through the point *a* parallel to the ground surface. Then a line is drawn through the point *A* parallel to the vertical until it intersects the line *ax*. The point of intersection is on the conducting body. By locating a series of such intersecting points a curve may be drawn which passes through the conducting body.

Survey Map.—After the plan location of the conducting body has been determined, a detailed survey is made to obtain the depth of the conducting material at various points from which an elevation view can be made. The complete survey map then consists of the plan and the elevation showing the location of the conducting body.

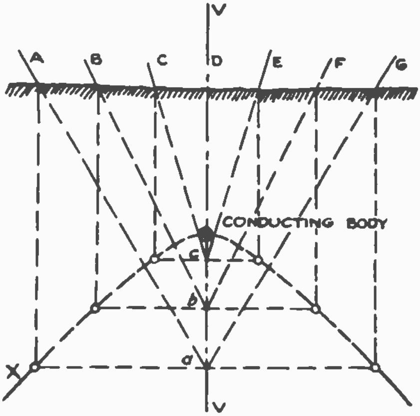


Fig. 13.—Diagram of radio survey for ores.

Artificial Fever Produced by Short Radio Waves.—It has been observed that the temperature of the human body is increased in those who are working in the vicinity of a short-wave radio transmitter. This phenomenon is being made use of in producing artifically the heat conditions resulting from fever. Evidence has been accumulating during the last few years that a fever is, in most cases, a beneficial condition in a diseased animal body and has been described as a "defensive" mechanism for the body. Furthermore, the value of heat as a physical means of curing disease has been recognized throughout the history of surgery. By exposure to the short waves of a radio transmitter, it has been demonstrated that any degree of fever may be produced in animals. By this method, internal heat is produced in the body in a way which seems to be little different from the heat produced by a fever due to an infectious disease.

The equipment which is used in this sort of heat treatment is the same in principle as a short-wave radio transmitter, with the exception that the energy is concentrated between two flat plates of a condenser instead of being projected in all directions from an antenna. The apparatus consists essentially of a vacuum-tube oscillator (page 627) and a full-wave rectifier (page 260), the latter supplying the high voltage required in the oscillator. The vacuum-tube oscillator is provided with two 500-watt three-element vacuum tubes operating at a frequency of from 10,000 to 14,000 kilocycles per second, the entire output being concentrated between the two flat plates of the condenser. There is a hard-rubber covering around the flat plates of the condenser which are of aluminum. The hard-rubber coverings of the plates are provided to prevent "arcing" in the event that the patient or an attendant might come in contact with the plates.

The full-wave rectifier supplying the high voltage for the oscillator is an oil-immersed transformer having a 7,000-volt secondary winding attached to two half-wave, hot-cathode, mercury-vapor tubes (page 499). There is provided also a suitable filter system. The rectifier furnishes a direct-current supply at 3,000 volts, which is practically non-pulsating at the terminals of the oscillator. An autotransformer (page 144) is connected to the primary winding of the oil-immersed transformer to provide the plate current required for the regulation of the vacuum tubes.

The greatest heating is obtained when the oscillator is operated with very *short radio waves*. Experiments seem to show that the most suitable wave length corresponds to about 30 meters, and the best frequency seems to be, therefore, about 10,000,000 cycles per second.

In the practical application of this device for the treatment of diseases, the patient is suspended in a sort of hammock stretched out across a wooden frame. The under surface of the frame is covered with a heat-insulating material which is about ½ inch thick. There is a heat-insulating cover of about the same thickness which has vertical sides about 8 inches high; but this cover is one foot shorter than the under covering. This heat-insulating cover is to be fitted over the patient so that his head projects through an opening at one end. Thus, there is formed a fairly tight air chamber about the patient's body. In this chamber the patient rests on his back, and the plates of the condenser are placed so that there is one plate on each side of the heat-insulating chamber. In the application of this device the short radio waves oscillate back and forth through the body of the patient, from one side to the other. A suitable distance between the plates of the condenser is about 30 inches. By applying the plates in this manner, the body of the patient is heated rapidly without causing great discomfort. The body temperature has been increased by this method from the normal temperature to 104 to 105° in from 50 to 80 minutes. When the desired temperature is reached, that temperature can be maintained fairly constant by any one of the following methods: (1) decreasing the voltage supplied to the high-voltage transformer; (2) increasing the distance between the plates of the condenser; (3) injecting hot air by means of a fan or blower into holes made in the side of the heat-insulating box.

Although by this method it is possible to produce artificially with short radio waves the temperatures of fever in a body, the *theory* of this phenomenon is not yet well established. The development of heat by this method in the human body is probably due to its resistance to the conduction of the electric current between the plates of the condenser. The analogy of body resistance to the resistance of solutions similar to blood serum is probably of some significance. When blood-serum solutions are heated by the method of passing an electric current through them, it has been found that the amount of heat generated is in direct proportion to the electrical resistance of the solution. Further, it has been shown that dilute solutions of different salts when of the same electrical resistance have practically identical heating effects.

This method of heating the human body is likely to be of considerable service, not only to clinicians and surgeons but also to biochemists and bacteriologists. It is probable that two desirable effects are produced by raising the body temperature. These are (1) that the increased heat within the body makes a less favorable environment for the multiplication of the virus of diseases and (2) that the heat increases the rate of those chemical processes which develop immunity to diseases.

Radio Fish Screens.—Fish may be kept within bounds in a stream or pond by the application of high-frequency or "radio currents of electricity." It is very difficult to prevent fish from wandering away from a place where a good food supply is available into places where there is very little food and where they may die because of the lack of the right kind of food. It is stated that nothing short of a stroke of paralysis will keep fish in a confined area in a river or large pond. Radio-frequency currents have been used successfully for this paralyzing force which may cause temporary paralysis without any permanent effects. This method of confining fish to certain areas has been used for diverting fish from irrigation canals and ditches. Unless very carefully designed, such radio fish screens are very likely to electrocute the fish rather than produce merely a temporary paralysis.

In the operation of screens of this kind, a high-frequency oscillator of the kind used in radio transmission stations is suitably placed so that an electric field is produced around the screens, the electric field having a frequency of 500,000 cycles per second. In order temporarily to paralyze and not electrocute a fish, it is necessary to decrease the voltage in relation to the size of the fish. Small fish require a higher voltage to produce temporary paralysis than larger fish, and, of course, the duration of an applied voltage has an appreciable effect on the severity of the paralysis. About 1.5 volts applied for a minute will not cause any deaths of the fish, while if the same voltage is applied for five minutes, more than half of the fish will be killed.

The electrical resistance of the water has, of course, a bearing on the necessary voltage that is required to paralyze fish; for example, some river water has a resistance to radio waves which is nearly one thousand times greater than that of sea water. It has been observed in the application of a device of this kind that when fish swim about in a stream or pond where there are such radio screens, they have a sense of direction of the danger and attempt to steer away from the electrified screens.

Radio Sets in Automobiles—The radio sets intended for operation on automobiles are, of course, intended mainly for purposes of entertainment en route, and for this reason, the tuning range of wave lengths is between 200 and 550 meters. If the tuning range of the receiving set were increased to 1,100 meters, it would be possible to pick up the weather reports at hour or half-hour intervals from the Department of Commerce ground stations (page 806). Some modification of the engineering details of receiving sets would be necessary to make these receiving sets suitable to the higher wave lengths. In fact, one American radio company is producing sets for sale in some European countries where there is a demand for sets which are adaptable for reception of the long-wave broadcasting stations in those countries.

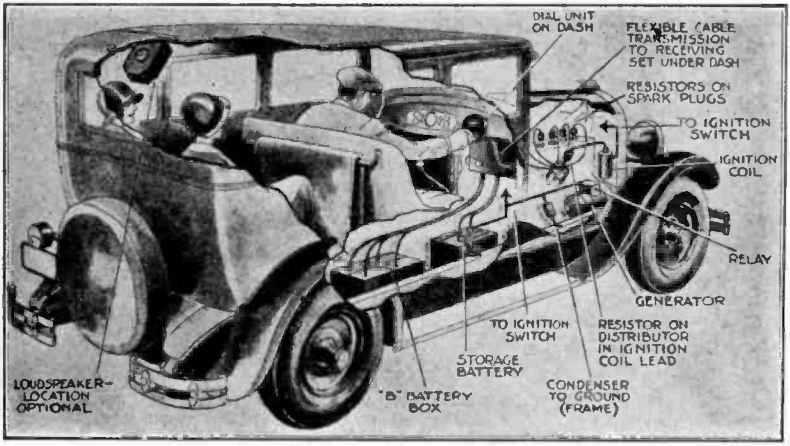


FIG. 14.—Radio-receiving set in automobile.

The receiver for automobile service should be built into a cabinet which can be fitted wherever the space, preferably underneath the cowl, will permit. The dials may be connected by means of a flexible shaft to a control panel on the instrument board. The tuning knob operates the variable condensers in the receiving unit by means of this flexible shaft. The installation of a radio receiving set in an automobile is shown in Fig. 14. A suitably enclosed receiving set for an autmobile is shown in Fig. 15.

An automobile radio installation differs from that in the home because it must be very sensitive and consequently cannot be constructed inexpensively. A cheap set would not be sufficiently sensitive to bring in adequate signals with what practically amounts to a short indoor antenna hidden in the top of the automobile body. Such a receiving set must of necessity be battery operated. The battery used for starting and lighting can supply current for the A circuit of the set. The high-voltage direct current must be obtained from a set of B batteries carried in a special battery box, which can be attached in any convenient place.

In some of the commercially built automobile radio sets the UY-224 (alternating-current) screen-grid tube is used in the radio-frequency and detector circuits. This tube is, of course, a powerful radio-frequency amplifier and supplies the necessary sensitivity. The output tube may be a UX-112A type.

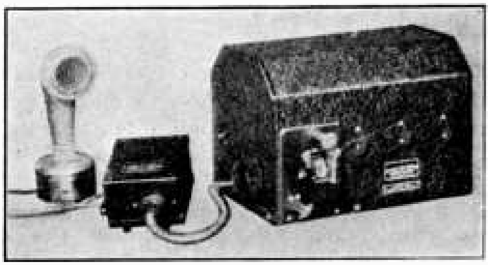


FIG. 15.—Enclosed radio-receiving set for portable service.

Suppressing the interference caused by the ignition system and electrical equipment of the automobile is necessary for good radio reception. The principal source of interference is the high-voltage wiring. Each spark produced at a spark plug induces in the high-tension wiring high-frequency oscillations which are radiated from the high-tension wiring to the antenna in the roof of the car, and these are reproduced by the loud-speaker as a steady string of annoying clicks. A 25,000-ohm fixed resistance placed in each high-tension wire close to the spark plug and another such resistance located in the high-tension lead from the spark coil to the distributor will suppress these high-frequency oscillations. A suitable method of attachment of the resistances is shown in Fig. 16.

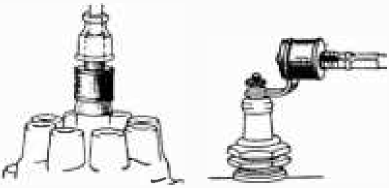


FIG. 16.—Resistances to eliminate interference.

Radio on Railroads for Car Switching.—The use of radio receiving sets on passenger trains of railroads has come to be a common practice. No special equipment is necessary but provision must be made for the installation of a suitable antenna. On most railroad trains, head sets (telephone receivers) are used rather than loud-speakers because reception from the head set is individual, so that those who do not wish to listen to a radio program will not hear it.

A more striking use of radio receivers and transmitters on railroads is in the engineer's cab of a "switching" engine. This equipment is used for controlling the shifting of long lines of freight cars and provides a means of communication from the main switching tower to the switching engines in a freight yard. Such radio equipment as used on switching engines displaces the ordinary colored-light signals at the switching tower of the so-called "hump" of a large freight yard at a distributing point.

A satisfactory four-tube radio receiving set for use on a switching engine will have sufficient amplification to operate a loud-speaker in the cab of a locomotive. Such a receiver does not require tuning, as the controls are locked after being set for the wave length of the transmitting station in the signal tower from which instructions are broadcast. The engineer in the switching engine needs only to turn the main switch on or off. A green pilot light may be provided, to indicate that the radio receiving set in the cab is operating properly; with a red light as a warning signal if one or more of the vacuum tubes are not operating. The receiving set in the switching engine is designed for operating with storage batteries and dry cells. The transmitting outfit need not have large power but except for smaller size or power is like a radio broadcasting transmitter. For this service, it was found that short wave lengths (about 125 to 130 meters) were more suitable than the wave lengths of the ordinary broadcasting stations.

Radio Equipment for Main-line Train Operation.—On some railroads where traffic is congested, train operation by radio equipment is being used in preference to other methods of relief, such as the construction of more tracks and the movement of trains at higher speeds. The element of time is also an important consideration, as the installation of radio equipment on trains can be made in a very short time, while very much longer periods are necessary, of course, for the building of locomotives to operate trains at higher speeds and for the construction of more tracks.

There are two methods of using radio equipment for train operation. One method is called *front-to-rear radio telephone communication;* the other *front-to-rear radio signaling.* All radio equipment for service on railways must be simple and rugged to insure reliability.

An important consideration in the use of radio equipment on railroads is the antenna clearance which in tunnels and under bridges is usually limited to the available space of a few inches over the top or at the sides of the locomotive. Under these conditions, it is impossible to construct a highly efficient antenna, and a sturdy and rigid structure must be made in order that the vibrations of the engine and of the train transferred to the antenna may be as small as possible. Because of the requirements of sturdiness, simplicity, and elimination of vibration, it has been found most satisfactory to design special forms of antenna rather than a single-wire or flat-top type.

The provision of power for the radio equipment for transmitting signals on trains is not a simple matter. Especially on freight locomotives operated by steam, electric power is not often available in sufficient quantities in the locomotive or in the caboose for the radio transmitters; and in such cases electricity must be supplied from batteries, which, in some cases, are charged from the current generated for the headlight of the locomotive or from an axle-driven generator on the caboose. Where it is possible to install on trains a relatively expensive equipment, a steam turbine-driven generator of special design may be mounted on the top of the locomotive to furnish current for the radio transmitting apparatus without the use of storage batteries. In any case, however, batteries of some kind are required for the radio transmitting apparatus in a caboose, because it is difficult to transmit the electric current from the generator on the locomotive, and an axle-driven generator on the caboose does not, of course, operate when a train stops.

One of the greatest difficulties in the way of the application of radio train operation is the limited space available in the cab of the locomotive, and the radio transmitting apparatus must be readily accessible for inspection and for tube and battery replacements.

The telephone communicating system which operates by transmitting the voice from one end of the train to the other is a two-way system of communication between the locomotive cab and the caboose. This system is, however, bulky and therefore difficult to install in the cab of a locomotive and is limited in its applications to trains having specially designed cabs for this service. The greater expense of this system over the cost of the ordinary signaling method is warranted only on trains having fast and difficult schedules, where complete telephonic communication is necessary in order to handle the train adequately.

The second method of train operation by radio is by the use of the so-called *signal* system, this being the one coming into use on some American railroads. This simplified signal system is intended for two-way communication and provides a means of producing an audible signal similar to a whistling signal at either end of a train. The apparatus required for this method is small and compact compared with that required for voice communication, the entire transmitting apparatus being mounted inside the locomotive cab with a simple installation in the caboose.

The system of train operation by the method of voice communication with telephone apparatus has been used successfully on several railroads. The necessary equipment for this system at each end of the train consists of the following apparatus: (1) storage batteries, (2) dynamotor, (3) filter box, (4) transmitter, (5) receiving set, (6) signaling switch (operated by "whistle" cord), (7) loud-speaker, (8) telephone receivers, and (9) control box.

The power for the transmitter is obtained from the so-called *dynamotor* (page 237) which supplies a current at about 1,000 volts. The dynamotor is a high-voltage motor-generator set, the motor taking current from the storage batteries at 24 volts and the generator supplying 1,000 volts to the transmitter. On a locomotive, the dynamotor and the batteries must be installed in a water-tight compartment, not only as protection from possible injury from rains but also to protect them from the overflow of water when the tender tanks are being filled. The batteries and dynamotor must be very securely fastened on both the locomotive and in the caboose, because the sudden jerks and the movements of a train around sharp curves are likely to loosen their fastenings. The filter box is provided to reduce the battery voltage, as, for example, from 24 to 5 or 6 volts for supplying the filaments of the tubes, also for the relays and necessary signal lights to indicate the operation of the equipment. The filter box contains usually a number of resistances of a compact type and also a filter which takes out the ripple in the direct current supplied to the plates of the tubes in the transmitter.

The transmitting equipment and also the receiving sets must be mounted securely, preferably with spring suspensions, limited in permissible movement. The containers for the transmitting apparatus and the receiving sets must be tight enough to keep out smoke, soot, dirt, and water. The delicate parts of each of the pieces of apparatus such as the vacuum tubes and the relays should be cushioned with sponge rubber to prevent damage from vibration.

The antenna may consist of a single loop made of one-inch brass pipe mounted horizontally on the roof of the locomotive cab and supported by porcelain insulators. The end of the antenna attached to the ground wire and the end attached to the receiving set pass through holes in the roof provided with porcelain bushings. The *transmitter* for an equipment of this kind may be provided with UX-210 tubes. These tubes may be connected to the voice modulators by transformer coupling (page 486). Two AT-20, 50-watt vacuum tubes intended for 1,000 volts on the plate are used in parallel as the voice modulators, supplying another AT-20 tube which is the oscillator. This equipment is suitable for the application of the Heising system (page 484) of modulation. The antenna when used for transmission is accurately tuned by the variable-condenser method. The energy from the oscillator passes through the antenna switch which is operated by a relay. The antenna is always connected to the receiving set, but when the transmitter is not being used it is disconnected from the antenna. When, however, the necessary voltage is placed on the filaments of the transmitter tubes, the antenna relay operates immediately so as to connect the antenna to the transmitting system.

The *receiving set* has four vacuum tubes, one being used as a detector and the other three as audio-frequency amplifiers. The detector and the tubes in the first two stages of audio-frequency amplification are of the UX-201A type. The fourth tube is a UX-112A type. The audio-frequency stages of the receiving set are transformer coupled (page 363). Sound volume is regulated by the method of controlling the amount of regeneration in the set. A variable condenser is used for tuning the antenna circuit. The filament voltage of the receiver is obtained from storage batteries, the voltage being regulated by means of the resistance coils in the filter box. The plate voltage of the tubes is supplied by B batteries.

Voice reception by the receiving set is accomplished mainly by the use of telephone receivers, and, under most circumstances, the loud-speaker is used only for signaling and calling the operator. When the microphone is taken from its box, the telephone receivers are put automatically in parallel with the loud-speaker; and when thus paralleled, the telephone receivers, because of their lower resistance, receive most of the output of the receiving set. When the microphone is put back into its box, an automatic switch cuts out the telephone receivers from the circuit of the loud-speaker so that only the loud-speaker is then in the output circuit of the receiving set. The loud-speaker is used mainly for obtaining the attention of the operator at the receiving set, but often the voice reception from the loud-speaker in the caboose is strong enough to be understood without the use of the telephone receivers.

The *microphone* used on sets of this kind should be preferably of the anti-noise type, as this type gives the most satisfactory service, especially when the transmission is from the locomotive, where there is always a great deal of noise.

In order to operate the receiving set in either the cab of the locomotive or the caboose, it is only necessary to manipulate a switch in the A-battery circuit so that the current will be supplied to the filaments of the tubes in the receiving set. A lighted blue or green pilot light on the cabinet of the receiving set indicates that the filament current is passing through the vacuum tubes.

When the operator wishes to communicate with the other end of the train, he takes the microphone and the telephone receivers from their container and listens with the telephone receivers for a few seconds to be sure that the other end of the train is not transmitting. He then moves a switch which operates the relay on the antenna so as to disconnect the filament circuit of the receiving set and connects the antenna to the transmitter. The same switch serves to operate another relay which starts the dynamotor and thus places the necessary high plate voltage on the transmitting tubes. The apparatus is then ready for the transmission of speech (voice modulations). In order to attract the attention of the crew at the other end of the train, the calling system must be operated. This is done by a second switch which operates a relay to connect a "howler" transformer so as to produce a high-frequency howl in the loud-speaker of the receiving set at the other end of the train.

Instead of operating the switches controlling the relays as explained in the last paragraph, the transmitting equipment may be provided with a "whistle" cord so arranged that it will operate the transmitter and the howler. The whistle cord should be arranged to operate through a series of suitable notches on a marked guide, so designed that when the whistle cord is pulled down to the first notch it starts the operation of the dynamotor and the transmitter. When pulled to the second notch, the relay on the howler is operated. The opening and closing of the switches on the relays may be continued by pulling the whistle cord up and down as long as enough pressure is kept on the whistle cord to continue the operation of the transmitter. This signal system may be used, therefore, for code messages, when it is easier to give signals than to talk. If telephone communication between the ends of the train is not required, then this code system of transmitting messages makes it unnecessary to provide some of the equipment that has been described. The important parts that are needed are, of course, the telephone receivers and the loud-speaker at the two ends of the train. The initial cost of the equipment for signaling is much less than that of the system required for telephone communication.

If all the vacuum tubes in the transmitter and in the receiving set are mounted on rubber-cushioned sockets, the breakage of these tubes is not excessive. If, however, the antenna is broken the oscillator tube will be excessively heated.

The Federal Radio Commission has assigned to the railroads for this kind of service a wave band between 126 and 133 meters. Apparatus of this kind has operated successfully on trains with as many as 130 cars under all conditions of service; in fact, such equipment has worked satisfactorily when the engine was four miles away from the caboose. The special advantage of this method of train operation is that the caboose may be a long distance away from the locomotive on curved tracks in wooded sections of the country where it is absolutely impossible for the train men in the caboose to have any view at all of the crew in the locomotive.

This type of equipment has also advantages for the rapid movement of freight trains on heavily loaded trackage. It is one of the first principles of efficient railroading to keep a freight train moving. When a train is stopped by signals, it is important that it should start again just as soon as a clear track is available. Now, if a long train is stopped by a signal, the train can be started again by the radio method of signaling at a moment's notice instead of delaying, as would otherwise be necessary, until the conductor could walk the length of the train. As long trains are now operated, it happens frequently that after a freight train has stopped and then the signals have been set to indicate a clear track, the engineer with his engine whistle calls the flagman left at the rear of the train. Often it is impossible for the flagman to hear the engine whistle. In that case, the engineer usually waits five minutes for the flagman to get on the caboose and then moves the train, possibly leaving the flagman behind because he could not hear the whistle. On trains equipped for radio signaling, it is only necessary for the engineer to call the conductor and tell him to call the flagman. The engineer is notified when the flagman at the rear of the train has entered the caboose.

Another way by which radio signaling can improve train operation is illustrated by the delay which results when an axle on one of the cars has a hot box. By utilizing this radio method of communication, the time required for the brakeman to go back to the caboose over the tops of the cars and then return to the locomotive is saved. In some cases as much as 45 minutes at a time has been saved by the use of radio for freight-train operation.

The principal difficulty that has been experienced in the use of radio equipment for the operation of trains has occurred in tunnels and deep "cuts." When a train is inside a tunnel, the close proximity of the masonry sides changes the effective wave length of the antenna, which in turn changes the wave length of the radio waves so that they are beyond the range of the special type of receiver developed for this kind of service. This difficulty can be partly overcome by running guide wires through the tunnel and using these as carrier-current wires (page 34). Another method which can be used successfully requires the installation in the transmitter of a *master oscillator* (page 474), which will keep the wave length of the antenna system constant when outside conditions are changing, as, for example, such conditions as the closeness of the sides of a tunnel or deep cut.

Fading of radio signals and other transmission has also been observed on railroad curves, especially when the curves are in deep cuts. The same effect has been observed also when a train is rounding a steep hillside. When a train is going under large steel bridges, fading occurs for an instant with generally an increase in signal strength just before and just after the bridge is passed.

Interference of the transmitters on the trains with the reception of broadcasting in houses near the right of way has been largely overcome by the use of choke coils in the transmission circuits. One of the most important advantages of the operation of trains by radio is that during the dense fogs, rain, and snowstorms, when it is almost impossible to see signals, the radio signals can be operated as efficiently as in the best weather conditions.

Vacuum Tubes for Controlling Electrically Operated Elevators.—A recent application of vacuum tubes is in a device for automatically bringing electrically operated elevators cars to the various floor levels. This device includes five or more three-element vacuum tubes, similar to those used in radio receiving sets. The vacuum tube used in this case is of the type which has been used on railroad locomotives for transmitting block signals into the engineer's cab in visible form so that the engineer does not have to depend on watching the semaphore and light on the side of the track. This vacuum tube, though similar to the kinds commonly used in radio, is not operated at the same values of voltage.

The automatic levelling device for elevators is based on the characteristic change of plate current when a vacuum tube changes from an oscillating to a non-oscillating condition. A suitable number of vacuum tubes, normally in oscillation, are included in the equipment of each elevator car. By suitable arrangement of coils and vanes, a car when approaching a designated floor level is made to stop by reason of the oscillation of the vacuum tubes which, in turn, operate electric relays. The relays control circuits which reduce the speed of the car and stop it automatically at the correct position when running either upward or downward.

In the operation of an automatically controlled elevator car, the operator throws the switch to the "off" position as he approaches the floor at which the car is to be stopped. On nearing the designated floor, the relays are actuated by the coils and vanes on the elevator car, thus reducing its speed and bringing it to the proper stopping point.

Another similar application of vacuum tubes in elevator operation makes it unnecessary for the operator to watch his position with respect to the floors of the building. In the operation of this system, each passenger, upon entering the automatically controlled car, indicates to the operator the floor at which he wishes to get off, and the operator presses a push button corresponding to that floor. When all passengers are in the car, the operator starts by the usual method. As he approaches the first floor at which a stop is to be made, a signal light flashes and a bell rings, notifying the operator that a stop is to be made. He then throws the car switch to the off position and the car continues at full speed to the stopping point, where it is brought automatically to the required floor level.

In addition, push buttons are installed on each floor. A passenger waiting for a car presses a button which lights a signal and rings a bell in the first car approaching in the direction in which the passenger desires to travel.

A corridor lantern also lights to show the passenger which car traveling in the desired direction will be the first to reach his floor.

Amplification of Currents in Telephone Circuits by Vacuum Tubes.—In every telephone circuit there is some transmission loss of energy and, consequently, also of sound value, which is technically called *attenuation*. The attenuation loss is due partly to the length of the circuit and partly to the losses in the various instruments and other devices which are included in the circuit. Audio-frequency amplifiers have been used with good results in reducing the attenuation in telephone circuits, and this reduction of attenuation in the circuit has been done much more cheaply than if so-called "load" inductance had been used. An audio-frequency amplifier in a telephone circuit has an effect which is exactly opposite to that of attenuation; that is, the audio-frequency amplifier delivers more electrical energy to the line than it receives from it. In other words, if the electrical energy at any point in a telephone circuit is to be increased, it is passed through some sort of device which gives energy back to the telephone circuit in much larger amount than was received; the amplification is in proportion to the increase in electrical energy. It is, of course, impossible to deliver more energy to the telephone circuit at any point than is received from the circuit at that point, unless some external source of energy is drawn upon. Amplification of telephone currents means the adding of energy from an external source to the energy already present at the point where amplification takes place. Before the invention of the vacuum tube for radio transmission and reception, a magnetic type of amplifier was in use on long telephone circuits to overcome the attenuation.

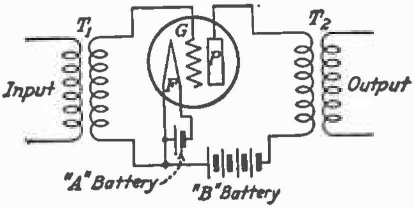


FIG. 17.—Amplification circuit for telephone service.

The invention of the vacuum tube as used in radio transmission and reception immediately suggested the application of this device as a substitute for the magnetic type of amplifier. Vacuum tubes of this kind are now an essential part of all the amplifiers used in modern telephone installations.

One of the simplest applications of the vacuum tube for amplification in telephone service is illustrated in Fig. 17, in which the vacuum tube is shown diagrammatically by the filament F, the plate P, and the grid G. An A battery is shown as it would be used for heating the filament F. The B battery has its positive terminal connected to the plate P and its negative terminal connected to one side of the filament.

The input telephone circuit as shown at the left-hand side of Fig. 17 may be assumed to be carrying a very small incoming current. This may be considered the primary circuit. A corresponding circuit which includes a secondary winding is connected at one end to the grid *G* and at the other to the filament *F* when the A and B batteries are connected to this circuit, as shown in the figure. If the voltages of these batteries are constant and the grid voltage does not vary, then the current flows continuously in the same direction through this circuit.

The flow of electrons is from the filament to the plate *P*, but the presence of the grid *G* interposes a barrier which has effects on the flow of electrons of very much the same kind that a window shutter has on the passage of rays of light through it. It may be assumed, for the purposes of this illustration, that the window shutter has a number of revolving vanes, all of which are connected to a single vertical rod, which when moved upward opens the vanes and when moved downward closes them. If a force is applied to the vertical rod so as to move it up and down, there will be alternating opening and closing of the spaces between the vanes as well as, also, an alternating enlargement and reduction of the space through which rays of light may pass. The grid *G* in the vacuum tube may be actuated in very much the same way, the size of the openings in the grid determining the number of electrons which may pass through from the filament to the plate. It has been shown in the study of the theory of vacuum tubes that the flow of electrons between the filament and the plate sets up a current in the plate circuit.

Starting with the input telephone circuit at the left-hand side, which carries a feeble incoming current, it will be found that this current sets up a voltage equal to the drop of potential between the filament and the grid, this built-up voltage varying directly with the variations of the incoming current. As this voltage on the grid changes from a positive to a negative value, it attracts or repels some of the electrons which must flow through the grid to the plate. When it attracts the electrons, most of them go through, but when it repels them, the number flowing through to the plate is reduced. Thus, the action of the grid in regulating the flow of electrons is very much like the operation of the vanes in the shutter, as they may be used to vary the amount of light passing through.

The current in the "plate circuit," however, is much larger than that coming from the input telephone circuit, because of the additional energy which is added to the circuit by the B battery. From the secondary winding of the transformer T_2, this additional energy from the B battery flows out on the output telephone line in an amount which may be made equal to the amount of attenuation in the input circuit, thus entirely overcoming the attenuating losses of the entire telephone circuit.

Use of Radio Vacuum Tubes in Telephone Repeaters.—The use of the vacuum tube in telephone repeaters depends upon the same principles that apply to its use in amplifiers for overcoming attenuation, as explained in the preceding paragraphs. Telephone repeaters are now quite generally used in modern telephone lines.

The radio vacuum tube reproduces exactly the transmitted sounds and at the same time can be used to amplify to any extent the currents in the input telephone circuit. Since the introduction of the vacuum tube in telephone service, the use of repeaters has steadily increased, with the result that telephone service has been extended over distances which previously had offered apparently insurmountable difficulties. One of the first important uses of vacuum-tube repeaters was in the transcontinental circuits between New York and San Francisco, a distance of nearly 3,500

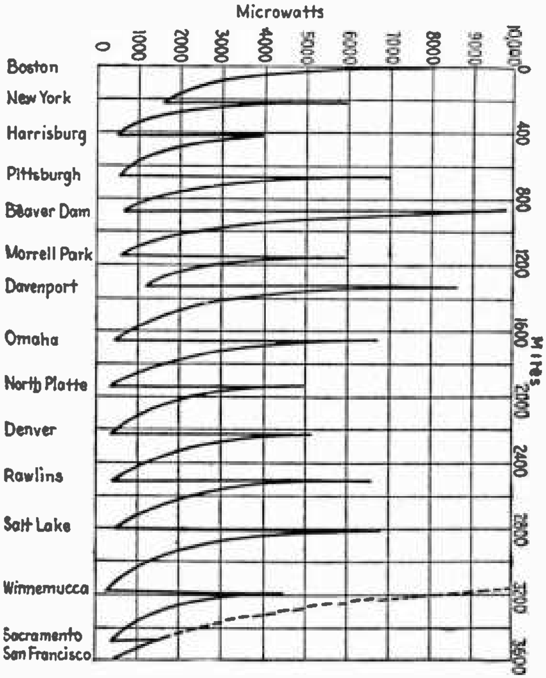


Fig. 18.—"Power-level" diagram of long-distance telephone circuit.

miles. Later, the use of vacuum-tube repeaters made possible telephone communications without wires with Catalina Island, off the Pacific Coast, and by submarine cable with the island of Cuba. Without vacuum-tube repeaters, such telephonic connections would not have been economically possible.

A so-called "power-level" diagram of the telephone circuit from Boston to San Francisco is shown in Fig. 18.

In this figure, it is assumed that 10,000 microwatts (0.01 watt) of electrical power enter the line at Boston and, approximately, 350 microwatts of electrical power are received from the line at San Francisco. Each of the marked cities between Boston and San Francisco is a point at which repeaters are connected into the circuit. The curved lines in each case show how the electrical energy dies out as it travels along the line, and the straight vertical line indicates the amount to which this incoming electrical energy is amplified by the repeaters.

It will be noticed that, at the extreme right of the curve, a dash line is indicated as going off the curve. If this line were continued, it would intersect the axis along which the amount of power is indicated at a point equal to the total amount of power that would have to be put into the line at Boston in order to receive 350 microwatts at San Francisco, provided there were no repeaters in the circuit. Actually, this amount of power would have to be several million kilowatts or many times the total power of the sun delivered to the entire earth.

In telephone practice, the vacuum tubes used in repeaters are operated just above the saturation temperature (page 284) to avoid changes of performance due to small changes in filament current. The vacuum tubes in this kind of service are operated at a point on the curve showing the variation of plate current with plate voltage where the values are well below the voltage saturation and above the temperature saturation, as it is essential that the plate current should be variable for the voltages impressed on the grid circuit.

Since in normal repeater operation no direct current flows from the filament to the grid by the transfer of electrons, it is evident that this circuit is open or presents an infinite impedance to the flow of direct currents. Due, however, to the capacity between the grid and the other two electrodes of the tube the circuit from the grid to the filament has a finite impedance at telephone frequencies, and a small alternating current flows in this circuit. For ordinary telephone frequencies, it may be assumed that this impedance is practically constant as long as the grid remains negative with respect to the filament. The impedance of this circuit is very high, and for this reason input transformers are employed in telephone repeater circuits which step up the voltage of the incoming line before applying it to the grid circuit.

One-way Repeater.—The one-way repeater is the simplest form of repeater circuit. It is a device that can be connected between two telephone lines and will amplify the voice currents in one direction only.

Figure 19 shows one such arrangement for the one-way repeating of telephone currents by the use of a vacuum tube. In this figure, the A battery lights the filament, the B battery is the plate battery, and the C battery maintains the grid negative with respect to the filament. The B battery could be connected to the winding of the output transformer and such an arrangement is used in some of the latest types of repeater circuits.

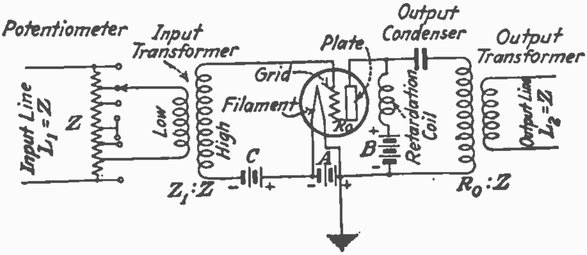


FIG. 19.—One-way type telephone repeater.

The potentiometer shown on the input side of this repeater is a series of resistances with taps so arranged that any portion of the total resistance may be connected across the input coil. The voltage drop across this potentiometer is equal to the voltage across the line at that point. If by means of taps a resistance equal to one-tenth of the total resistance is included in the circuit, the voltage across the input transformer will be only one-tenth of that of the line. This method gives a means of controlling the voltage delivered to the repeater. In addition, the resistance of the potentiometer is so chosen as to make a good termination for the line. The potentiometer, therefore, has two principal functions.

The input transformer as shown in Fig. 19 has the voltage from the potentiometer impressed on its low side. The inductance of this winding is made high enough to avoid disturbing the voltage drop across the potentiometer taps; that is, the inductance is so high that the winding of the input transformer draws a very small current. The purpose of the transformer is merely to act as a voltage-changing device, as all the energy of the input current is absorbed by the potentiometer and the losses in the circuit. The small voltage across the "line" winding of the input transformer is stepped up and applied from the secondary to the grid circuit, variations in this voltage causing variations in the plate current.

The alternating current is excluded from the B battery by the retardation coil shown in Fig. 19 and flows through the output condenser and the output transformer. The direct current flows from the B battery through the retardation coil and is kept out of the output transformer winding by the condenser.

Since the output impedance of the vacuum tube is usually quite different from that of the line into which it is to work, the output transformer is used to step it down to a more suitable value. The output transformer also serves to insulate the line L_2 from the filament circuit of the tube which is usually grounded.

Transmission losses are usually expressed in terms of *transmission units.* This same unit is employed to measure the *gains* of telephone repeaters, a gain of one transmission unit being the same in effect as removing from the circuit a portion having a loss of one transmission unit.

In practice, repeaters are usually operated between circuits of practically the same impedance and are designed so as to offer a reasonably smooth termination for the lines to which they are connected. Since this is nearly always true, definitions of repeater gains or amplification are based on the assumption that the repeater for which the gain is to be determined operates between circuits having practically the same impedance terminated in a reasonably smooth manner by the impedance of the repeater itself.

On the basis of the above assumption, the gain ratio may be expressed in terms of power, current, or voltage amplification. The *power-amplification ratio* equals the power delivered to the circuit connected to the output terminals of the repeater divided by the power received by the repeater from the circuit connected to its input terminals. The *current-amplification ratio* equals the current flowing into the circuit connected to the output terminals of the repeater divided by the current received in the repeater input circuit. In a similar manner, the *voltage-amplification ratio* equals the voltage across the output terminals of the repeater divided by the voltage across the input terminals.

When the input impedance of the repeater smoothly terminates the circuit connected to its input terminals and is equal to the impedance of the circuit connected to the output as assumed above, the power-amplification ratio is equal to the square of either the current amplification or the voltage amplification. It should be carefully noted, however, that this square relation, as well as the relations given above as an expression of amplification ratios, holds only under this condition. When the output impedance does not equal the input impedance, allowance must be made for the differences in impedance in any computation involving these factors. As repeaters usually work between circuits of equal impedance, and the repeater impedances approximately fit those of the circuit, it is convenient to think of the gain as depending upon the current or voltage ratio. It is, then, understood that the two currents or two voltages being compared act in circuits of equal impedance.

In order to compute the gain of a repeater it is necessary to know the characteristics of the various parts of the circuit. Referring again to Fig. 19, let us assume that the impedance of the lines L_1 and L_2 and that of the potentiometer are each Z ohms, the impedance ratio of the input transformer is Z_1/Z, the output impedance of the tube is R_0, and the impedance ratio of the output transformer is Z/R_0.

Assuming, further, that the energy coming in over L_1 sets up an alternating voltage E in the potentiometer and that the potentiometer switch is turned to its highest step, the alternating voltage across the low-impedance winding of the input transformer is necessarily equal to E, which is the voltage set up in the potentiometer. The voltage applied to the grid by the high-impedance winding is equal to $E\sqrt{Z_1/Z}$, since the voltage ratio of a transformer equals the square root of its impedance ratio. The total voltage acting in the plate circuit of the tube, due to the action of the grid, equals the grid voltage multiplied by the *voltage-amplification factor* of the tube, or $uE\sqrt{Z_1/Z}$.

Since the impedance of the high-impedance winding of the output transformer equals the output impedance of the tube, the voltage drop across this winding equals one-half of the total voltage acting in the plate circuit, or $\frac{uE}{2}\sqrt{\frac{Z_1}{Z}}$.

The voltage impressed on the line L_2 is

$$\frac{uE}{2}\sqrt{\frac{Z_1}{Z}}\sqrt{\frac{Z}{R_0}} = \frac{uE}{2}\sqrt{\frac{Z_1}{R_0}}.$$

The voltage amplification A of the repeater equals the output voltage divided by the input voltage, or

$$A = \frac{\frac{uE}{2}\sqrt{\frac{Z_1}{R_0}}}{E} = \frac{u}{2}\sqrt{\frac{Z_1}{R_0}}.$$

From the above equation it is seen that the gain depends only upon the value to which the potentiometer impedance is raised by the input transformer, the output impedance of the vacuum tube, and the voltage-amplifying factor of the vacuum tube. This would be true even if the lines were of different impedances, because it would be necessary to reduce the current or voltage amplification to a common impedance before converting it into a gain.

The above explanation may be illustrated with a practical example by assuming that the repeater circuit is equipped with a 101D vacuum tube with $u = 5.9$ and $R_0 = 6{,}000$ ohms. The input transformer is designed for 600,000 ohms on the high-impedance side. The voltage amplification is

$$A = \frac{5.9}{2}\sqrt{\frac{600{,}000}{6{,}000}} = 29.5.$$

This example illustrates the method of computing the gain of a one-way repeater circuit containing a single vacuum tube. The same method may be applied to any repeater circuit of one or more tubes by following through each voltage change due to transformers, potentiometers, or vacuum tubes themselves.

There are three general types of repeater circuits, each of which has its own field of use, depending upon the types of circuits and other factors associated therewith. In the preceding sections, the operation of the various parts of a telephone repeater circuit have been described in considerable detail. Let us now consider how the repeater circuit, as a whole, operates.

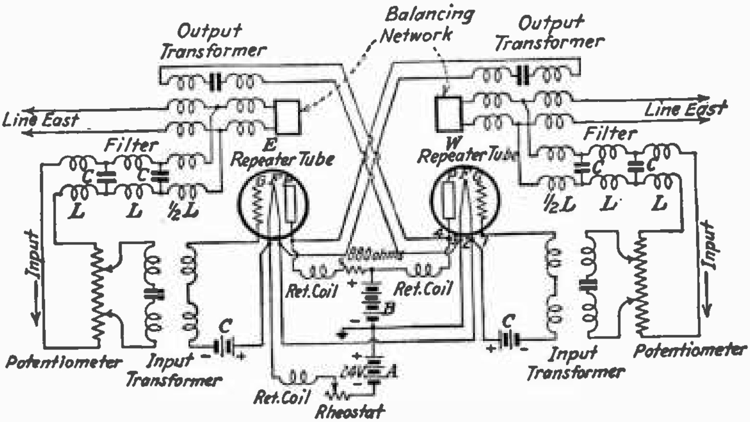


Fig. 20.—Circuit of 22-type telephone repeater.

The first of these types of repeaters which we shall consider is known as the *22-type repeater* circuit, and a simplified diagram of this is given in Fig. 20.

In the operation of this circuit, it will be assumed that in every case the balancing networks exactly equalize the lines to which they are connected. For example, if the current comes in over the "line west," the received power is divided into two equal parts, one part of which flows through the output circuit of the "west" repeater bulb and is lost, and the other part of which flows through the filter potentiometer and input transformer of the input circuit to the "east" repeater element. This power is amplified by the "east" repeater element and flows from the output circuit to the bridge transformer associated with the "line east." Here again it is divided into two halves, one half flowing into the balancing network and the other half flowing out on the "line east" to the distant listener.

It will be noted that in the 22-type repeater instead of balancing one line against the other, as has been indicated in the previous discussion of repeater circuits, we balance the line with an artificial line known as a *balancing network.* This network is made to have, as nearly as practicable, the same impedance as the line with which it is associated in order that the transmission loss through the bridge transformer from the output to the input circuit will be as high as possible. This, of course, is desirable, since it gives a high singing point and, consequently, more satisfactory operation of the repeater circuit.

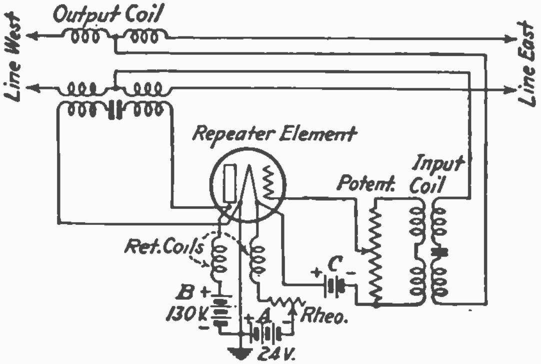


Fig. 21.—Circuit of 21-type telephone repeater.

The only other piece of apparatus appearing in this circuit which has not been previously discussed is the filter, which is shown between the input terminals of the bridge transformer and the potentiometer. The purpose of this filter is to cause a large loss to alternating currents above a certain frequency. This frequency is determined by the characteristics of the line with which the repeater is associated. In loaded lines, in particular, it is very difficult to match the impedance at high frequencies, since, above a certain point, the impedance of such lines changes very rapidly with the frequency. The filter is so designed that when the point is reached where the impedance of the line begins to change rapidly with the frequency, it cuts off the current, thereby avoiding certain difficulties in operation.

The second type of repeater circuit is known as the 21-*type repeater* and is illustrated in the simple sketch given in Fig. 21.

This repeater has the bridge transformer connected on one side to the "line west" and on the other side to the "line east," thus eliminating the necessity for networks. In explaining its operation, let us assume that the current comes in over the "line west" to the bridge transformer. If the input and output impedance of the repeater element balance each other, the incoming power is divided into two equal parts, one of which flows into the output circuit and is lost, and the other of which flows into the input circuit and is amplified. This amplified power is again divided by the bridge transformer into two equal parts, one of which returns to the talker on the "line west," and the other to the listener on the "line east." This type of repeater circuit has several limitations, some of which are listed below.

1. Since the amplified energy is sent out from the repeater in both directions, more than one 21-type repeater cannot be used in a connection under practical conditions, since energy would be sent back and forth between adjacent repeaters and thus result in sustained singing or impaired quality.
2. The return of amplified energy toward the talker makes it impracticable to use a single 21-type repeater in a circuit which may be connected to toll circuits involving the use of 22-type or four-wire repeaters, since the resulting connection, in many cases, would be long electrically, thus causing the currents returning from the 21-type repeater to be delayed sufficiently to constitute objectionable echoes.
3. As the amplified energy is sent in two directions from the repeater, circuits on which repeaters of this type are worked will tend to cross-talk into each other more than circuits equipped with 22-type repeaters, which, of course, send the amplified energy only in the direction of transmission.
4. In general, a 21-type repeater circuit gives less gain with good quality than a 22-type repeater circuit worked between the same telephone lines.
5. 21-type repeater circuits must be used in general between circuits having the same impedance characteristics.

Opposed to these limitations of the 21-type repeater we have the considerable advantages of simplicity and cheapness. It should be noted that this repeater uses only half as much apparatus as the 22 type. It also makes unnecessary the provision of networks and balancing apparatus. The power consumption is about one-third of that of a 22-type repeater owing to the fact that three tubes for three different 21-type repeaters can be worked in series from a 24-volt battery.

The remaining type of repeater circuit is known as the *four-wire circuit* and is shown in simplified form in Fig. 22.

As will be noted from the drawing, the four-wire repeater consists, really, of a 22-type repeater stretched out over a long distance. The bridge transformers in this case are at the terminals of the repeater circuit and the amplifying elements are placed somewhere between the two terminating points. Thus, we have two one-way transmission paths with a one-way repeater in each path terminated by two bridge transformers. The major differences, between this repeater and the other two types mentioned in the foregoing, lie in the fact that the four-wire repeater is designed to be used with two separate and distinct one-way channels between repeater stations.

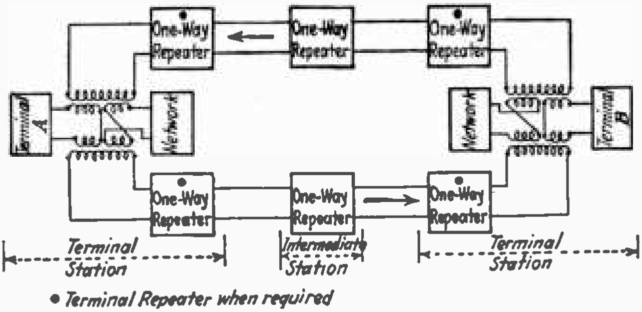


FIG. 22.—Four-wire type telephone repeater.

Assume that a person at the terminal *A* is talking to a person at terminal *B*; the power from his transmitter enters the terminating circuit and is divided into two equal parts. One of these parts is transmitted into the upper branch of the circuit where it is lost in the output circuit of the repeater element. The other half of the power goes into the lower branch of the circuit, is amplified by the one-way repeater, and flows along the circuit finally reaching the terminating circuit at terminal *B*. Here the power again divides, one half flowing into the two-wire line to the listener and the other half into the network where it is lost. Transmission in the opposite direction takes place in a similar manner, the useful power in this case flowing over the upper branch.

The repeater elements or repeater sets, as they are called, used on four-wire circuits consist of two one-way repeaters. These usually work at high gains, and for this reason it is necessary to employ two tubes in tandem in each one-way repeater, the complete repeater set thus requiring four tubes. A one-way repeater with two tubes in tandem is similar in principle to the one-way repeater already described, with the exception that the output of the first tube goes to the input circuit of the second tube.

Since four-wire repeater sets are worked at high gains, it is necessary to keep the circuits transmitting in opposite directions separated from each other as much as possible in order to prevent the high-power output from one repeater cross-talking into the very low-power input of the other repeater. To minimize this difficulty, cables are used which have the oppositely bound circuits separated from each other by special devices. This separation is, also, usually carried throughout all central-office wiring and apparatus up to the point where the circuits connect to the bridge transformer.

The principle of operation of the *vacuum-tube type of oscillator* for telephone work on transmission measurements depends upon the fact that if the output terminals of a vacuum tube are connected back to the input terminals, the tube will produce a tone, or "sing," and that if the proper circuit is built around this tube, the frequency of this tone can be regulated. Figure 23 shows the output and input of a vacuum tube connected together so that a tone will be heard in the receiver R. The figure shows, in dotted lines, a condenser which may be added to the circuit so that the frequency of the tone can be regulated.

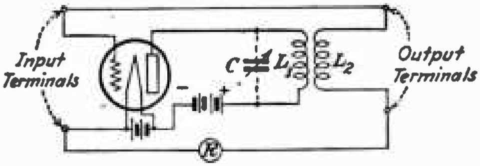


Fig. 23.—Vacuum-tube oscillator for telephone-transmission measurements.

Any electrical disturbance, such as a slight rush of current produced by the closing of a battery switch, will start the oscillations, thereby producing a tone in the receiver. In Fig. 23, the output from the tube is fed back to the input or grid circuit by means of the inductive coupling between the windings L_1 and L_2, and, as this energy is retransferred from the grid back into the output circuit, it is somewhat increased or amplified. If the values of L_1, L_2, and C are properly chosen, these oscillations can be sustained and built up to a final constant value which depends upon the characteristics of the tube for its value. If this value is not large enough, stages of amplification can be added. The frequency of this oscillator can be regulated by the condenser C or inductance L_1.

Sometimes, it is desired to produce a band of frequencies; that is, the alternating current which is generated is made to vary continuously and periodically between two limits. This condition may be produced by making the condenser C vary continuously between its minimum and maximum values, and *vice versa*. A convenient means to do this is to attach a small motor to the condenser to keep it revolving. This continuous change in the circuit causes the band of frequencies to be produced. The frequencies in the band, of course, depend upon the value of the condenser. If the inductance of L_1 can be made to vary continuously instead of the condenser, then the same result can be obtained by the use of the varying inductance.

Another type of oscillator makes use of two oscillating tubes arranged for different frequencies. For example, one may be arranged to oscillate definitely at 100,000 cycles and the other may be capable of regulation between 90,000 and 100,000 cycles. Voltages from these two sources are impressed upon a common circuit, giving rise to a frequency which is the difference between the two. The fundamental frequencies are then suppressed, and the beat frequency forms the useful output of the oscillator. An oscillator of the heterodyne principle can be designed to have a quite uniform output over the useful frequency range and the full frequency range can be covered by the adjustment of one dial.

Radio Direction Finder.—A radio direction finder is intended for taking bearings in navigation. It must be calibrated and adjusted to compensate for errors caused by metal objects in its vicinity, especially for the steel in the hull and decks when used on ships. The instrument is so constructed that once the necessary adjustments are made, these errors are automatically compensated and the correct readings may be taken directly from the indicator.

The calibration procedure is to take simultaneous sight bearings with a pelorus and radio bearings with the direction finder on some station while the ship is in motion. The difference between the sight bearings and the radio bearings will be the error of the direction finder. The maximum error will usually exist on bearings taken on stations off the bows and quarters. The error on bearings right ahead, or astern, or on the beam, is usually negligible.

At the time the direction finder is calibrated, the ship should be in condition for sea, with booms stowed.

To prevent the wind from turning the loop, a lock has been provided on the shaft of the hand wheel. It is recommended that this lock be set whenever the instrument is not in use.

The calibration should be checked from time to time by taking simultaneous sight and radio bearings when the ship is approaching and passing lightships equipped with radio for signals, or by asking any passing vessel to transmit signals. Stations used for calibrating the direction finder must be within the range of visibility but should not be less than one mile distant.

To avoid confusion, it might be well to point out that the terms "radio direction finder" and "radio compass" are synonymous. "Radio direction finder" has been used in the belief that it more truly defines the function of the instrument. The terms "radio position finder" and "radio pelorus" might also be used to describe this instrument. In fact, it should be regarded as a pelorus with which bearings may be taken at distances greatly beyond the range of visibility.

The device consists of a rotatable loop arranged for outside mounting and connected by a shaft passing through the deck to an indicating unit which allows bearings to be taken directly from a compass card or gyro repeater. Between the loop and the indicator is a mechanical compensator which automatically provides the necessary correction to offset errors introduced on account of metal objects aboard the ship. The wires from the loop are connected to a receiver amplifier mounted in the base. The receiver has a wave length range of 550 to 1,050 meters. Another model has a range of 300 to 1,050 meters. The entire instrument as made by the Radio Corporation of America (model ER-1445B) as shown in Fig. 24 is self-contained in one unit. The complete wiring diagram is shown in Fig. 25 and the radio-frequency part of the receiver in Fig. 26.

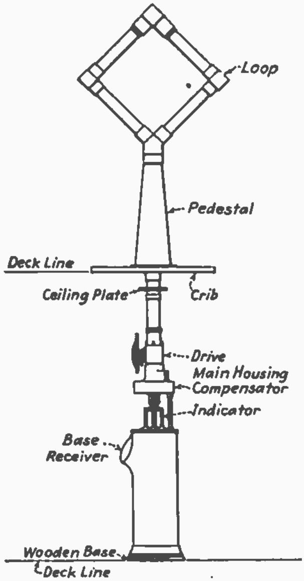


FIG. 24.—R. C. A. direction finder.

The loop consists of a number of turns of wire enclosed in water-tight tubes to form a square. Its container is mounted on one corner with its plane vertical. A hand wheel is provided for turning the loop. When the plane of the loop is in the direction from which the signal for bearings is coming, the signal has its maximum strength. Conversely, the signal received is zero when the plane of the loop is at right angles to the direction of the signal. As the loop is turned through 180 degrees the manner in which the signal changes in intensity is shown in Fig. 27. Thus it is seen that a change of 30 degrees from the position 1 to the position 2 changes the signal intensity only from 100 to 85 per cent, whereas the same movement of 30 degrees from the position 3 to the position 4 changes the signal intensity from 50 per cent to zero. Consequently, to obtain accurate bearings the indicator is set to take readings on the minimum signal strength.

Bearings are observed by means of parallel lines engraved on a piece of plate glass, which revolves above a scale as the loop is turned. The

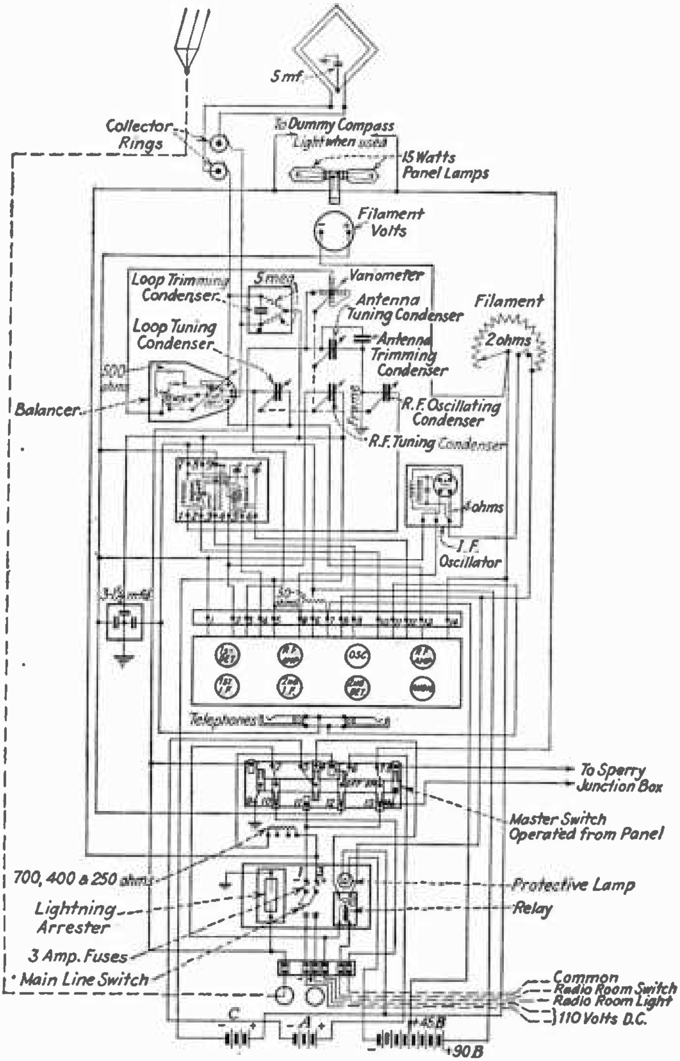


FIG. 25.—Wiring diagram of instruments shown in Fig. 24.

scale consists of a standard pelorus card adjusted so that readings are referred to the ship's head. One side of the indicator is equipped with a reading glass and is also marked with an arrowhead. This side should always be used for reading the bearings, as it is the side used when the instrument is calibrated. The short pointers marked "red" and "white" are used only when the relative direction from which the signal is coming is not known. On ships equipped with a Sperry gyro compass, the pelorus card may be replaced by a gyro repeater. In such cases, readings with the radio direction finder are referred to the true meridian.

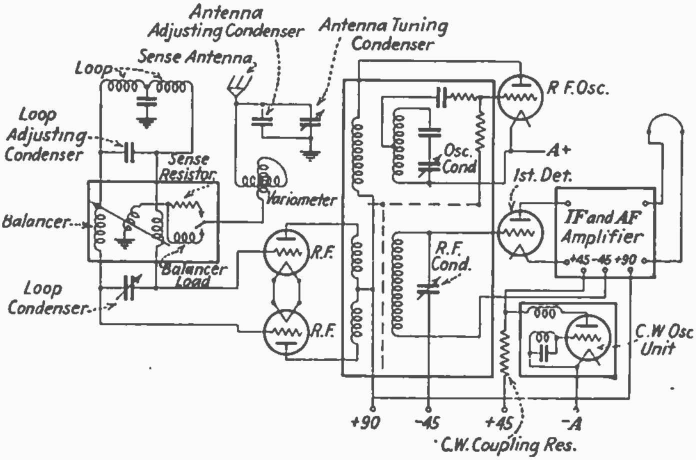


FIG. 26.—Radio-frequency part of receiver for direction finder.

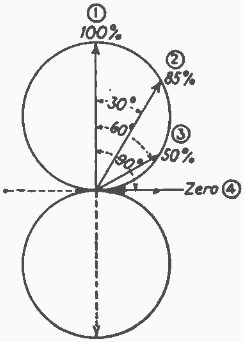


FIG. 27.—Variation of signal intensity with position of loop.

The receiver amplifier must function to give a relatively loud signal in order that the minimum signal may be well defined and to eliminate other signals or disturbances of whatever sort which would otherwise seriously interfere with obtaining an accurate reading. The *superheterodyne* receiver ranks highest in accomplishing this; and, at the same time, with a simplicity of controls. There are two controls, one for tuning the loop and the other for secondary tuning. Each control scale is marked to show the approximate position of the tuning for given wave lengths. The receiver-amplifier uses nine vacuum tubes of the 201A type, one of which functions as an oscillator for the reception of C.W. signals. A storage battery is used for filament lighting, and heavy-duty dry B batteries for the plate-voltage supply.

In choosing a station on which to take a bearing, the following limitations should always be considered: (1) A bearing should be avoided which involves a signal that has traveled any appreciable distance along the shore line. In such cases, the line of separation between the water and land acts as a partial reflection, bending the radio waves and possibly resulting in an erroneous bearing. (2) A bearing taken on a station separated from the ship by intervening land should be considered as approximate. (3) A bearing taken on a station more than 150 miles distant should be considered as approximate. (4) On bearings taken shortly before or after sunrise or sunset, errors due to the so-called "night effect" on radio waves may be observed. These errors are manifested by a rapid swinging of the minimum signal strength so that the signal station seems to be changing its position while a bearing is being taken. Errors due to night effect are usually negligible at distances of less than 100 miles.

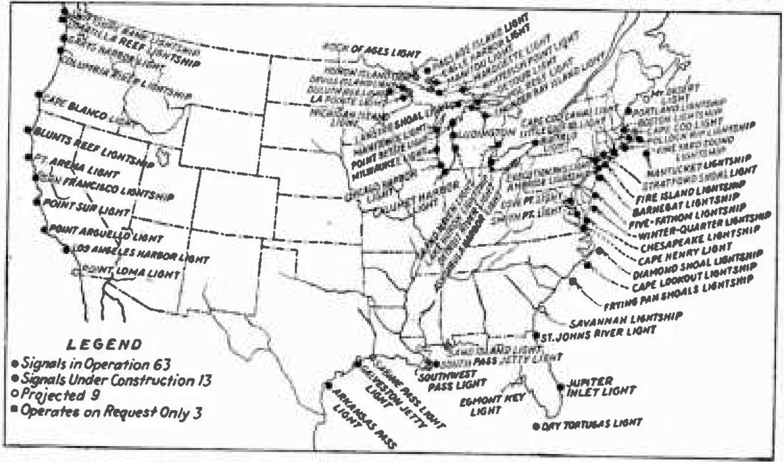


FIG. 28.—Location of radio fog-signaling devices.

The special radio *fog-signaling device* (Fig. 28) should be used wherever available for taking bearings in preference to any other station, for the following reasons: It has been erected by the United States Government and various other governments, specifically for navigation aids in connection with radio direction finders. It emits a characteristic signal which may be readily distinguished by anyone without knowledge of the telegraph code and is so located on lightships and at lighthouses that the bearings will, in most cases, be entirely "over water." The radio fog-signal stations are operated continuously during fog or thick weather.

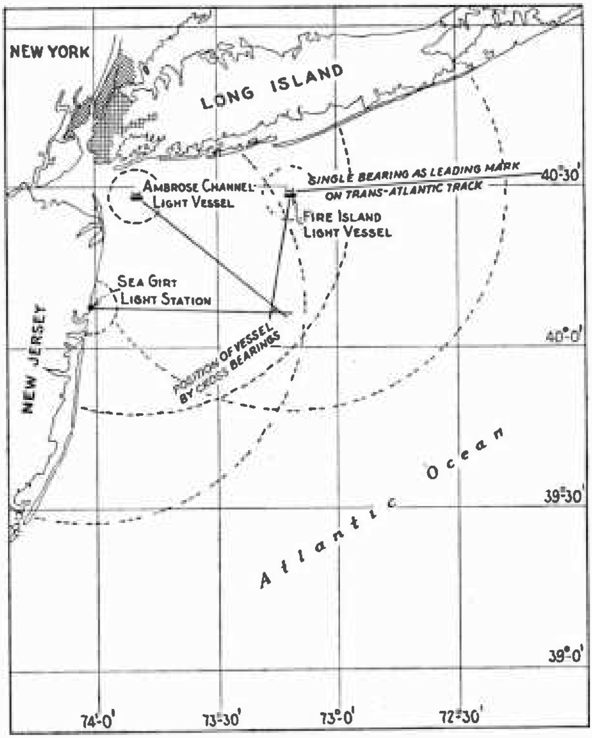


FIG. 29.—Characteristics of radio fog signals (dots in circles).

To obtain bearings on other than the government-operated radio fog-signal stations, it is necessary to call on the radio operator of the station to identify the desired station by its radio call letters.

The radio signal may be used as a *leading mark*, as, for example, to enable a vessel to make a lightship anchored in the approach to a harbor, or to pass outside a lightship anchored to guard against dangers off the coast.

Examples of this are given in Fig. 29. The distinctive characteristics of the signals from the stations shown are indicated by dots in the circles.

In the operation of this apparatus the procedure is as follows: The button on the control panel marked "on" is pressed. This turns on a light in the radio room, which is a signal to the radio operator to open the antenna circuit. When the antenna switch in the radio room is opened, it automatically operates a relay in the battery compartment of the receiver, which closes the filament circuit. Then the filament rheostat is turned to the position where the voltmeter reads "5 volts" on the lower scale of the meter. The next step is to turn both tuning controls to the approximate wave length of a station to be used for bearings. The so-called "station selectors" marked "1" and "2" are carefully tuned, the pointers being moved back and forth over the position for the loudest signal about three times to determine the setting that gives the most intense signal. The balance pointer is set at zero. The loop is rotated slowly until a dip in the signal strength is noted. The loop is left in this position, and the balance is set at the position which gives the minimum signal. Then the loop must be readjusted slightly to get zero signal strength. The bearings of the radio signal station are read from the end of the indicator that carries the reading glass. For best results both the balance and the loop must be slowly and carefully adjusted. When bearings are being taken on stations within 5 miles, it may be found desirable to reduce the signal strength. This can be done by reducing the filament voltage or by a slight readjustment of station selector 2. By proper adjustment of the balance, the bearings on beacons within a radius of 100 miles can be obtained which are definite, as to sharpness, to 1 degree and, in some cases, to ¼ degree, or they are about as accurate as it is possible to adjust the loop. If the line of direction is not known, the loop should be turned to give the maximum response. This is accomplished by turning the loop through 90 degrees after the line of direction is determined. The filament control and the station selector 2 are adjusted to give a signal of medium strength, and then the button on the panel marked "sense" is depressed so that the strength of the signal may be noted. The loop is turned quickly through 180 degrees while the "sense" button is held down and the strength of the signal is again noted. If the signal is now stronger, the station is in the general direction indicated by the red pointer; but if the signal is weaker, the general direction of the station is shown by the white pointer.

The Auto-alarm.—The auto-alarm is a mechanical device for attracting the attention of officers on a ship having no constant "wireless watch," when a vessel in the neighborhood may be in distress. A device for this purpose must be made which will be serviceable for conditions at sea and for operating with certainty the "S O S" (distress) signal without responding

The plate of the first tube is connected through a reaction coil to the medium-resistance winding of the first transformer, a condenser being connected across this winding. The low-resistance winding of the transformer is taken to two terminals to which telephones can be connected for testing purposes, and the high-resistance winding is connected between the grid of the second tube and the filament circuit.

The plate of the second tube is "choke-capacity" coupled to the grid of the third tube, the high-resistance winding of the second transformer (with a condenser across it) being used as the choke coil. Another pair of testing telephone terminals are connected to the low-resistance winding of this transformer.

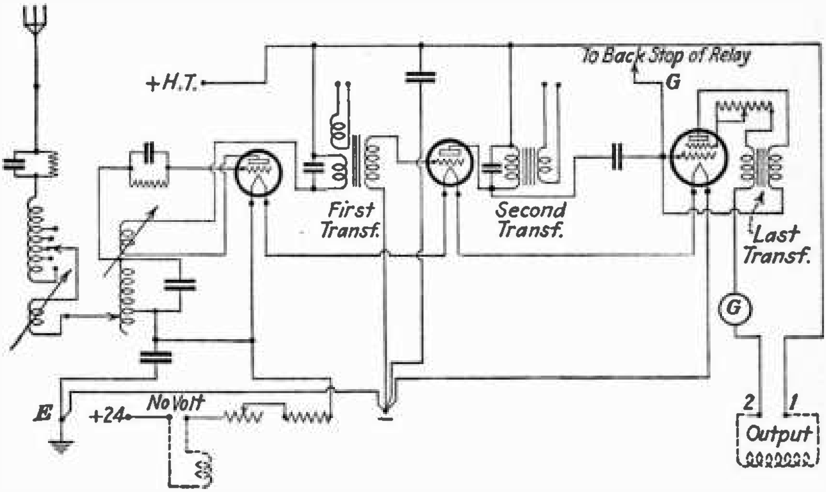


Fig. 30.—Circuit of receiver and selector of auto-alarm.

The inner grid of the third tube is connected through a large variable resistance to the medium-resistance winding of the last transformer, then through a shunted galvanometer to the output terminal marked "No. 2," thence through the coils of the relay to the No. 1 output terminal, and finally to the high-voltage supply line. The plate of the third tube is connected through the high-resistance winding of the last transformer to its own grid.

The three filaments of the tubes are in series with one another and also with a fixed and a variable resistance and the "no-volts" relay in the selector. The voltage of the filament circuit is 24 volts.

In the absence of any signal, a steady current of about 0.7 milliampere flows from the filament to the inner grid of the third tube and then through the last transformer through the main relay coils, thus holding the tongue of the relay in contact with its front stop. When a signal is received, it makes the grid of the third tube more negative than it had been and reduces the current in the circuit to a value at which the tongue of the relay is released and pulled over by its grid-bias-voltage coil. Any sudden reduction in the current going through the relay coil sets up a voltage in the high-resistance winding of the last transformer, these windings being connected in such a way that this change makes the grid still more negative and thus intensifies the signal strength.

There is no grid leak to the third tube, so that its grid when made negative will retain that polarity, with the result that the relay would be satisfactorily operated at the beginning of a received signal but that this tube would remain paralyzed by the accumulated charge on its grid. By connecting this grid (through the *G* terminal) to the back contact of the relay, however, so that the grid is discharged when the tongue of the relay falls, this paralysis of the tube is avoided, this connection being made to a point in the filament circuit which is at such a voltage with regard to the filament of the third tube that the grid will be restored to its original voltage, thus eliminating surging currents through the windings of the last transformer, which might cause the relay to chatter.

The resistances in the filament circuit are on the positive side of the filaments, and the negative end of the filament of the third tube is grounded. The filament-supply current passes through a no-volt relay in the selector, which acts as a "telltale" when the filament current is below the value for the proper emission in the tubes. The three tubes are supplied with the same plate voltage, 36 volts above the negative point, of this voltage 24 volts being derived from the 24-volt battery which supplies the filaments and actuates the selector mechanism, and the remaining 12 volts from an extra battery. A condenser is connected across the battery terminals.

The selector (type 333) is governed by the movement of the main relay, which is a polarised instrument so adjusted that the grid-bias voltage pulls the tongue of the relay over to the back stop, which is connected through the *G* terminal to the grid of the third tube. The wiring diagram is shown in Fig. 31.

The primary movement of the selector is governed by the movement of the tongue of the relay. In the state of rest this tongue is held against its front stop and a circuit is completed through the first magnet, thus holding the primary arm down against the action of its spring. When a signal of sufficient strength is received, the tongue of the relay falls away from the front stop, the current through the first magnet is broken, and the selector operates. If the incoming signal is too feeble, the tongue will fall back to the front contact, the current will flow through the first magnet, and the action of the selector will be stopped. If the next signal is of the proper working strength the tongue of the relay will cross the back stop, the grid of the third tube will be discharged, the inner grid current will begin to grow through the relay coils, and the tongue of the relay will start its return journey to the front stop; and if the signal continues, the main relay-coil current will be again reduced and the tongue will be pulled back to the back stop. During the continuance of an incoming signal of sufficient strength, therefore, the relay tongue chatters against its back stop. During this time the circuit through the first magnet is open and the selector continues in operation.

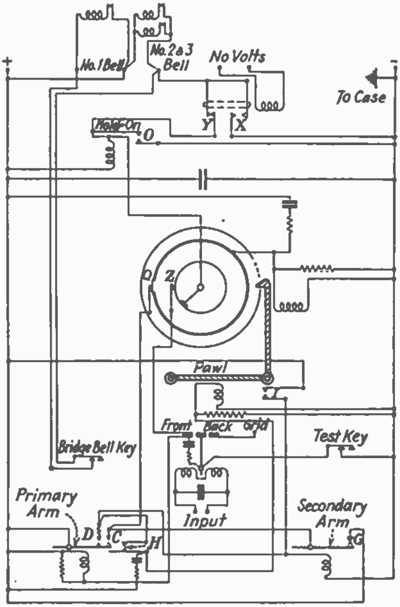


FIG. 31.—Wiring diagram of selector.

The primary movement of the selector consists of an arm having a spring at one end, and at the other an air dashpot fitted for quick recovery. The first magnet pulls this arm down against the action of the spring. When the current through the first magnet is stopped, the spring pulls the arm up against the drag of the dashpot; and if this movement continues, the arm will close the first working contact *D*. Now if the movement continues still longer the arm will also close the second working contact *C*. The dashpot adjustments are permanent as well as also the position of the *D* contact; but the time required in order that the arm can close the *D* contact may be varied by altering the tension of the spring. The *C* contact can be moved bodily so that the time elapsing between the closing of the *D* and *C* contacts can be varied. The *C* contact should be closed five seconds after the selector begins to operate. When the *D* contact is closed, a simple pawl-and-ratchet wheel train is operated which rotates by one tooth of the pawl wheel a shaft carrying the contacts which when closed ring the signal bells.

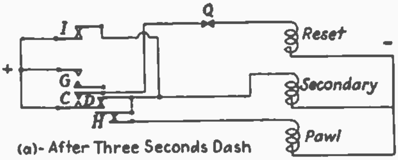
If the primary arm closes the *C* contact, both the holding and driving pawls are drawn back out of engagement with the pawl wheel by the resetting magnets, and the shaft returns to its starting position. The current flowing through the windings of these resetting magnets flows also through a contact *Q* carried by the shaft, which opens when the shaft is in its starting position and is closed as soon as the shaft is turned. Were it not for this arrangement the circuit through the resetting magnet would be completed through the *G* contact when the selector was in the "ready" position, and the pawls would be unable to start the rotation of the shaft.

Since the movement of the primary arm is governed by the movement of the tongue of the main relay, which, in turn, is controlled by the incoming signal, the shaft will be advanced by one tooth of the pawl wheel if the signal consists of an unbroken dash lasting for three seconds, and if this dash continues to a total of five seconds the shaft will be returned to its starting position. Hence a four-second dash will cause the shaft to advance one tooth of the pawl wheel, and an allowance of practically one second each way is made to cover bad sending.

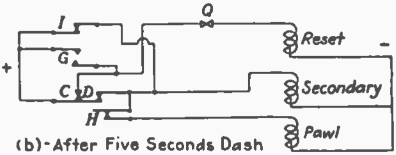
As soon as the *D* contact closes it also starts the secondary action of the selector by energizing the magnet of a second arm, which is similar to the primary arm, and pulls it down against the action of its spring. As soon as this circuit is opened, the secondary arm will begin to rise again, its rate of movement being adjusted so that it closes its contact *G*, five seconds after the circuit is opened. Thus, if a correctly made four-second dash is received, the primary arm rises, and at the end of three seconds the *D* contact closes and the secondary arm descends. When the four-second dash has been received, the primary arm flies back to its starting position and the *D* contact is opened, the secondary arm rising and closing the *G* contact in five seconds, if nothing intervenes to stop it.

But suppose that after a one-second space another four-second dash is started; when it has lasted three seconds the *D* contact will again be closed and the secondary arm will be pulled down before it has reached the *G* contact. The arm rises to the *G* contact in five seconds; and when operating as described, it has been allowed only four seconds, one during the *space* and three seconds of two four-second dashes. Had the space lasted for two or more seconds, a sufficient time would have been allowed for the *G* contact to be closed, and as the *G* contact is in parallel with the *C* contact, the pawls would have been pulled back, and the shaft would have been released and returned to its starting position. A dash of less than three seconds has, therefore, no effect on the shaft; a dash of three seconds or over allows the shaft to advance one tooth; and a dash of five seconds returns the shaft to its starting position.

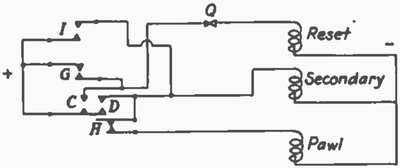
A second dash of not less than three seconds following the first at an interval of less than two seconds will allow the shaft to advance another tooth, but if the space exceeds two seconds the shaft will return to its starting position; and if the space is too short to allow the selector mechanism to operate, the two dashes will be run into one, and the shaft will return after a dash requiring a total of five seconds. Thus an allowance of nearly one second each way is made in the permissible length of the space, which can be anything less than two seconds and more than about one-fifth of a second.



(a)- After Three Seconds Dash



(b)- After Five Seconds Dash



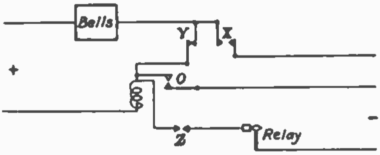
(c)- During a Space after a Correct Dash

(d)- Result of Too Long a Space

FIG. 32.—Straight-line diagrams of selector circuits.

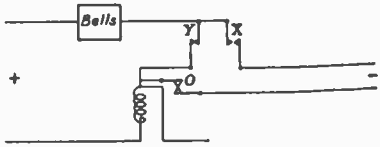
A third dash of the correct length, separated by the proper space (both within the allowances mentioned above), will cause the shaft to advance by one more tooth, making three teeth in all, and at the termination of this dash the ringing circuits will be completed by the contact *Z*. If the last dash exceeds five seconds, the ringing circuit cannot be completed, because the pawls will have been drawn back before the dash is finished. This *Z* contact is in series with a hold-on relay and the connection made by the tongue of the main relay when it touches its front stop. When both the *Z* contact and the contact of the front stop of the tongue are closed, the hold-on relay is energized, and when once closed, it will not open again. The *Z* contact is closed as soon as the third dash has lasted three seconds, but the contact at the front stop of the tongue does not close until the third dash ceases, and therefore the bells ring only on the completion of the third dash.

When the third dash has lasted three seconds, the shaft is moved for the third time and the *Z* contact is closed. But the tongue of the relay is away from the front stop so that no current will flow through the ringing circuit until the tongue of the main relay returns to its front stop, which will take place on the termination of the third dash. If the third dash continues over the limit of five seconds, the shaft will have returned to its starting position, because the resetting magnets are energized on the closing of the *C* contact, and there will then be no continuity through the ringing circuit, because when the shaft returns to its starting position, the *Z* contacts are open. The contact of the hold-on relay is in parallel with the combination of the *Z* contact and tongue of the relay front stop. Once it has been closed, these two contacts are short-circuited and the bells will go on ringing whether or not the contacts are open. When once the alarm bells, therefore, have been started, they will go on ringing until the whole apparatus is switched off.



(a)-Normal Conditions

(b)-Failure of Filament Current



(c)-Alarm Signal Received

FIG. 33.—Straight-line diagrams of bell circuits.

Figure 32 shows straight-line diagrams of the selector circuits, as follows: (1) dash in progress after three seconds; (2) dash in progress over five seconds; (3) result of too long a space.

If each of the nominal four-second dashes continues for a period longer than three seconds and under five seconds, and if the nominal one-second spaces are over a fifth of a second and under two seconds, a series of three nominal four-second dashes, separated by nominal one-second spaces, will set the alarm bells ringing after the completion of the third dash. The selector will respond, therefore, to any reasonably close imitation of the correct "alarm signal"—as the series of four-second dashes separated by one second spaces is called. If interference exists at the same time, either from Morse-code signaling or from atmospheric conditions, the operation of the apparatus is not affected appreciably. It is obvious, of course, that nothing which may occur during one of the "dashes" can have any other effect than to make the tongue of the relay leave the front stop and chatter against the back stop. So long as the signal is strong enough to work the relay, no addition to the strength of signals can produce any change in this respect.

If interfering signals occur during the "spaces," they can do no harm unless they bridge the space altogether. The design of the whole instrument, both electrical and mechanical, makes it very quick to recover, and, as stated before, a break between dashes as long as one-fifth of a second is

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similar to those in Fig. 30 will be obtained, the recording as shown in this figure being the variable-width method.

An improved film phonograph of the variable-width type is shown in Fig. 31. In the operation of this film phonograph, a 50-watt incandescent lamp is used for illuminating the slit which assumes varying widths for making the sound record. The light from this lamp is focused by means of a lens on the mirror of an ordinary oscillograph (page 38). This mirror in turn reflects the light upon the slit through which the film is illuminated; and another lens focuses this slit on the film with a 10:1 enlargement.

The film phonograph operated by this method will record from 10 to 15 sound tracks on a standard width of motion-picture film so that on a 400-foot film a program requiring one to two hours can be satisfactorily recorded. In order to avoid the interruptions which would occur at the end of each of the sound tracks when the record is being reproduced, a device is used whereby the ends of the film are sealed together to form a continuous band which can be operated continuously in one direction. The shifting of the scanning light spot is accomplished electrically by means of a little metal tab on the edge of the film which serves to complete an electric circuit which moves automatically the whole optical system from one sound track to the next. The shifting mechanism is actuated by an electromagnet.

with records of this kind, it is necessary to manipulate them every 5 or 10 minutes, the time depending somewhat upon the size of the disk.

Phonograph records which can be operated for one or two hours without manipulation can be obtained by making sound records on the full width

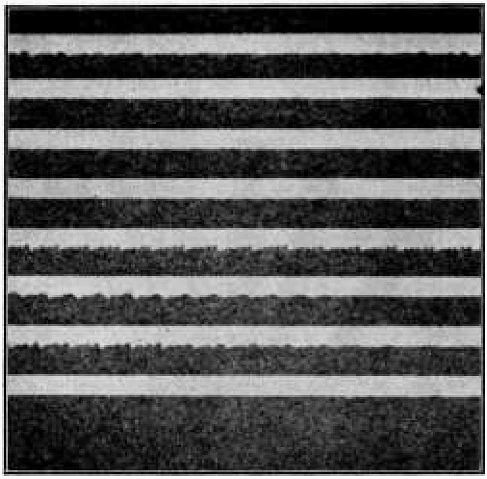

Fig. 30.—Standard-width film with eight consecutive sound tracks.

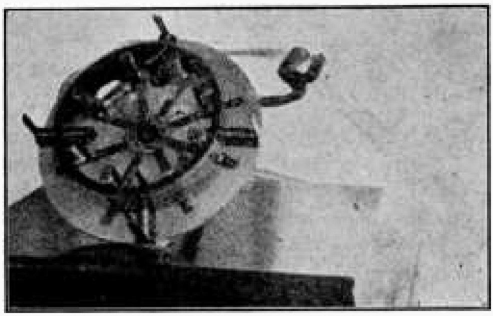

Fig. 31.—Experimental film phonograph.

of standard motion-picture film, the record being made in exactly the same way that the sound track is put on the edge of motion pictures. If a motion picture film is passed a number of times over the illuminated slit of an apparatus for making a sound track on the film, a series of sound tracks mouth of the horn bell; and, of course, when the horn bells are located at the motion-picture screen, the sound will be properly distributed. On the other hand, if a loud-speaker is used instead of a horn bell, which has otherwise identical characteristics but which radiates the sound in a wide angle, there is a tendency for the sound to *appear* to come from a point some distance back of the screen where the loud-speakers are located, thus tending to destroy the illusion that the sound is coming from a point just as far away from the audience as the picture.

Fig. 29.—Group of nine throats for horn bells of sound projector.

Under ordinary conditions the power supply for the motors and most of the equipment is obtained from the alternating-current mains of the city supplying the building except that direct current is required for the filaments of some of the vacuum tubes, as well as for the electromagnets in the loud-speakers and for the photo-electric cells and the amplifiers which are a part of the equipment of those cells.

Film Phonographs

Types of Phonographs.—The kind of phonograph in common use has its sound record impressed on a composition disk which is hardened so as to have a good wearing surface. The principal disadvantage of this type of phonograph record is that a relatively short time is required to traverse the spiral-shaped impressions on the record, so that in the operation of the phonograph output to the desired number of sound projectors or loud-speakers, to use them most efficiently and also to adjust the *relative* volume of the individual sound projectors or loud-speakers. In a theater of moderate size, it is customary to use four projectors or loud-speakers, two of these being mounted at the line of the stage where they are pointed upward toward the balconies, and two others which are mounted at the upper edge or slightly above the motion-picture screen and are pointed downward. This combination has been found by experience to give a satisfactory distribution of sound through the building. This arrangement of the sound projectors (horns) is shown in Fig. 26.

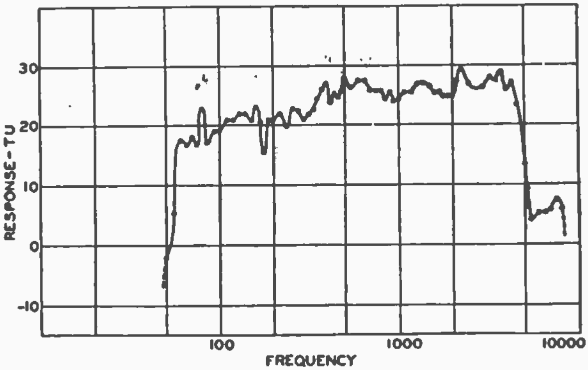

FIG. 28.—Frequency-response characteristic of large sound projector.

About 30 per cent of the electrical power supplied to a good sound projector or loud-speaker is radiated in the form of sound. It is important, of course, that this efficiency in the conversion of electric power into sound should be as high as possible, as the size of the amplifier unit can be reduced in proportion to the increase in efficiency. The frequency-response characteristic of a typical sound projector (horn) is shown in Fig. 28. In this case the sound response is represented in terms of transmission units (page 405). An individual loud-speaker (horn) may be equipped with one, two, three, four, or in fact as many as nine horn *bells* by using the *throats* shown in Fig. 29. In places where it is necessary to disperse the sound over a large angle, more horn bells are needed than when the sound can be concentrated over a comparatively small angle, as in the area in front of a stage of a theater.

This directive characteristic of the horn bell of a sound projector is important, as it creates the illusion of the sound coming directly from the be arranged in suitable combinations for the requirements of the hall or theater in which the equipment is to be used. In small halls or theaters only the first and second units are needed, while in large theaters or convention halls the third unit should be added to the first and second. For exceptionally difficult conditions, two or more of the high-power amplifiers in the third unit in parallel may be operated from the second unit.

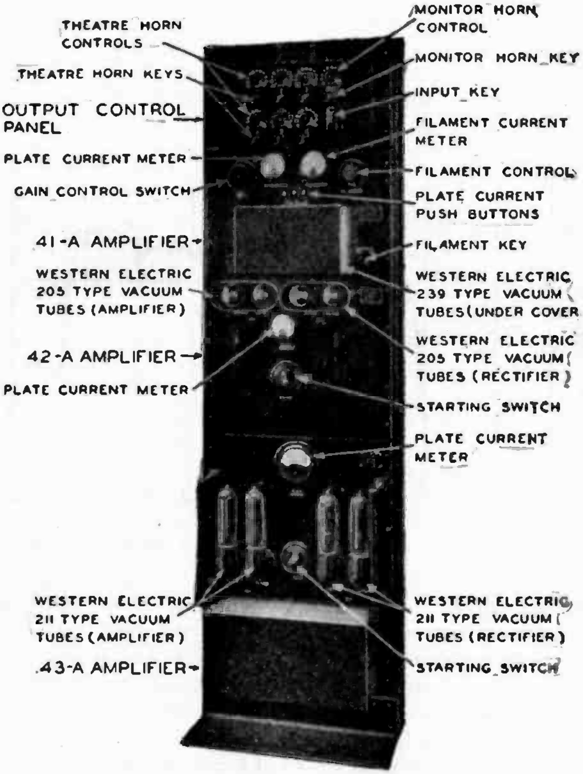

Fig. 27.—Panel for amplifier.

In the output circuit, between the amplifier and the rectifier, is an output-control panel consisting of an autotransformer (page 144) with a large number of taps to which the sound projectors or loud-speakers are connected. By means of this panel it is possible to match the impedance of the amplifier graph heads instead of the Simplex. A typical layout of a sound projector system for talking motion pictures is shown in Fig. 26.

In order to run a *continuous* program of motion pictures, it is necessary to use two projectors alternately. The shifting of the picture from one projector to the other without interruption is accomplished by the method of *fading*, which means that the pictures from one machine are gradually faded imperceptibly into the pictures from the other projector and the sound record from one projector is faded by the same method from one machine to the other without the audience being aware that a change has been made. For the accomplishment of this transition from one projector to the other, a device called a "fader" is used. In practical operation it is only necessary to turn a knob on this device at the same time that the *incoming* projector is started; the rest of the process is automatic.

The fader for motion-picture projectors is essentially a double potentiometer (page 39) which is arranged to vary progressively the sound volume from both projectors. When the fader first comes into action, which is of course at the normal operating sound range of the projector which is going out of use, the change in volume from one step to the next is scarcely more than perceptible, while in the lower range of sound volume the steps are larger and the volume decreases rapidly to zero on one machine and builds up with equal rapidity on the projector which is just coming into use. By choosing the proper steps in the normal sound range, it is possible to obtain any volume of sound within reasonable limits and thereby equalize the differences in sound between the two sound records.

Another important device required for the sound mechanism of the projector is the *main amplifier* which raises the feeble electric currents from the photo-electric cell to the required amount needed to operate the loudspeakers with sufficient volume to be heard in a hall or theater. A typical panel installation for the amplifier is shown in Fig. 27. This amplifying device increases the energy of the electric currents from the photo-electric cell 100,000,000 times and is so designed that all frequencies in the range from 40 to 10,000 cycles per second are amplified an approximately equal amount. This amplifier contains three units. The first of these units consists of three low-power tubes connected in series by means of resistance coupling. These tubes require a direct-current supply. The second unit consists of a single stage of two medium-power tubes connected in push-pull (page 39) arrangement, the filaments being heated by low-voltage alternating-current. Two similar tubes in this unit operate as a full-wave rectifier (page 271) and supply rectified alternating current for the plate circuit of the amplifier tubes of both the first and second units. The third unit has a single stage of high-power push-pull amplifier tubes and push-pull rectifier tubes operating with alternating current. The three units as described may picture and the corresponding sound record, there must be also this distance on the film between the *frame* of a picture and the corresponding sound *track*. This separation between the point where the picture is shown and its sound record is made necessary because, in the case of the picture, the motion is intermittent while the sound record has a uniform motion. In order to allow for this difference in movement, a certain amount of slack is allowed between the sprocket wheel which carries the picture with its intermittent motion and the sprocket wheel which carries the sound record. Special precautions are necessary to prevent vibrations and speed fluctuations from affecting the uniformity of rotation of the sprocket wheel carrying the sound record. For this purpose, devices have been designed for automatically controlling the speed of the motor (page 844) which drives both sprocket wheels, and a mechanical device is interposed between the sprocket wheel of the sound record and the rest of the moving equipment of the projector to prevent the transmission of any abrupt change of speed to the *sound* sprocket wheel. The automatic device for controlling the speed of the driving motor is intended to maintain that speed accurately at the same speed at which the sound records are made, that is, 90 feet per minute. It is possible, however, to operate a motion-picture projector of this kind without this automatic speed-control feature, and when the automatic device is disconnected, the mechanism of the projector can be controlled manually by the operator.

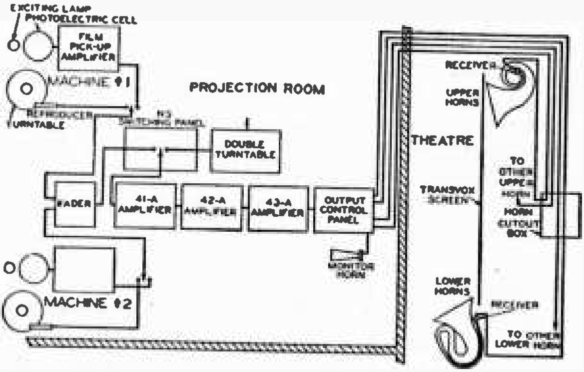

Fig. 26.—Sound projector system for theater.

The general arrangement of a typical projection machine, in this case as equipped with a Simplex head, is shown in Fig. 25. This mechanism can, however, be arranged for the attachment of either the Powers or the Motiohigh permeability (page 64). A sound reproducer of this type is shown in Fig. 21. The diaphragm is so arranged that as it vibrates the magnetic flux in the air gap of a permanent magnet M varies according to the vibrations. The magnet will induce, therefore, in suitably placed coils C, electric currents which are representative of the variations in the wavy groove in the disk record over which the needle travels. Although the sound volume delivered by an instrument of this kind is comparatively low, it is quite uniform over a wide range of frequencies. This satisfactory result is accomplished largely by the care taken in adjusting the parts so that all resonant sounds from them are out of the working range of the instrument. A device which serves for the accomplishment of the same purpose is a heavy damping oil in the back part of the magnet chamber behind the diaphragm.

In order to provide a means of adjusting a sound record of this kind so that it will be in synchronism with a motion-picture film, it is only necessary to mark a point on one of the *frames* of the motion-picture reel corresponding to the beginning of the sound record.

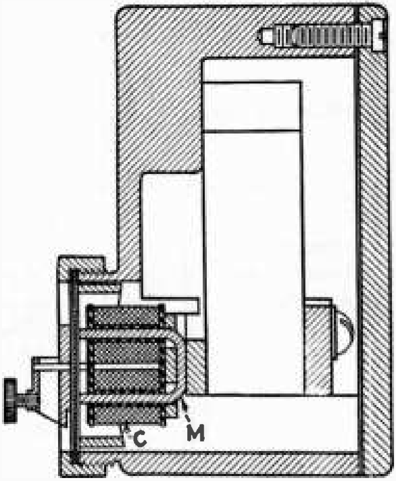

Fig. 21.—Theater type of sound reproducer for disk records.

Film Sound Records.—The type of sound record which is made in the form of a track near the edge of a motion-picture film may be made in either of two ways, one by a series of consecutive lines of equal length which vary in density. In this method the changes in *intensity of sound* are represented by the differences in the density of the record, while the *pitch* is represented by the number of *changes* from dark to light and back again in a given length of the track at the edge of the film. In the second method a series of lines of constant density are used to make the track, the *variation in length* being proportional to the *pitch* and *volume* of the sound. In both of these methods the sound record on the track is converted into corresponding electric currents by arranging a narrow beam of light of high intensity to pass through the sound track on the film and fall upon a photo-electric cell. The light from the bright filament of a lamp is focused as a very narrow line upon the film by passing this light through a system of lenses and then through an aperture plate. In a typical apparatus for this service, the slit upon which the bright filament is focused is 0.1875 inch long and 0.0015 inch wide. The image of this slit is then brought to a focus upon the film as a line 0.001 inch wide, the length of the line being reduced in its passage through the aperture to 0.08 inch. This reduction in the length of the lines composing the track allows 0.01 inch on either side for variations in the position of the sound track. The position and focus of the lens are fixed, but the carriage supporting the bright filament is movable, so that when a filament lamp is to be replaced, the filament may be conveniently brought to the best focus.

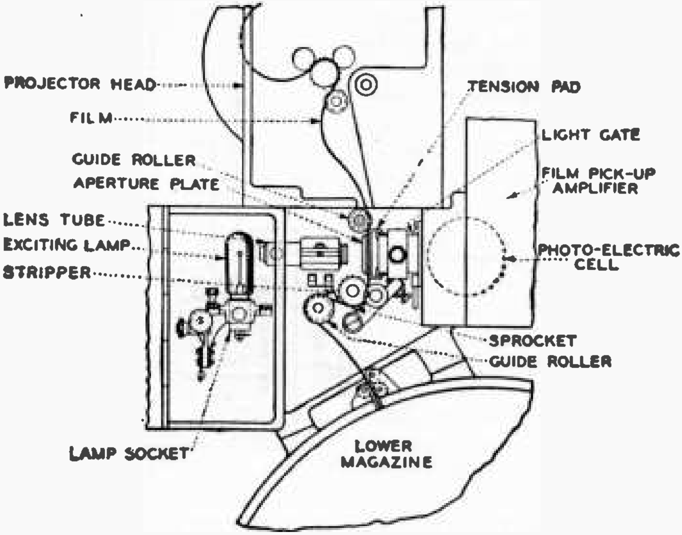

Fig. 22.—Typical apparatus for reproducing sound from a film record.

The diagram of the equipment for reproducing sound from a film by the first of these methods is shown in Fig. 22, and the photo-electric cell suitable for this service is shown in Fig. 23. The photo-electric cell within the range of its most suitable adaptability has the property that the current through it is proportional to the amount of light which falls on the cell. The arrangement of the circuit of the photo-electric cell for this service is shown in Fig. 24. It will be observed in the arrangement of this circuit that the voltage supplied to the photo-electric cell passes through a very high resistance and there is, therefore, a considerable voltage drop across this resistance, the voltage drop being proportional to the amount of light falling upon the photo-electric cell and obviously also to the varying density of the sound track on the film which is interposed between the bright filament of the lamp and the photo-electric cell. In circuits of this type there is always likely to be the difficulty produced by local interference, otherwise called "static." This is particularly noticeable when the *energy level* is low so that the *static* currents may be appreciable in comparison with the sound currents. The circuit of the photo-electric cell has a rather high impedance so that by the use of a vacuum-tube amplifier the sound energy can be increased and made available across a low-impedance circuit. The photo-electric cell and the amplifier are enclosed in a heavy metal box which serves as a shield.

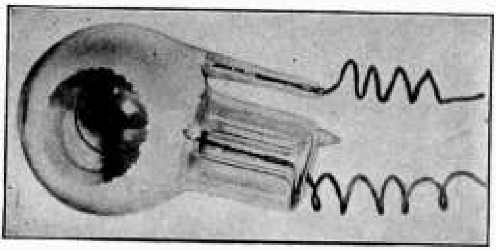

FIG. 23.—Photo-electric cell for sound reproduction.

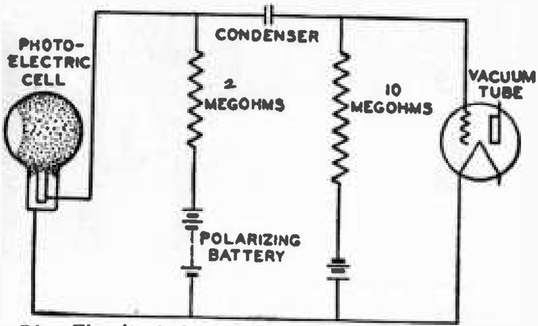

FIG. 24.—Circuit of photo-electric cell for sound reproduction.

In the ordinary operation of this equipment the filaments of the vacuum tubes in the amplifier have sometimes so much vibration that there is sufficient motion of the elements of the tube with respect to each other that they produce changes in the flow of electrons between the filament and the plate; and these vibrations may appear, when sufficiently amplified, as noises from the loud-speaker. There is also some vibration of the motion-picture projector under practically all circumstances, when it is in operation, and this vibration would have its effects on the elements of the vacuum tubes. For this reason it is necessary to provide an elaborate shockproof mounting for the amplifier in the circuit of the photo-electric cell.

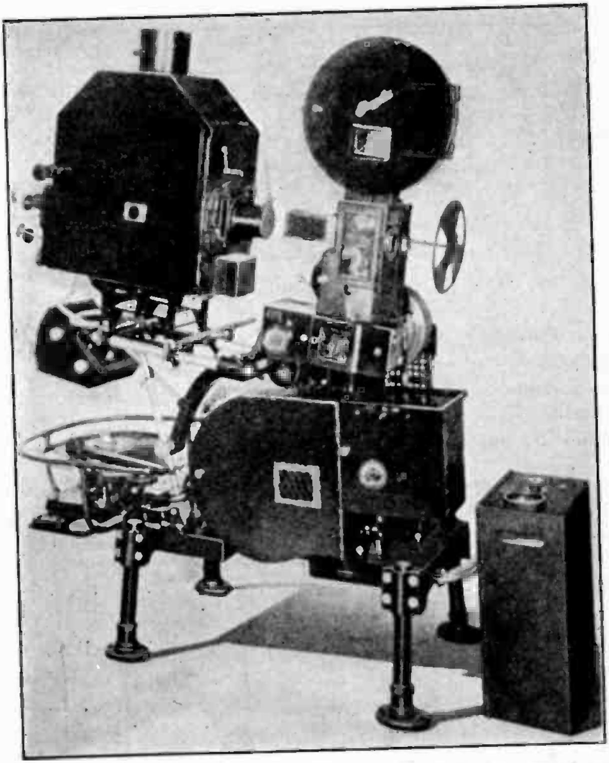

Fig. 25.—Motion-picture projector with attachments for sound records on film.

There is a considerable distance between the point in the motion-picture projector where the picture is shown and the point where the corresponding sound record is illuminated. In fact, in a typical machine the distance between these two points is about 14½ inches. For practical reasons it is not feasible to print the sound record on a film directly beside the picture to which it applies; and if there is this interval of 14½ inches between the accompaniment; and this system will operate satisfactorily for this kind of service. When starting this system, it is necessary that the various units should be *lined up* properly as to phase, as otherwise there will be a local flow of current in the rotor circuits, which will cause the motors to operate as induction motors, so that they will tend to operate at excessive speeds. Under ordinary conditions this system of control is stable, and there is no tendency to hunt or surge in speed.

If the load on any unit of the system is varied, there will be a corresponding variation in phase between this unit and other parts of the system, in the same way as when synchronous motors of the ordinary type are operated. The variation in phase, however, will not exceed 30 electrical degrees or 15 mechanical degrees, and is therefore sufficiently small so that the variation in phase will not produce appreciable effect on the synchronization of the units.

SOUND PROJECTING DEVICES

Sound Projector System for Motion-picture Theaters.—To reproduce in a theater the sounds associated with a series of motion pictures, some equipment must be added to that required for silent motion pictures in order to reduce as much as possible the distortion of sounds and also the resonance of the recording system. In general, it can be stated that two methods can be applied to avoid the harmful effects of resonance in transmitting apparatus. One method is to design each piece of the transmitting equipment so that its period of resonance in vibration (page 11) is outside of the range of the frequencies which are to be transmitted. Another method is to arrange the apparatus for such transmission so that the resonance of vibration due to one piece of the equipment will compensate or equalize the resonance in an opposite direction of some other piece. The first of these methods is not, as a rule, easy to apply; and when it is successfully applied, there is likely to be low sound efficiency. The second method is likely to produce a loss of energy. In both methods it is necessary to provide amplification of the sounds for satisfactory service.

Disk Sound Records.—The records which are obtainable for use on ordinary phonographs are not very much different from the disk records which are used in motion-picture theaters for the sound records, except that they are usually made considerably larger in diameter and operated at a much slower speed so that a single record will play through an entire reel, that is, from 10 to 15 minutes. The sound reproducer used in connection with these records in theaters is somewhat similar to the kind used on acoustic phonographs, the needle holder being connected to a clamped diaphragm. This diaphragm is made of highly tempered spring steel and is fastened to an armature of a special kind of steel having the property of circuits which will produce a torque, tending to make the unit *B* assume the same position as the unit *A*. If, now, the unit *A* is rotated continuously, then the unit *B* will follow it to a synchronous speed of the stator field, at which point the torque will drop to zero, since no electromotive force is induced in the rotor of either machine.

Sound-recording Circuit.—The circuit as shown in Fig. 19 is only a part of the complete *recording* circuit, being merely the electrical equivalent of a mechanical gear for interlocking the cameras with the sound-recording devices. Neither the unit *A* nor the unit *B*, as described in that figure, will rotate as a motor by itself. In order to produce rotation, a *distributor set* is added, as shown in Fig. 20. In this case, the distributor set acts (in a mechanical analogy) like the *driving* gear of the system, and each of the units of the system acts like *driven* gears. The distributor set is operated by the direct-current motor, the speed being controlled by a device similar to the one shown in Fig. 18. The speed of such an arrangement is thus dependent only on that of the direct-current driving motor and is independent of the alternating-current excitation. This system is controlled by the operator when he manipulates the distributor set and the switches, so that any number of cameras, sound-recording machines, or projectors may be thus controlled. Projecting machines are mentioned because it is sometimes desired to make up a sound record to accompany an ordinary silent motion-picture film which has previously been recorded without a sound

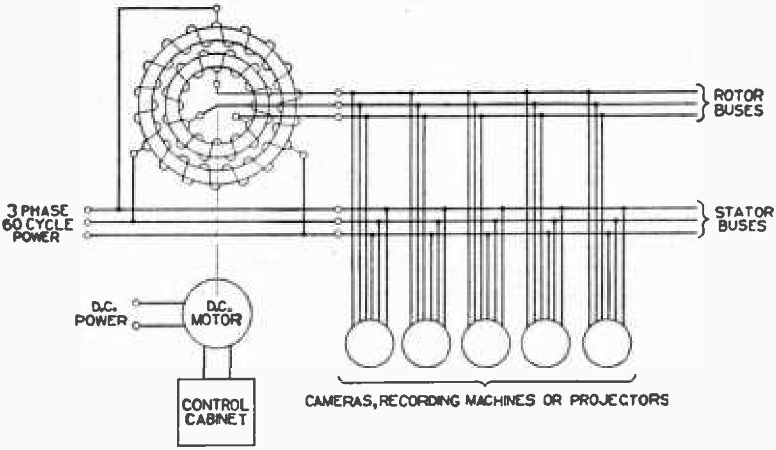

Fig. 20.—Circuit of distributor set.

direct-current motor by a movement of the switch S_1, and then the speed of the motor may be varied with sufficient constancy by means of a field rheostat.

Motor Drive of Recording System.—The simplest method of synchronizing the cameras required for motion pictures and sound records is by a mechanical coupling or connection. For practical reasons, however, it is not desirable to make a permanent mechanical connection. This is because the cameras must be movable. while the sound-recording equipment should be stationary. It has been necessary, therefore, to develop a motor drive equipment which will satisfactorily *interlock* the camera and the sound-recording device, but, at the same time, permit the free movement of the cameras. It is essential that this interlocking should be effective not only during normal conditions of operation but also during acceleration and deceleration of the machines. In other words, the arrangement must be the equivalent of a mechanically geared system. The electrical principle applied for this purpose is not new, as it was included in a patent issued to Michalke in 1901.

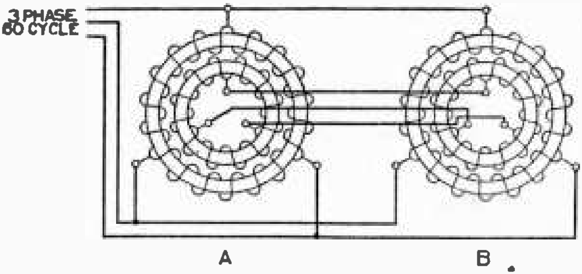

FIG. 19.—Circuit for electrical interlocking of camera motors.

In the electrical system of interlocking to be described, it will be assumed that two units *A* and *B* are to be connected, as shown in Fig. 19, and that each of these two units has a three-phase stator and also a three-phase rotor, the latter being provided with slip rings. The magnetizing current for the system is supplied from an independent three-phase 60-cycle supply. If now the rotors of the two units *A* and *B* are in exactly the same positions with respect to the stators, the electromotive forces produced in them by transformer action will be identical as to voltage and phase. There will be no flow of current, therefore, over the leads connecting the rotors, and no torque will be developed. If, however, the unit *A* is turned through a small angle, then the phase of the electromotive forces produced in the rotor circuits will differ from that in the unit *B* and a current will flow in the rotor therefore weak, so that the motor increases its speed. This condition is maintained until the normal rated speed of the motor is reached. The phase of the voltage supplied to the grid of the tube V_3 then coincides with the phase of the voltage supplied to the plate, so that the grid of this tube becomes positive at the same time that the plate is positive. Under this set of conditions a current will flow through the coupling resistances R_1 and R_2 which will make the grids of the tubes V_1 and V_2 negative, thereby reducing the current through these tubes and maintaining a weak field in the motor. This weak field of the motor causes an increase in speed up to the normal rating. At this point, as already explained in the description of the bridge circuit, the phase of the output suddenly reverses, so that the grid of the detector tube V_4 becomes negative at the same time that the plate becomes positive. This change has the effect of stopping the current through the detector tube V_3 and reducing the negative grid-bias voltage on the grids of the tubes V_1 and V_2. This increases the plate current through the regulating field, increasing the field strength of the motor and checking the rise in its speed. In the practical application of this device, the current through the detector tube V_3 is at neither extreme but reaches an equilibrium condition at approximately the normal rating of speed. A feed-back network having a *delayed action* effect for preventing hunting or surging is included in the same way as explained in the alternating-current control circuit. The characteristic curves for the direct-current motor are similar to those shown in Fig. 16 for the alternating-current motor. For ordinary motion-picture work, the motor as described is changed to a simple shunt

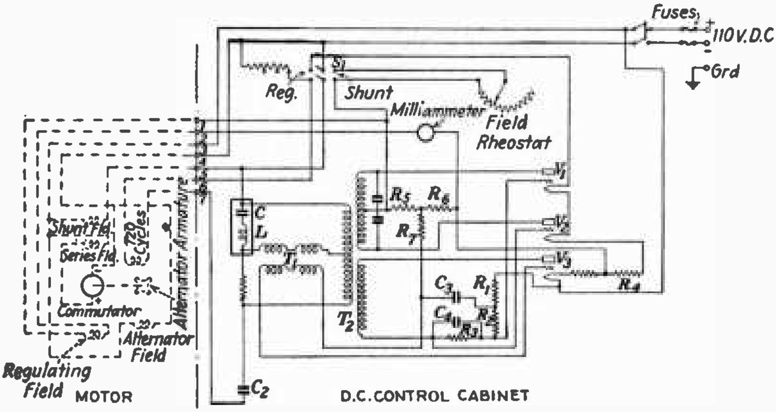

FIG. 18.—Circuit of direct-current speed control device.

nized) pictures. The reason for this is obvious in the case of theaters having an orchestra which is being directed so that its music is "in step" with the motion picture as it is being shown. In this case, it is easier for the orchestra leader to direct his musicians with synchronized pictures than without such speed regulation.

Direct-current Motor Control Circuit.—A direct-current motor circuit very much like the circuit described in the last paragraph may be used for the speed control of motion pictures. A direct-current motor and its control cabinet are shown in Fig. 17, and the corresponding circuit diagram in Fig. 18. The principal difference between this and the alternating-current control circuit is that an auxiliary regulating field winding is used on the motor instead of a variable reactance. The voltage required for the plates of the vacuum tubes is obtained from an auxiliary generator instead of from a transformer. It is a well-known fact that when the field strength of a direct-current motor is increased, its speed is reduced, so that it is necessary to reverse the phase relationship of the transformer T_1 in order that the current in the detector tube V_4 may be decreasing at speeds above the normal rating instead of increasing, as in the case of the alternating-current control circuit.

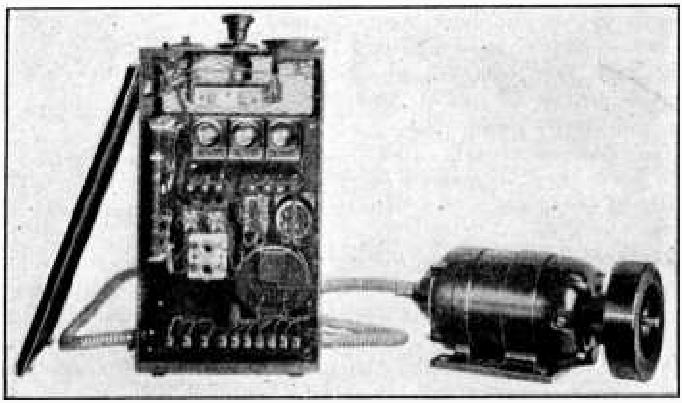

FIG. 17.—Direct-current motor and speed-control cabinet.

In the operation of this equipment, the motor normally acts as an ordinary direct-current shunt motor so that it increases in speed when the switch is closed. At low speeds, the output of the auxiliary alternator is low and, consequently, there is no plate voltage supplied to the tubes, and no current passes through the auxiliary field winding of the motor. This field is of the inductance L_1. In the design of a compensating network for speed regulation, it is necessary to avoid too great sensitivity, as this might produce hunting or surging of the speed. If any type of governor is adjusted to too great sensitivity, the speed will fluctuate up and down, above and below a mean value instead of remaining constant. The simplest method of preventing such fluctuations of speed, therefore, is to make the speed-regulating device less sensitive, permitting, in other words, a greater change in speed, with changes in the load, than there would be with greater sensitivity, and then compensating for this change of speed by means of *delayed-action* devices. This phenomenon is well understood by the designers of mechanical governors. (See "Governors and the Governing of Prime Movers," by Trinks.)

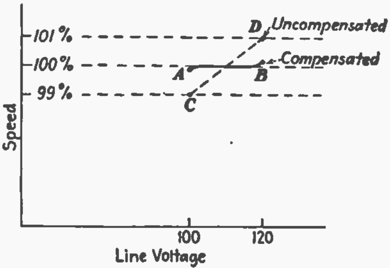

FIG. 16.—Typical speed-control characteristic curve.

The electrical equivalent of the method used to compensate mechanical governors is obtained by introducing the condenser C_2 in series with the high resistance R_4, so that when there is a change in the current through the regulating reactance L_1, the corresponding change in voltage drop is not transmitted to the condenser C_2 immediately, but the change of voltage on the condenser occurs after a certain time lag which is due to the presence of the resistance R_4. The effect of this time lag is to obtain the required precision of the circuit for a flat speed characteristic without any hunting or surging of the speed.

Variable-speed Operation.—The apparatus illustrated in Fig. 15 is intended for constant-speed operation when the switch marked S_1 is turned toward the left, as indicated in the figure. When, however, this switch is turned toward the right, the tuned circuit is disconnected and the grid voltage of the detector tube V_4 is obtained from the potentiometer P_1. By the adjustment of this potentiometer, it is possible to *vary the speed of the motor* from 900 to 1,500 revolutions per minute, corresponding to a film velocity of about 70 to 110 feet per minute. When this equipment is to be used for the so-called "silent" pictures, this variable speed device is satisfactory because speed regulation for this kind of service is not important, and the length of time required to show a reel of film may be adjusted to the time requirements of the program. It is interesting to note, however, in this connection that many motion-picture theaters prefer to use the regulated speed device for ordinary motion pictures as well as for talking (synchrofrom the bridge output circuit through the transformer T_3, and this voltage, as already explained, is subject to sudden reversal of phase, as the speed of the motor passes through the value set for its standard operation. The current flowing through the detector tube V_4 goes also through the coupling resistance R_1, which makes the grids of the tubes V_1 and V_2 of negative polarity, reducing the plate current through the tubes V_1 and V_2, and therefore reducing also the current through the direct-current winding of the inductance L_1, which controls the amount of current in the armature of the motor.

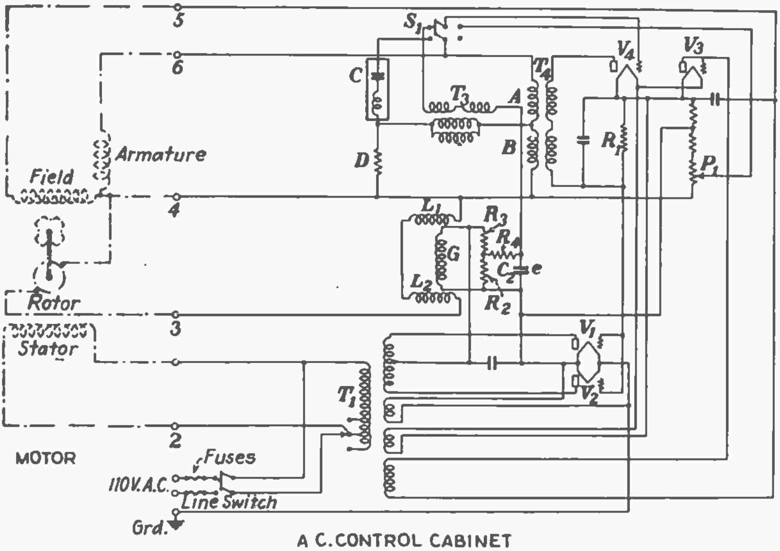

FIG. 15.—Complete speed-control circuit.

A rectifier tube V_3 is used to supply excitation to the field of the auxiliary alternator and also the negative grid-bias voltage of the potentiometer P_1. The speed characteristic of the motor is practically flat, as shown in Fig. 16. A flat characteristic of this kind is obtained by a compensating network consisting of the resistances R_2, R_3, and R_4, together with the condenser C_2. The compensated characteristic is shown in the figure by the line *AB*. Without the use of this compensating network, the speed characteristic of the same motor would be represented by the dotted line *CD*. The effect of this compensating network is to *feed back* to the grid of the tube V_4 a portion of the voltage drop across the direct-current winding which are supplied with alternating current on the two outer legs, and with direct current in the middle leg. By this method of winding, an alternating-current flux circulates around the two outer legs, and a direct-current flux flows from the middle leg and returns in *parallel* through the outer legs. When the direct-current flux is sent through the middle leg, it has the effect of saturating with flux the outer legs and thereby reducing the impedance of the windings on these legs to the flow of alternating current. Alexanderson used a similar device as a magnetic modulator in his early radio work.

One element of the speed-control circuit is shown in Fig. 13. This circuit consists of a somewhat conventional bridge having one variable and three fixed arms. The variable arm comprises a tuned circuit consisting of the inductance L and the capacity C which are designed to tune at exactly the frequency corresponding to the desired motor speed. When this circuit is tuned, it has a resistance impedance which is balanced by the resistance of the fixed arm R of the bridge. The other two fixed arms on the left-hand side are windings of a transformer which has a middle tap. Now, if the voltage as indicated in the figure as $2E_0$ (at a frequency of 720 cycles per second) is supplied to the bridge, the output voltage E_2 will be zero. If, however, the speed of the motor is less than the required value, the tuned circuit will have a condensive reactance, while if the speed is too high, it will have an inductive reactance. The output voltage E_2 will, therefore, change abruptly as the speed varies from a speed below that required to a speed above. These characteristics are shown in Fig. 14. This type of circuit gives accurate results in speed control.

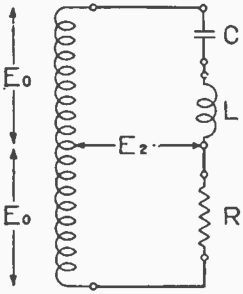

FIG. 13.—Circuit of speed-control device.

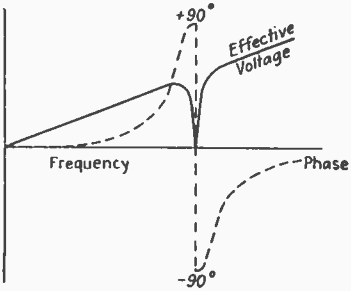

FIG. 14.—Characteristics of speed-control circuit.

The complete control circuit is shown in Fig. 15. The output from the bridge circuit is supplied to the grid of the tube V_4 which is called the "detector" tube. The plate voltage of this tube comes from the 720-cycle generator through the transformer T_4. The grid voltage, however, comes variation than this amount. It happens, however, that it is not unusual to have a voltage variation of 5 per cent above or below the mean value in most cities, with occasional momentary variations of as much as 10 per cent above and below the mean value. In the large cities, however, the frequency variations are practically negligible. In New York City, for example, the frequency variation is not more than one-quarter cycle per second, and the changes are not rapid. In some small power systems, however, it may happen that there is a frequency variation of five cycles above and below the mean value, and in some cases the change is relatively rapid. If the motors of projection machines are not operating with very close speed regulation for even a short time, the usual effect will be to make the music sound as if it were "off pitch," this effect being similar to that observed when a phonograph runs down while in operation.

Motor-control Circuits.—A system of motor control for motors operating with alternating current is shown diagrammatically in Fig. 12. This circuit is intended to be used with a repulsion type of motor which is directly connected to a small auxiliary alternator providing current at a frequency of 720 cycles per second. This auxiliary alternator, through a control device, operates a variable reactance which is located across the terminals of the armature of the motor. This control device operates in such a way that when the speed of the motor is too high, the control circuit produces a maximum impedance in the reactance marked L_1, thereby reducing the armature current of the motor and reducing its speed. On the other hand, when the speed of the motor is too low, the control circuit causes the reactance L_1 to have a minimum of impedance, so that the armature current and also the speed of the motor are increased. The reactance L_1 has windings

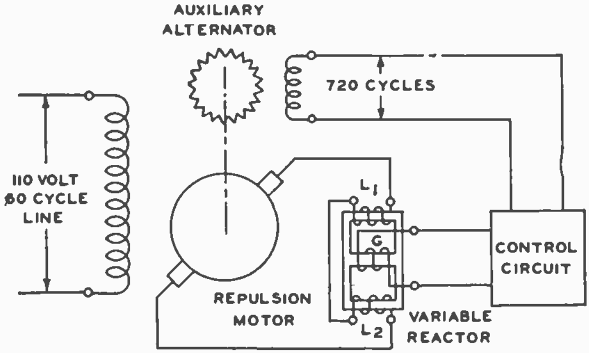

FIG. 12.—Motor-control system.

sound record when the part of the film previously exposed to the picture is masked. The reason for this is that a much greater illumination is required for printing the pictures on the film than when the sound record is similarly transferred.

On the variable-density type of sound track, as made by the Western Electric equipment, the sound record is 14½ inches ahead of the corresponding picture; and the apertures in the recording machines are made so that there is a dark line, called "no man's land," which is 0.017 inch wide between the pictures and the sound record, as shown in Fig. 6. There is also a space of 0.004 inch between the sound record and the inner edge of the perforations.

Synchronization of Sound Record with Motion Pictures.—A number of years ago when Edison was successful in synchronizing motion pictures with his acoustic phonograph, it was necessary to locate the phonograph behind the screen on which the pictures were shown, in order to make the sound appear to come from the picture. Since it was customary to have the motion-picture projector at the other end of the room, it was necessary to operate a system of belts and pulleys running from one end of the theater to the other in order to snychronize the projector in its booth with the phonograph behind the motion-picture screen. The development of the electrical method of sound reproduction to replace the acoustic phonograph made it possible to locate the sound-reproducing mechanism in the projecting booth with direct mechanical coupling between it and the motion-picture projector, electric wires connecting loud-speakers or horns behind the motion-picture screen with the sound-reproducing device. By this direct method of synchronization, it became possible to reproduce sound very simply in exact synchronism with motion pictures. The greatest difficulty encountered in the application of this method was in obtaining a satisfactory speed regulation in the motor of the projector. It was found that speed variations which caused no undesirable effects in pictures might produce very undesirable sound effects, the variations in speed producing, of course, proportional changes in the pitch of the reproduced sounds.

A good musical ear, while having a sense of absolute pitch of only about 3 per cent is extremely sensitive to *sudden changes* in pitch. It has been found that a sudden change of pitch as small as 0.5 per cent may be noticed if the change is made quickly. It is obvious, therefore, that careful attention must be given to speed regulation, so that this variation will not exceed about 0.2 per cent. It is also necessary that the absolute speed be held near the standard requirements, so that when the end of one film is reached, the motion pictures can be continued from another film on another projector with a minimum amount of change of pitch in sound reproduction. It would be relatively easy to accomplish this result if the voltage variation on the lines used for operating the projector motors did not have a greater

A complete rehearsal of the sound picture is made with no film in the recording machine to check the operation of the microphones for sound quality before any recording is done. When it is shown by this checking that the sound quality is satisfactory, the film is loaded into the cameras and the previously synchronized sound recorders are interlocked for taking the "sound picture," the exact time of starting being recorded on the several films by punch marks or light flashes. A light signal from the recording room is used to inform those in the studio that the recording equipment is operating. Then the machine operator starts the cameras and sound recorders, and when the machines are at the proper speed, he again signals the studio that the record is being made. During the time of recording, the mixer operator hears the sound being recorded by monitoring one of the recording machines which is connected to a loud-speaker. It has been found that this procedure is necessary in order to be sure that no sound record is being lost.

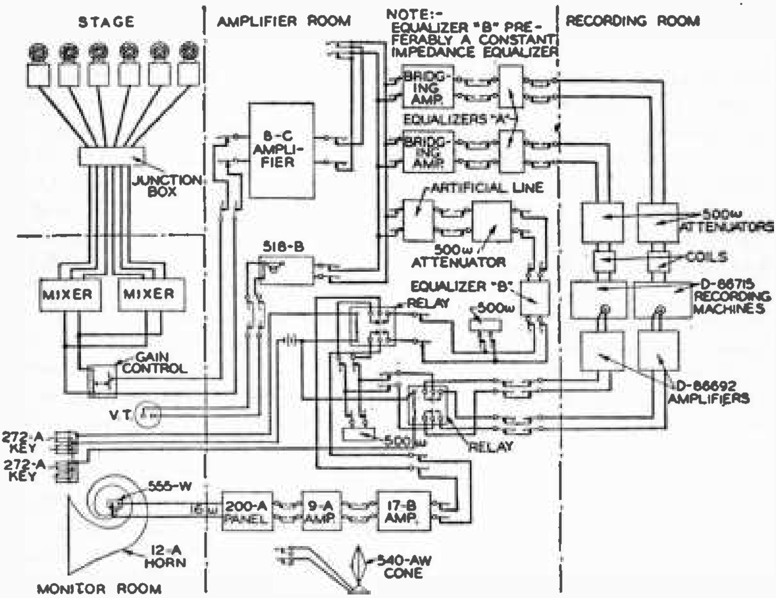

FIG. 11.—Diagram of circuits for sound recording by variable-density method.

In printing on film the sound track in combination with motion pictures, it is customary first to print on the film the picture negative, and later the and the film then passes to the take-up magazine shown in the lower part of the figure. The sprocket wheel of the take-up magazine is driven from the motor shaft through a worm and a worm wheel. The left-hand sprocket wheel is also driven by a worm and worm wheel.

The addition of the sound track to a motion-picture film adds no great complication in obtaining the combined motion picture and sound record. As a rule, a considerable amount of rehearsing is necessary to make sure that there is a satisfactory reception of the sound. In this respect, the placement of the microphone is an important consideration and the amplifiers must be adjusted to vary the light so that the line of light appears clearly on the edge of the sound track on fortissimo passages of music and the loudest conversation of speakers. As the apparatus is arranged in Fig. 10, a photo-electric cell is mounted inside the left-hand sprocket wheel which carries the film past the line of exposure to light. New film which has not been stored for any considerable time transmits about 4 per cent of the light falling on it, and modulation of this light, while the sound record is being made, is made possible by means of the photo-electric cell inside the sprocket wheel, this cell being connected to an auxiliary amplifier which is mounted below the exposure chamber, so that with suitable further amplification the operator of the apparatus may hear from the loud-speaker the sound record as it is actually being recorded on the film. The so-called "full modulation" of the sound record requires the complete closing of the slit by one side of the wave of electric current; and this amount of modulation should not be exceeded for satisfactory photographic results.

The photographic cameras and the sound-recording machines used for making picture and sound records on films are driven by motors which are electrically synchronized from a common distributor. It is customary to make a check of the synchronization of the driving motors at least once every day.

A diagram of the equipment usually required in a studio for sound recording is shown in Fig. 11. In an arrangement of this kind, provision can be made for combining the sound received from several microphones. This combination of sounds is under the control of the so-called "mixer" operator. As shown at the bottom of the figure, relays are provided by which the mixer controls can be connected to the horn or trumpet circuit, either *directly* to the recording amplifier or to one of the *monitoring* photo-electric cells in the film-recording machines. The *direct* connection is preferably used for arranging the location of the microphones in the studio, so that the program may be rehearsed until satisfactory arrangements of microphones and amplifiers are obtained. This equipment is so designed that the sound quality heard in the horns in the studio will be the same as that of the reproduction of sound from the positive print in a theater.

If this apparatus is set up between a source of light and a photographic film, it can be used like the shutter of a camera. The diagram of the optical system for recording light effects by this device is shown in Fig. 9. There is a source of light at the left-hand end of the figure, which is a ribbon-shaped filament in a typical projection lamp, centrally focused on the slit. The light passing through this slit is then focused with a 2:1 reduction on the photographic film at the right-hand side. A simple condensing lens system is used to form the image of the filament of the source of light, but a more complicated lens is required for focusing the image on the film at the right-hand side of the figure. The *undisturbed* or *unmodulated* opening of the slit is 0.001 inch wide and 0.128 inch long, its length being at right angles to the direction of travel of the film. The width of this slit varies with the sound currents, so that the film receives a varying exposure; that is, the *light is of fixed intensity*, and passes through a slit of varying width.

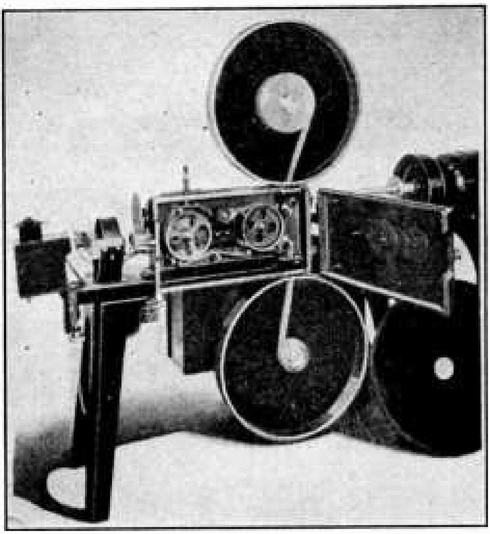

FIG. 10.—Machine for making sound-records on motion-picture film.

A typical studio recording machine is shown in Fig. 10. In this machine, the film travels at 90 feet per minute, and the sound track is made at the edge of the film which is away from the observer. The line of light actually overruns the perforations in the film. The right-hand sprocket wheel is used to draw the film from the feeding magazine which is located above it

A and A', one of which is grounded, are connected to the output terminals of the amplifier in the recording apparatus. When the magnet is energized and the amplifier supplies a sine-wave (page 72) current from an oscillator, the metal loop opens and closes according to the alternations of the current. In other words, one side of a sine wave of electric current opens the slit and the other side of the wave closes it, so that full modulation of the aperture is accomplished. The natural frequency of the mechanism opening and closing the slit is adjusted by varying the tension on the pulley B, the natural frequency being about 7,000 cycles per second. About 10 milliwatts of alternating-current power are required for full modulation at a frequency which has the maximum *difference* from the natural frequency (or resonance), and about one hundredth of this power is required at the resonant frequency (page 80).

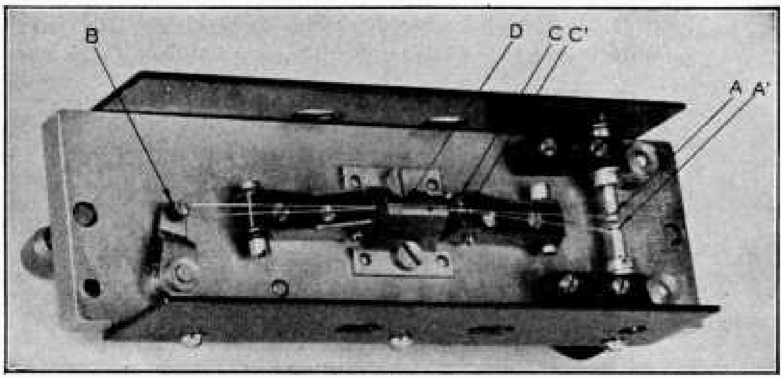

Fig. 8.—Recording apparatus for making variable-density sound record.

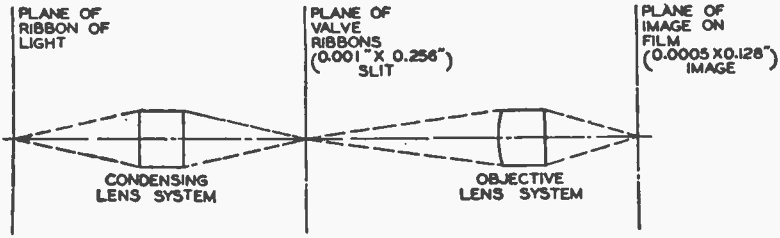

Fig. 9.—Lens system for light effects for variable-density method.

and is very sensitive to light. This is the kind, therefore, which is used in the motion-picture cameras. The other kind called the "positive" emulsion is much less sensitive to light and is used for printing the pictures which are to be distributed for use in projectors showing pictures on a screen. About ten times more positive than negative film is used.

Use of Dyes in Motion-picture Film.—Dyes are used extensively in the manufacture of film for motion-picture work. When only the film base is dyed (for positive film) the pictures as shown on the screen will be tinted over the entire surface with the object of producing a more pleasing effect. When the film base of negative film is dyed, it serves as a color filter and limits the light passing through the film to definite ranges of the color spectrum. Dyes are also sometimes added to the sensitized emulsion of negative film to make it color sensitive. Emulsions sensitized in this way to yellow and green are called "orthochromatic." Other sensitized dyes may be used to give sensitivity to red, and such emulsions are called "panchromatic." Panchromatic motion-picture film came into use about 1927, and at this time a large percentage of all the motion-picture film which is used for negative stock is of the panchromatic kind. For color-photographic processes, the use of this kind of film is necessary and from one to three exposures must be made for negative records, each exposure being made through the proper color filter. Panchromatic film is also used for making pictures which are taken in sunlight but are intended to resemble night exposures.

SOUND RECORDING DEVICES

Making Sound Records of Variable-density Type.—A sound-recording device of the variable-density type including a photo-electric cell as used in the Western Electric system is shown in Fig. 8. Essentially, this device consists of a loop of tough metal tape suspended in a plane at right angles to a magnetic field. This metal tape is attached to two windlasses A and A', and is kept taut by means of a spring attached to the pulley B. At the points C and C' insulated pincers confine the central portion of the tape between the windlasses and the pulley B to form a slit 0.002 inch wide. An irregular piece of metal D supports the loop of tape as well as the necessary adjusting devices and serves also as the armature of an electromagnet. The middle portion of the loop of tape is supported on insulating bridges so that the tape is a short distance above the piece of metal D. At this point, the sides of the loop of tape are centered over an opening which, as viewed from the direction of illumination, appears as a slit 0.002 inch wide. This slit is in a plane at right angles to the lines of force of the magnet and is approximately centered in the air gap of the magnet. The windlasses

The light to which this cell is exposed is, therefore, continually varying with any changes in the intensity of the sound record on the film. With this variable exposure to light, the conductivity of the photo-electric cell changes correspondingly, with similar variations in the current passing through the circuit. The current upon which these variations are impressed is weak and may be strengthened, as shown in Fig. 5, by the use of an amplifier. When the reinforced or amplified current carrying still the same modulations or fluctuations passes on through a circuit including a microphone or, what is the same thing in a slightly different form, a loud-speaker, sounds corresponding accurately to those originally delivered to the microphone and recorded by the apparatus shown in Fig. 1 may be reproduced in sufficient volume to be heard by large or small audiences. More in detail than in Fig. 2 the sound record of the variable-density type is shown in Fig. 6.

A simple illustration of the operation of a photo-electric cell is shown in Fig. 7. As already explained, when a beam of light, as shown in the figure, falls on the photo-electric cell, the pointer of the ammeter in the circuit shows that a current is flowing between the cathode and the anode of the cell, while, if the photo-electric cell is in darkness, the pointer of the ammeter will be at zero.

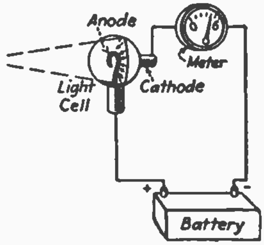

Fig. 7.—Typical circuit of photo-electric cell.

Construction of Motion-picture Film.—The kind of motion-picture film which is so generally in use today is manufactured in two separate layers. One of these layers is a thin translucent film containing light-sensitive silver solutions mixed with gelatine. The other layer is a much thicker but transparent film made of either cellulose nitrate or cellulose acetate. The cellulose acetate transparent film does not burn readily and is, therefore, called "safety film." The motion-picture films to be used in portable projectors should be made of cellulose acetate rather than of cellulose nitrate transparent film. The light-sensitive layer of the motion-picture film is called the "emulsion" and the lower layer is called the "base" or "support."

The light-sensitive layer on the film contains a large proportion of silver. In fact, metallic silver is the active element in the sensitizing layer with which the film is coated. In the process of making the sensitizing emulsion pure silver bars, each weighing about 42 pounds, are dissolved in nitric acid in porcelain dishes, and, after evaporation, pure crystals of silver nitrate are obtained. Motion-picture film is usually coated with either of two grades of emulsions. One of these grades is called the "negative" emulsion

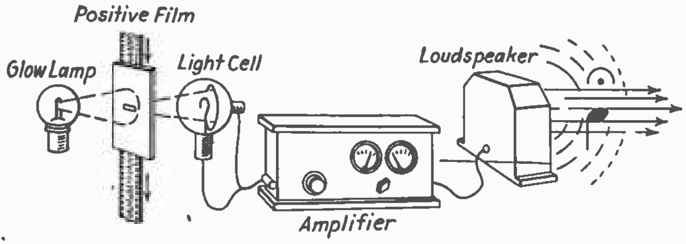

Fig. 5.—Amplifier for use with photo-electric cell and loud-speaker.

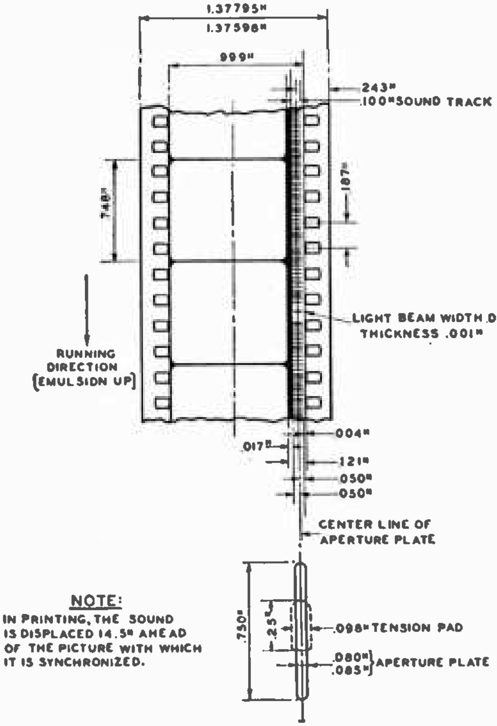

Fig. 6.—Details of variable-density sound record on motion-picture film.

this method of recording is used, a sound record is made which is similar to the one shown in Fig. 2

Variable-width Sound Record.—The second photographic method is different from the first in that the pitch of the sound which is recorded does not produce a variable-density effect as in Fig. 1 but makes instead a *variable-width* or *sawtooth* record as shown in Fig. 3. The apparatus used for this method is essentially the same as that shown in Fig. 1, the only difference being that the device used for making the record of the varying light intensities from the neon-glow tube on the photographic film operates in a slightly different way to produce the sawtooth effect. In this variable-width method the slit for the illumination of the photographic film is exposed to a light of constant intensity; but the length of the *illuminated portion* of the slit varies with the amplitude of the sound to be recorded. A sound of *lowest* pitch corresponds to the highest elevation of the sawtooth record, and the sound of *highest* pitch corresponds to the valley in this kind of record. The combination of the sawtooth sound record with motion pictures on a standard film is shown in Fig. 4.

It is obvious, of course, that the sound of a tuning fork corresponds to a very small series of sound vibrations compared with the much more complicated ones of an orchestra, for example, with all its tones and overtones. The present sound-film devices, however, have the capacity of recording very accurately even such complicated musical structures upon a very narrow portion of the ordinary motion-picture film.

Transformation of Light Record to Sound.—After the sound record has been made on a motion-picture film, a somewhat different device must be used to transform the *light record* on the film to *audible sounds*. In this part of the process, the photo-electric cell (page 677) is used to advantage. A photo-electric cell, which in general appearance is very much like an ordinary vacuum tube, has the unusual property that when this so-called "light cell" is in darkness, the space inside the cell between its cathode and anode has a very high resistance to the flow of electric current through it, and an ammeter placed in the circuit will register a zero current. The moment, however, a ray of light falls on the cathode of the photo-electric cell, this very high resistance between the cathode and the anode is greatly diminished, and this space between the cathode and the anode becomes a fairly good conductor of electric current. In the reproduction of audible sounds from the sound record on a motion-picture film, the photo-electric cell must be used so that the rays from a neon-glow tube may fall upon the photo-electric cell through a narrow slit. In this arrangement, however, the film on which the pictures and the sound record have been made passes between the neon-glow tube and the photo-electric cell; the sound record on the edge of the film thus varying the intensity of light falling on the photo-electric cell.

this case the sound corresponding to the musical note passes through the air as a vibration to the microphone (page 38) shown in the figure, where the sound vibrations cause a modulation or fluctuation of an electric current corresponding to the pitch of the sound coming from the tuning fork. The electric current passing through the microphone is too feeble, however, to be used for a sound record, so this small current is increased in power by an amplifier (page 33). The next step in the process of sound recording is to pass the amplified current, still, of course, corresponding in voltage to the pitch of the sound given off by the tuning fork, to a so-called "neon-glow vacuum tube" (page 701) in which a ray of light is produced corresponding to the voltage of the electric current passing through the microphone, and, consequently, also to the pitch of the sound waves produced by the tuning fork. The arrangements shown in Fig. 1 indicate how the ray of light from the neon-glow tube can be made to fall upon a narrow slot, through which the beam of light can produce a record varying according to its intensity upon the edge of a sensitized motion-picture film. The neon-glow tube is better than an incandescent lamp for this purpose for the reason that its *intensity of light* responds more quickly to any changes in the current passing through the tube; the lower the pitch of the musical note struck by the tuning fork the greater the illumination and, consequently, the greater the intensity of the light record produced on the motion-picture film. When

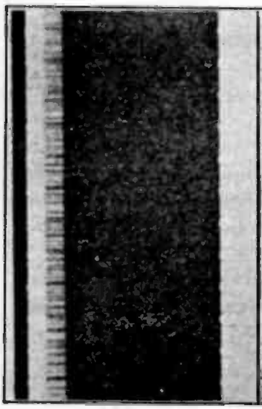

FIG. 2.—Sound record made by variable-density method.

FIG. 3.—Sound record made by variable-width method.

FIG. 4.—Sound record on edge of motion-picture film.

SECTION XVI

SOUND MOTION PICTURES

Methods of Making "Talking" Pictures.—The methods used for producing the sound records and pictures going with *talking* motion pictures consist of two separate parts: (1) the silent motion picture and (2) the record of the sounds accompanying the picture as it was produced. For the reproduction of sound at the same time that the silent motion picture is being shown it is only necessary to synchronize the movement of the sound record with the operation of the projector used to show the motion picture.

The really successful applications of sound motion pictures are those based on a photographic process by which rays of light are used to record on the film showing the pictures the vibrations of sounds which were recorded at the same time that the pictures were made.

Variable-density Sound Record.—There are two *photographic* methods for recording sound on motion picture films. These are called, respectively, the "variable-width" and the "variable-density" or "bar" methods. In the latter method a narrow slit of *light* is focused on the moving photographic film and the amount of *light* passing through the slit is varied according to the amplitude of the *sound* to be recorded. A simple device for operating this method is shown in Fig. 1, which illustrates the making of a sound record corresponding to the musical note of a tuning fork. In

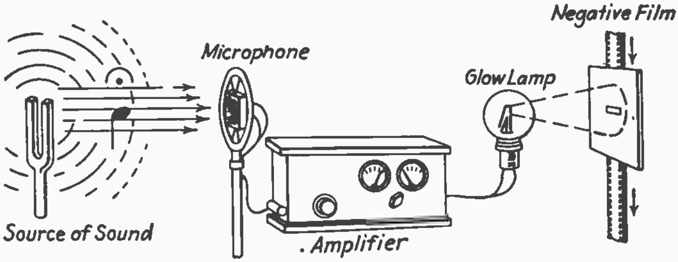

FIG. 1.—Device for making sound record of tuning-fork note.

in the pilot's cockpit, includes the following: (1) "on-off" switch; (2) volume control; (3) tuning control with calibrated dial; (4) filament control jack.

All engraving which it is necessary to see in the dark is filled with a luminous paint. The dial is provided with a set of stops which may be set to limit the tuning range. Two adjustable dial pointers are also provided which can be used for marking tuning points of interest. The mechanical layout of the remote-control box is arranged so that it can be easily mounted. The connecting link between the remote-control knob and the receiver is a flexible-steel shaft and casing. This shaft can be successfully employed in lengths up to 30 feet. The electrical connections between the receiver, shielded battery, and remote-control box are made through plug-and-jack connections and a special shielded seven-conductor cable.

The approximate weights of the various units are as follows: receiver, 16 pounds; remote-control box, including control gears and electrical plug, 3 pounds; shielded battery, including electrical plug, 14 pounds; metal-pole antenna, 4 pounds; electrical cable and mechanical cable, 2½ ounces per foot.

The volume-control arrangement to adjust the overall gain is a potentiometer control of the screen-grid voltage. This makes possible a wide range of volume control. The receiver is designed for operation with a small vertical antenna extending above the fuselage, of the kind usually called a "pole" antenna. This is coupled to the first tuned circuit through a small series condenser incorporated in the antenna binding post. Six feet of antenna above the fuselage of the aircraft is sufficient.

The following voltages are required: filament or A-battery supply, plus 6 volts; plate or B-battery supply, plus 45 volts and plus 135 volts; grid-bias or C-battery supply, minus 1.5, minus 3, and minus 9 or minus 27 volts (depending on whether a UX-112A or a UX-171A output tube is used). The filament supply for the receiver is normally obtained from the aircraft 12-volt landing-light storage battery. A suitable series resistance or ballast lamp is provided for use between the landing-light battery and the receiver. The total filament current for the receiver is 1.25 amperes. The total plate current, when using the UX-112A tube, is approximately 10 milliamperes and when using the UX-171A tube is approximately 20 milliamperes. The useful life of the B battery in this receiver is prolonged by a small filter system between the plate-supply terminal and the B battery. This filter is an integral part of the receiver and, in addition to increasing the number of hours that the B battery can be used, makes it possible to utilize a source of power which is inherently of high resistance, such as a dynamotor (page 237).

The receiver unit is arranged for mounting on two rigidly connected U-frames which form a cradle for it. Special rectangular cups filled with sponge rubber form the support between the U-frame and the receiver to dampen vibrations and landing shocks. The receiver unit is locked to the mounting frame by lateral catches which secure the feet of the rectangular cups. The electrical and tuning control connections to the receiver are made through plug-and-jack combinations. This arrangement facilitates installation or removal of the receiver from the mounting frame, thereby making possible quick and efficient maintenance. This feature is extremely important, as it would be difficult to service the receiver efficiently when mounted in the aircraft on account of the inaccessibility of the space usually available for the receiver. A shielded B and C battery is a part of each complete equipment and this battery is provided with a multipoint, jack-and-plug combination, through which the proper voltages are carried to the receiver.

The space available in present-day aircraft for radio apparatus is usually small and inaccessible. This being the case, it is essential to install radio receiving equipment which can be supplied with a reliable and practical *remote-control arrangement*. The remote-control box, arranged for mounting band wide enough to pass good speech. A gang condenser (page 419) is used for the four tuned circuits, making possible a single continuously variable tuning control. The frequency range of the receiver is 500 to 270 kilocycles (600 to 1,100 meters), which covers the established intermediate-frequency marine stations, as well as the aircraft weather and beacon service.

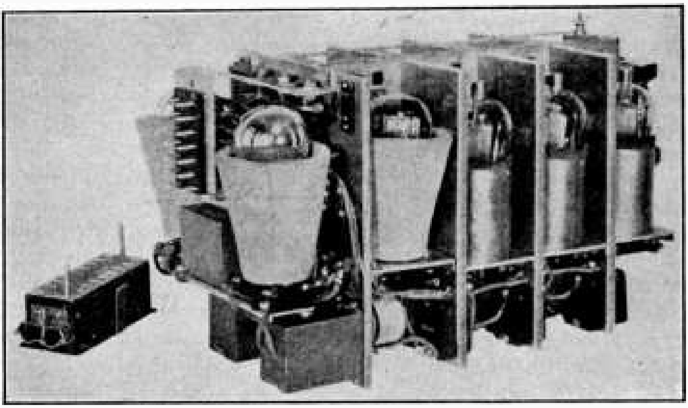

Fig. 54.—Apparatus with casing removed.

The plate-rectification type of detector used permits a maximum degree of sensitivity with a minimum of distortion. The resistance-coupling method is used between the detector and the audio-frequency tubes. An output transformer is provided between the output tube and the head phones or indicating instruments. The type of radio range beacon transmitter in use at present is the so-called *aural type* using modulation frequencies between 500 and 1,000 cycles. Future plans contemplate the use of radio range transmitters of the visual type which will necessitate the use of modulation frequencies between 30 and 120 cycles. The output transformer has a step-down ratio which provides an efficient match for the audio-frequency wiring installation used on aircraft. The transformer is designed to match circuits having an impedance between 600 and 1,400 ohms. The output circuit is arranged for either a UX-112A or a UX-171A tube. The UX-171A tube will provide a greater undistorted output and minimizes "blocking" effects.

The overall voltage amplification will vary between 1,000,000 and 7,000,000, depending on the input voltage and the output load characteristics along the airways for the purpose of furnishing weather information and other news of vital interest to aircraft. If aircraft operating along the radio-equipped airways are furnished with such beacon receivers, both radio beacon service and weather information will be available. This equipment is also useful for long-distance flights over water, which require radio communication with the existing intermediate-frequency marine shore stations.

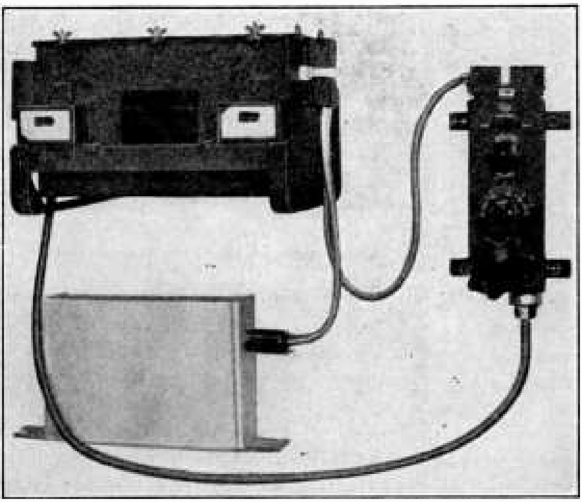

Fig. 53.—Receiver, remote control, shielded battery, and cables of beacon receiver.

The circuit arrangement of the R.C.A. beacon receiver consists of three stages of tuned radio-frequency amplification (four tuned circuits), a detector arranged for plate rectification, and two stages of audio-frequency amplification. The radio-frequency stages use UX-222 screen-grid tubes, a UX-240 tube is used as a detector, and a UX-240 tube is placed in the first stage of the audio-frequency amplification, with either a UX-112A or a UX-171A tube as the second-stage audio-frequency or output tube. The circuit layout is arranged for modulated signals, no provision being made to receive signals from continuous-wave transmitters. The complete receiving set is shown in Fig. 53 and the chassis in Fig. 54.

Tuned impedance coupling is used between the UX-222 tubes. This arrangement makes possible four tuned circuits with an overall degree of selectivity which reduces interference to a minimum and still allows a heterodyne principle, meaning that the intensity of the received beat frequency depends on the product of the intensities of the two impressed oscillations. It is possible, then, to arrange two loop systems or other directive radiations so that their maxima and minima intensities are displaced in space. An arrangement of two crossed loops energized with high-frequency current differing in frequency by 1,000 cycles, for example, yields a space distribution of the heterodyne beat intensity of 1,000 cycles, as shown in Fig. 52. The reason for the occurrence of two minima is that the received signal is proportional to the product of the two intensities, so that if either is reduced to zero their product will be zero. One of the prime requirements of this arrangement is that the two directive systems must not be coupled in any manner. For use in a rotating beacon the double sharp-zero signal on either side of a narrow range is precisely the type of variation that is most suitable. The procedure with this type of rotating beacon is to send out a non-directional timing signal when the maximum sharp signal is directed toward the north. At this instant the directive system is rotated clockwise at such a speed that it makes one revolution per minute. The observer starts a stop watch or other device on hearing the timing signal and then listens for the first sharp maximum signal, at which time he stops the watch. The angle through which the hand has moved gives the azimuth of the observer from the transmitter. This may be in error by 180 degrees, so that it is necessary to know the general direction of the station from the observer. This chance for error may be eliminated by combining an antenna with each loop.

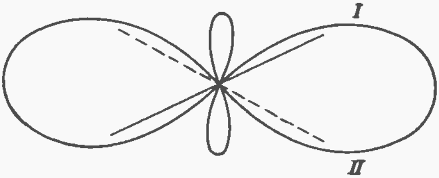

FIG. 52.—Space distribution of 1,000-cycle beat note.

Aircraft Beacon Receiver.—The aircraft beacon receiver, R.C.A. model AR-1286, is primarily intended for use on aircraft in conjunction with the U. S. radio range beacon transmitters which are being installed along all authorized mail airways. Working in conjunction with these transmitters, this receiver, when properly installed on aircraft, provides an accurate means of following the airway. The usefulness of a beacon receiver equipment under adverse weather conditions is well known.

In addition to radio range transmitters, the airways division of the U. S. Department of Commerce provides radio broadcast telephone transmitters two loops usually make an angle of about 135 degrees with each other. They may be mounted so that one is on each wing, the leading edge usually being outward in order to avoid ignition difficulties. The electrical connections are given in Fig. 51. The two loops are tuned simultaneously to the incoming wave by the variable condenser. Each loop supplies a radio-frequency amplifier which is in turn connected to a bridge arrangement. The rectification of the high-frequency current is made to control the plate current of the bridge tubes. An inspection of the arrangement shows that both loops are operating well off their maximum positions. When the plane is pointing toward the transmitter, a swing toward the left increases the voltage impressed on the right-hand coil and decreases the voltage impressed on the left-hand coil. This shift causes the balance on the bridge to be disturbed, and the appropriate indication takes place. Ignition difficulties may occur with this type of installation, but, if the airplane structure permits, the angle of the loops with respect to the framework can be so shifted that the source of ignition interference can be located in the minimum position of the loop. This reduces the interference materially and still leaves a strong signal for the forward direction.

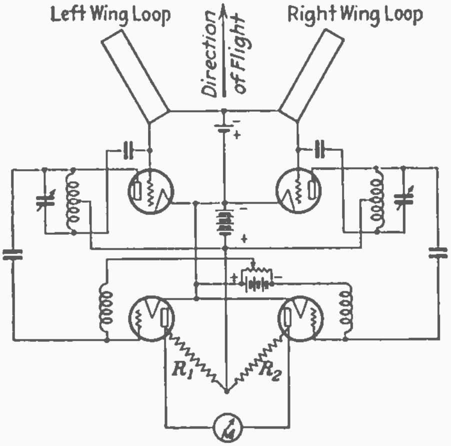

FIG. 51.—Circuit of homing system.

The two general systems just described appear to be the most promising for general usage and development. Should greater necessity for radio navigation arise and numerous rotating beacons be located at suitable points so that positions could be obtained by simple triangulation, then there is a third system which deserves consideration. This system depends on the by the audio-frequency amplifier. This output goes to the two tuned coupling units which have a selective-frequency action and impress an alternating current on the grids of the bridge tubes, the amplitude of this current depending on the amplitude of the "received" modulation frequencies. On the equisignal zone the potentials impressed on the grids of the bridge tubes are substantially the same, and the balance of the bridge is undisturbed if the two tubes have the same characteristics. If, however, one modulated frequency becomes greater in amplitude than the other, the voltages on the grids change and the bridge is unbalanced. This causes the indicator to move one way, and if the other modulated frequency predominates the bridge will be unbalanced the other way, causing a reverse deflection. The indicator can be arranged, therefore, to indicate by a middle position when the airplane is on its course; and right or left, when it is off its course, to right or left. The situation is reversed going way from the beacon. The system may be extended to a red-, white-, and green-light system by the addition of a few contacts to the indicator; or it can be made to operate the rudder. The advantage of this new system is that the additional equipment is light, rugged, and sensitive. When a moderately large power input is available, it compares favorably in range with the aural methods. This system can be extended to the case of a rotating equisignal device, and the time from a non-directional reference signal to the time that the indicator goes through zero gives the azimuth of the plane from the station, provided the period of rotation is known.

The beacon system is exceptionally simple in operation in the aircraft and the ground equipment is also relatively simple, requiring no special attention. Tests of the Bureau of Standards show that at night the equisignal zone over mountainous country may be erratic. This is unfortunate but there is reason to believe that such variations are very small over level country and over water.

A *homing indicator* has been developed which serves only as an indicator to keep aircraft headed toward some fixed non-directive radio station such as a broadcast station when the indications of the meter are followed. By listening to the receiver, the pilot can hear the broadcasting from a station located in the city to which he wishes to fly. The indicator will then guide him toward the station selected. This system in common with the radio beacon not only tells the pilot when he is headed for his goal but also tells him which way he is off his course. This latter consideration is of some importance, since constantly swinging a plane to determine which side of a minimum or maximum he is flying is troublesome, and few pilots will want to do this extra work unless they are actually lost.

The homing system makes use of two crossed loops or other directional absorbers working into a double amplifier and bridge arrangement. The some other low audio frequency, which is not too near the original frequency and not a harmonic of it. On the aircraft a simple non-oscillating receiver is used, and the amplifiers of the receiver are connected in series to two audio-tuned coupling units. The secondary coils of these coupling units are attached to the grids of two vacuum tubes incorporated into a bridge circuit as shown in Fig. 50. The indicator M is a sensitive direct-current micro-ammeter with a zero center. To operate the device the antenna is disconnected and the bridge is properly balanced, bringing the indicating microammeter to the center of the scale. This is done by properly adjusting the grid-bias voltage of the "bridge" tubes. This voltage is usually maintained quite high, since the deflection of the indicator depends on the curvature of the characteristic at the point of operation, when an alternating current is applied to the grid. The operation of the system is as follows: The high-frequency carrier wave is received and rectified by the detector as usual, and the alternating-current modulation frequencies are then amplified,

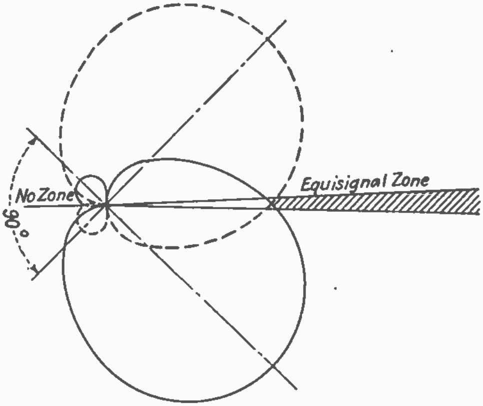

FIG. 49.—Effect of shifting angle of directive systems.

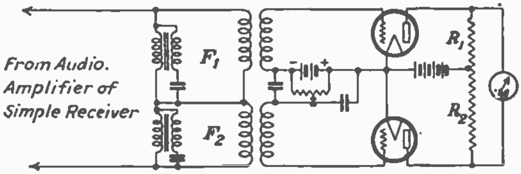

FIG. 50.—Audio-frequency selector and bridge circuit.

is indicated in Fig. 48. It will be observed that there are four equisignal zones, two being very broad zones and two narrow, useful ones. The selection of 135 degrees as the angle between the loops is a compromise between a narrow equisignal zone and a strong signal. The nearer the equisignal zone is worked to the minimum of the loop the sharper the signal, the result of an excessively sharp zone being a weak signal.

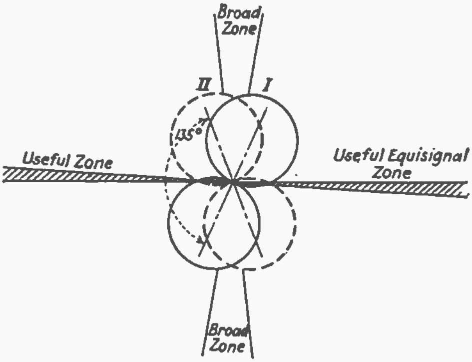

FIG. 48.—Polar energy-distribution curve.

The loops used on the Hawaiian flights were effective at an angle of 120 degrees and the width of the equisignal zone was reported to be 3½ miles in midocean using a 2-kilowatt tube transmitter. The sharp zone at 1,000 miles making use of a 120-degree angle was most remarkable and may be attributed for the most part to the use of continuous-wave transmission and a heterodyne receiver which would be expected to sharpen the equisignal zone. Unfortunately, these systems are bi-directional and an 180-degree error is possible. This difficulty has been overcome by combining an antenna effect with the loop effect and shifting the angle of the two directive systems so that they are approximately 90 instead of 135 degrees apart. This is shown clearly in Fig. 49 and offers many advantages. A system of this type has been tried out which was capable of rotation and it proved to be a possible and practical extension of the usual equisignal method.

Any of the systems just discussed may be adapted to visual indicators in place of aural devices. Some sacrifice in range must be expected, since the operation of the device near the noise and ignition level will be more erratic than the human ear. In one such indicator the transmitter is so modified that a directional radiator is supplied with modulated high-frequency waves of some convenient low audible frequency. The companion directional radiator is supplied with high-frequency modulated waves at quency, and a moderate hearing power only is necessary. This method depends on the physiological fact that the human ear is able to judge with great accuracy the equality of intensity of two similar tones when they are sounded successively and close together. The signals are arranged so that they interlock, and when there is exact equality of the two signals, one continuous signal or dash is heard. In case the intensity of one signal is stronger than the other, its characteristic code letter is distinguished against the weaker. The predominance of one or the other informs the pilot as to which way he should bear to keep his ship on its course. To accomplish this result two directive systems, usually simple-coil antennas, are arranged in such a manner that the predetermined aircraft course lies along the radius vector of the polar energy-distribution curve where the change in intensity changes rapidly with angle. This statement is made clearer with the help of Fig. 46.

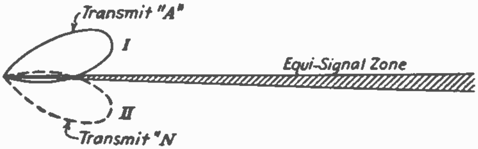

FIG. 46.—Layout of equisignal zone.

One directive system radiates energy into space as indicated by the solid polar curve. Another transmitter is adjusted to radiate as indicated by the dotted curve. A plane flying across the radius vector as shown would hear signals as indicated in Fig. 47. As the ship proceeds, the signal from the system I increases through a maximum and drops off; in the meantime the system II is increasing and there will be some point E where the intensity of the received signals will be equal. This region is known as the *equisignal zone* and is usually very narrow.

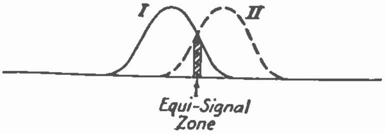

FIG. 47.—Signal observed on airplane when perpendicular to vector in Fig. 46.

At frequencies available for beacon work in this country an energy-distribution curve of the type shown in Fig. 46 is next to impossible. A simple loop system in which each loop makes an angle of 135 degrees with the other is satisfactory for many purposes. An installation of this type using two loops 60 by 240 feet and operating at 300 kilocycles has been found quite effective. In this installation using aural reception and a spark transmitter the width of the useful equisignal zone at 20 miles was but 75 feet, while at 200 miles it was 3 miles. A polar energy-distribution curve for this system wires do not solve the difficulty, since the "pulse" sent out by the magneto excites any oscillating circuit in the vicinity and acts much like static.

It often happens that ignition installations which, to all appearances, should produce much interference are comparatively quiet, while others which should be good are noisy. In some cases interference or excessive static clicks have been traced to true static sparks on the airplane caused by the charging of the framework due to the ionized exhaust gases. The electrical "noise level" and engine din on an aircraft in the average unshielded installation is so high that ordinary static is very seldom troublesome, and no signal less than approximately one volt applied to the phones can be heard continuously. Few static clicks exceed this limit unless the plane is very near the storm through which it is passing. The real limitation on reception at the present time, therefore, is that imposed by the ignition system. When continuous-wave or interrupted-continuous-wave transmission of a definitely determined frequency is used, a method of reducing the interference by the use of a tuned audio-frequency stage has been successful. The audio-frequency stage will respond to the audio-frequency heterodyne beat note or the modulation frequency. Any single "pulse" from the magneto will not communicate sufficient energy to the audio-frequency oscillating circuit to excite the tuned stage into oscillation, but a series of pulses of the correct frequency (the incoming signal) will set it in oscillation. Thus, the signal due to the ignition can be made small while the incoming signal may be maintained. Care must be used to keep the regeneration to a point where the audio-frequency amplifier will not "ring," for in some cases transmission may be delayed by the persistance of the signal. An improved electromechanical coupling device has been used recently which includes a tuned reed. A coupling unit of this kind may be made very selective to frequency changes without the attendant difficulties of electric instability. These units have largely replaced the electrically tuned transformers shown in the diagrams in Fig. 45 illustrating this method.

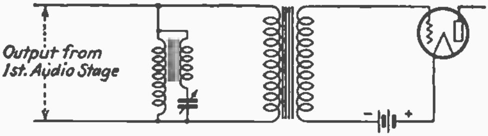

FIG. 45.—Tuned audio-frequency stage.

One of the most valuable uses of radio on aircraft is for direction and course finding. The simple-coil radio compass and its modified form, the Bellini Tosi, have been successfully used on land and on ships. The radio beacon may be simply a non-oscillating receiver tuned to the beacon fre-

This difficulty has led to the rather wide adoption of interrupted continuous-wave (I.C.W.) transmission on aircraft, since some periodic detuning is permissible. The reason for this procedure is not fundamental, since the difficulty may easily be eliminated in the transmitter by the use of a master oscillator operating with a properly balanced power amplifier. A correct balance of the power amplifier ensures no reaction of the plate or output circuit on the grid or master-oscillator circuit. The difficulty in the receiver is overcome by the use of a coupling tube which effectively removes the reaction of the antenna on the local oscillator. There is no outstanding difficulty in the way of proper antenna installation but the antenna reel should be placed so that there is little localized capacity between these elements and the frame of the ship.

The peculiar physical arrangement of the trailing-wire antenna in conjunction with the metal parts of the ship used as a counterpoise gives rise to certain directional characteristics. In general, transmission and reception are accomplished most easily in a forward direction, whereas if a radio compass bearing be taken on an aircraft flying at high altitude the apparent bearing is to the rear of the true plane position. This deviation is unimportant so long as the aircraft altitude is less than 2,000 feet and may be corrected at higher altitudes.

Air fans for driving radio generators are now available that have excellent regulation and load characteristics, but these are usually attached to a generator far larger than the size that is necessary. An air-driven generator as used on airplanes operates in a blast of cold air traveling at least 80 miles per hour, and since the rating of a machine is limited only by the amount of heat that can be dissipated, it would appear that if suitable ventilating ducts were provided the power output per pound of the present generators could be quadrupled. Air-driven generators offer the advantage of operating in a glide, if the engine should fail; but for every pound of head resistance offered by a generator fan, about 7 pounds is lost in pay load, so that even in a small installation the loss in pay load may amount to 60 pounds. By directly connecting the generator to the engine the advantage of radio operation during gliding periods is lost; but the head resistance is reduced to a negligible amount and the pay load is reduced only by the weight of the generator. The transmitter and the receiver must be light, rugged, small in size, efficient, practically vibrationless, and without appreciable effect of the swinging antenna on the frequency of the transmitter or receiver.

Interference from the ignition apparatus is a serious difficulty and, being *continuous*, is especially important. Sometimes it is so great that the tubes are partially paralyzed. No simple solution is possible except that of the complete shielding of magnetos, leads, and plugs (including the switch leads from the magneto). Devices intended to suppress oscillations in the lead loops has another very advantageous effect in that it sharpens the course to a considerable degree. By referring to Fig. 39, it is seen that since the intersection of the smaller figure of eight is at the point of the most rapid change of the large figure of eight, the resulting course is quite sharp. By measurement the courses have been found to be approximately 3 degrees wide. This is much sharper than the usual course resulting from a 90-degree separation of the primary coils of the goniometer.

One other modification of the system is possible. When using a vertical-wire antenna it may be keyed by a relay in the same circuit as the primary coils of the goniometer. The result of this is to affect only one phantom loop and thus shift both the 90- and the 180-degree courses. With these three means at hand it becomes a relatively simple matter to satisfy almost any requirement where the number of courses to be served does not exceed three, and also a great number of four-course air terminals. The adjustments are not so critical as to be unstable, and, once made, they remain indefinitely.

Antenna System for Aircraft Radio.—The preferred antenna on aircraft has been the so-called "trailing-wire antenna." The advantage claimed for this type over the fixed antenna is that the antenna resistance is for the most part radiation resistance and the length of the antenna is readily changed by reeling the antenna in or out, thus tuning this system and making it possible to eliminate one tuned circuit in the transmitter. When a trailing antenna is used the metal framework of the aircraft serves usually as the counterpoise or "ground." For this service all the metal parts of the ship must be bonded together and conductors must be provided throughout the wing sections if they are made of wood and fabric. It is necessary to install the bonding well and carefully in order to secure the greatest possible effectiveness of the antenna system. Adequate bonding is one of the best safeguards against fire, since it prevents sparking at points where gasoline vapor is liable to be found. The gases discharged from the exhaust of the engine are highly charged, so the aircraft is constantly accumulating a charge of opposite sign to that of the exhaust gases which on contact with a properly charged cloud may cause small sparks which make their presence known by a peculiar type of "static."

One of the major disadvantages of the trailing-wire antenna has been that it constantly swings and thus its apparent capacity changes constantly. In the earlier days of spark transmission systems this constant swinging was not a problem, but with the advent of continuous-wave (C.W.) transmission it has become a real difficulty. If a self-oscillating transmitter or receiver is used which is coupled directly to the antenna, it is obvious that a shift in antenna capacity (due to swinging) will alter the frequency of the oscillator, thus shifting the beat note and making it almost impossible to read.

of the amount of shift was then achieved and displacements of 28 degrees were obtained. The final adjustment was made by controlling the amount of the antenna coupling. The antenna must, of course, be in tune to prevent dephasing; and, consequently, detuning will not accomplish the desired result.

It was also necessary to have an accurate knowledge of the amount of shift in order that the course might be properly oriented. For first adjustments a receiving set using a 6-foot vertical antenna was amounted in a truck and driven around the loops at a distance of about 100 yards from the base of the tower. Readings were very sharp at this distance and the 14-degree bend was easily checked. By locating landmarks from compass bearings it was possible to align the course with the airways.

In order to secure the observed field-intensity patterns shown in the figures, the same receiving set was employed with its vertical-pole antenna. The output was connected to a calibrated thermo-element and the signal intensity was adjusted to keep the tubes under saturation at all times. In employing the vertical-wire antenna for distorting the pattern, the receiving set was stationary and the goniometer was rotated through 360 degrees. With the series-resistance method, the set was moved around the beacon tower.

For a further check the truck was taken to Snowshoe Junction, Pa., to the west and to Aaronsburg, Pa., to the east, these towns being, respectively, 10 and 20 miles from the radio range. The readings at these places checked with those taken at the beacon tower to within half a degree, which is well within the accuracy of measurement. As a final check, the course was flown over, and again the readings were checked with those taken at the beacon tower. An accuracy of one degree may be expected from measurements made at the beacon tower in spite of the predominating induction field.

Besides being the eastern terminus of the Transcontinental Airway, Hadley Field has two other air lines entering it. Hartford to the north and Washington to the south need to be served by the same radio range. Washington and Hartford lie in a straight line through Hadley Field, but the course to the west is not at 90 degrees to the line joining Hartford and Washington. This presented an opportunity to use the first method described, namely, that of inserting a resistance in the link circuit of one of the primary coils of the goniometer, which has the effect of shifting the 90-degree courses. It was found that when the current in one primary coil of the goniometer was approximately one-half the value of the other, the courses were shifted the desired amount. The primary coils of the goniometer were adjusted to 90 degrees in order that the courses might be of equal power. This change in relative field intensity of the two phantom

In some beacon systems the primary coils of the goniometer are at an angle of 120 degrees, so that a narrow course may be obtained; but when means are employed to "bend" the course, this method does not give good results, as there is the danger that one lobe may move so far as to intersect the adjacent lobe on the wrong portion of its contour, as will be seen in Fig. 43. In this case, four courses are available, as far as the ear can detect, but as the lobe decreases the course will not shift properly and is not sharp enough to be used. A picture of the complete installation for this service at Hadley Field, New Brunswick, N. J., is shown in Fig. 44. The airway route through Bellefonte, Pa., has a 14-degree bend at Bellefonte, and, consequently, the antenna-effect method is used. For this service, a vertical-wire antenna was installed on the tower of the radio range and this was tuned to resonance by using a suitable inductance in series. The circuit was of sufficiently high resistance to have a broad resonance curve. This antenna was at first excited by coupling it to a master oscillator; but the results from this method were poor, and a careful analysis showed that a pronounced phase shift occurred between the master oscillator and the goniometer, due to the kind of coupling circuits that were used. To eliminate this difficulty, a coupling coil was inserted in the common primary circuit of the goniometer, and the antenna was coupled to it. Excellent control

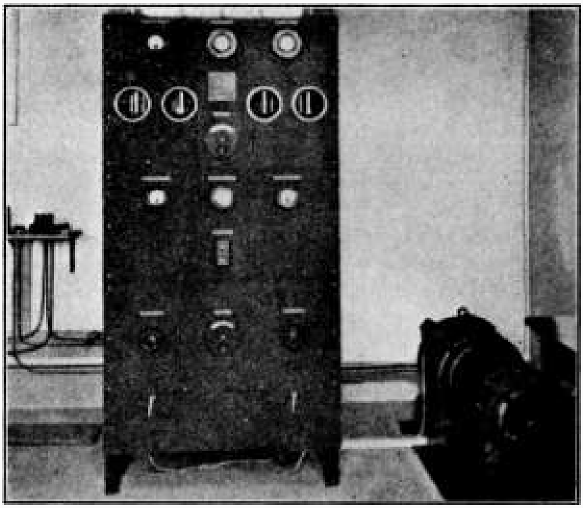

FIG. 44.—Typical radio range installation.

Equisignal Beacons (*Jour. Soc. Automotive Eng.*, 19, p. 209, September, 1926).

Since the normal polar pattern of crossed-loop antennas is a pair of figures of eight at 90 degrees, there are four equisignal zones (Fig. 40) which are referred to as "courses" in radio beacon work. In order to increase the sharpness of the course, the primary coils of the goniometer are frequently set at 120 instead of 90 degrees. This gives four courses, two of which are about 3 degrees wide, while the remaining two are 12 degrees wide, as shown in Fig. 38.

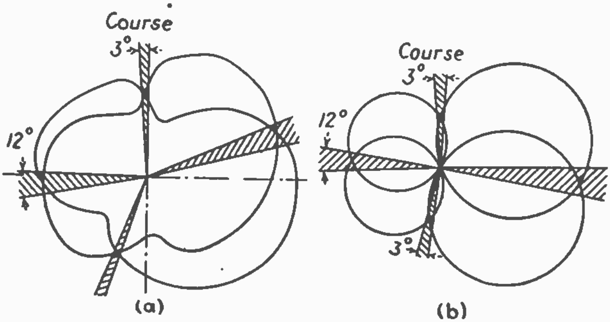

FIG. 42.—Field intensity of radio range with vertical antenna in addition to loops, goniometer primaries at 120 degrees; (*a*) observed; (*b*) theoretical.

If a vertical wire is now permitted to radiate in time phase with the radiation from the phantom-loop antenna, the field-intensity pattern will be distorted as shown in Figs. 41 and 42. It will be noted that two lobes diminish and two increase. This changes the relative position of the equisignal zones so that the course approaching the beacon is not 180 degrees from the one leaving. The amount of this shifting of the angle may be controlled by adjusting the magnitude of the current in the vertical wire. This shift is limited only by the disappearance of two of the lobes forming two cardioid patterns at right angles, thus giving two equisignal zones displaced 180 degrees from each other, instead of four such zones which are displaced at various angles.

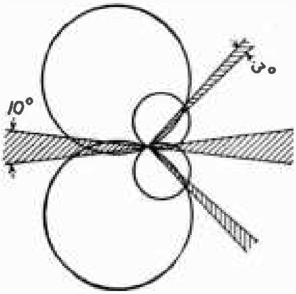

FIG. 43.—Field pattern of Fig. 42 with incorrect magnitude of current in vertical antenna.

antennas by the use of resistance, the courses may be made to shift from their normal 90-degree displacement to any angle between 45 and 135 degrees, as shown in Fig. 39. This angular variation depends on several variables, including loop-antenna resistance, mutual inductance between the primary and the secondary coils of goniometer, and the power factor of the link circuit.

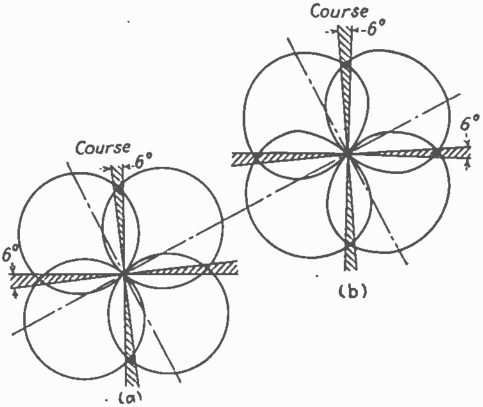

Fig. 40.—Field intensity of typical radio range with goniometer primaries at 90 degrees; (*a*) theoretical; (*b*) observed.

A *phantom-loop antenna* is the "figure-of-eight" space pattern which is made when both of the loop antennas are coupled to one primary coil of the goniometer. There is one phantom-loop antenna in space for each primary coil of the goniometer. The angular relation of the phantom-loop antennas is the same as that of the primary coils of the goniometer. For a further treatment of this subject see Murphy and Wolfe, Stationary and Rotating

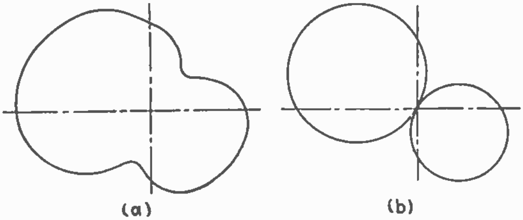

Fig. 41.—Field intensity of loop antenna and vertical antenna; (*a*) observed; (*b*) theoretical.

Placing radio ranges in this manner has one particularly annoying feature in that the course is usually broadest where it should be narrowest. In this connection it should be understood that an equisignal course is a true angular function, meaning that directly over the center of the loop antenna the courses have an infinitesimal width but that gradually the width increases to approximately 6 miles at 100 miles from the radio range. When a pilot flies from a point at a distance from the radio range it is evident that his course gradually becomes narrower as he approaches the beacon installation, and if he keeps on his course it will take him directly over the radio tower. This feature alone is one of paramount importance and cannot be neglected, since experience has shown that when the radio range is located adjacent to the terminal airport, pilots are able to locate the airport and make safe landings when conditions are such that they would otherwise be unable to find the terminal airport. When a radio beacon is located at a terminal airport there are two very distinct advantages: (1) The course becomes narrower as the pilot approached the beacon; and (2) the beacon informs the pilot definitely when he has passed over the tower, a point in space being thus located directly over the antennas. If a point in space similarly determined is located halfway between two airports, it will be of very great value. Two fundamental schemes have been developed which permit the use of two of the fixed courses which are displaced at any angle varying between 45 and 180 degrees. Courses emanating at angles less than 45 degrees, however, cannot be serviced with only one installation, because an excessive decrease in power results from such an attempt.

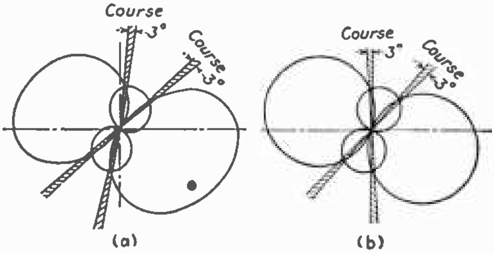

Fig. 39.—Field intensity of typical radio range with resistance in series with goniometer primaries at 90 degrees; (*a*) observed; (*b*) theoretical.

The method used to serve courses emanating from an airport at angles varying between 45 and 135 degrees requires the use of a non-inductive resistance in the link circuit in series with one of the goniometer primaries. This resistance reduces the power in one loop antenna while the power in the other is not affected. By varying the ratio of power in the two loop method is used because the (— ·) and (· —) characters give unusually good results. The characteristics formerly used were (— · · and · · —); (— · · · and · · · —). These were used for some time and have eliminated difficulties encountered with dissymmetrical arrangements but are not favored by pilots. Recently the airways division changed the signals to (— ·) and (· —) combinations, transmitted in groups of 2 to 12 signals per cycle. By counting the number of signals the station may be identified, this system being similar to a clock tolling the hour. In addition, beacons are identified by station announcements every 15 minutes.

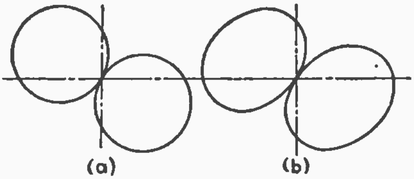

FIG. 37.—Field intensity of single-loop antenna; (*a*) theoretical; (*b*) observed.

A limitation of the radio range in its early form was that the four courses emanating from a single radio range were at fixed angles of 90 degrees to each other. It is obvious that such an arrangement could serve only one course at a time, when situated at an airport, except where by rare coincidence two courses extended at 90 or 180 degrees from an airport. In order to make at least two of the four available courses useful, the radio beacon installations may be located at halfway points on the straight airways at distances of approximately 200 miles, thus making it possible to use two of the four courses and, at the same time, reduce the angular width of the equisignal zone, since the two courses are displaced by 180 degrees. This is accomplished by increasing the angle between the two primary coils of the goniometer to about 120 instead of 90 degrees (Figs. 37 and 38). There are some installations of this kind on the Transcontinental Airway.

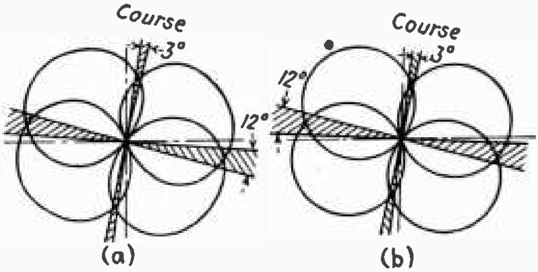

FIG. 38.—Field intensity of typical radio range, goniometer primaries being at 120 degrees; (*a*) theoretical; (*b*) observed.

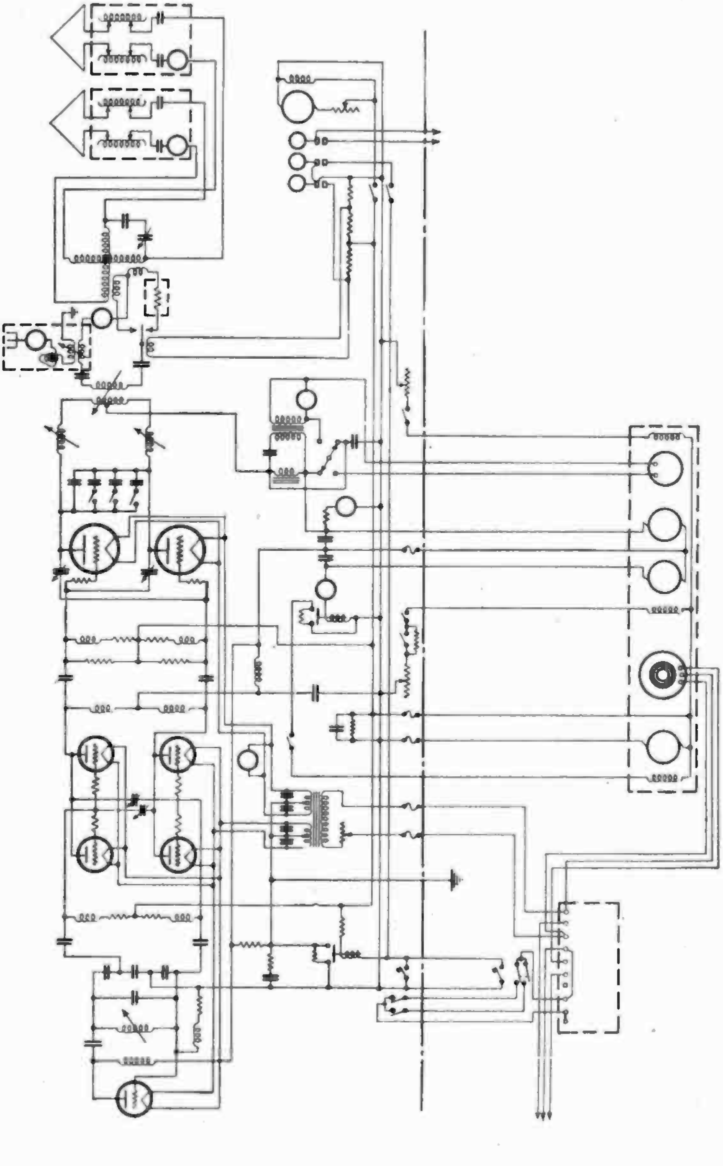

FIG. 36.—Diagram of typical radio range.

shifting the 90-degree courses as desired, and the vertical wire antenna introduces the shift of the 180-degree courses.

The second method used to eliminate possible confusion between radio ranges depends on a system of distinctive code signals. The signals must be such that they interlock and gave the resulting long dash when on the course. The first group of signals adopted are (— · and · —); (— · — and · ·); (— · · — and · · ·); and (— — — and · ·); two characteristic signals being required for each interlocking radio range. Results showed that radio ranges using the (— ·) and (· —) characteristics give distinctive courses. When the characters (— · —) and (· ·) are used, however, as interlocking signals, a peculiar physiological effect is observed. Tests indicate that the course is apparently bent slightly in an S shape. In reality, field-strength measurements proved the course to be straight. When close to the range and on the course as indicated by field-intensity measurements, the character (— · —) apparently predominates, causing the pilot to bear toward the (· ·) side of the course. When at approximately 100 miles from the range, the (· ·) character predominates while on the course, thus causing the pilot to compensate for this effect by flying on the (— · —) side of the course. As a result the pilot does not fly on the true course but on a curved course which does not coincide with the airway.

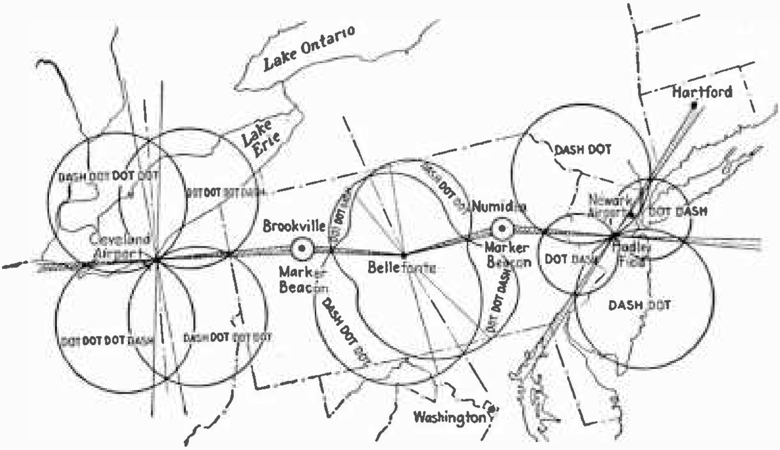

Fig. 35.—Air route, Cleveland to New York.

In order to eliminate this confusing effect it is necessary to use characteristics that have equal time durations and are the inverse of each other. This to be impressed by the reassuring messages from the ground as received by voice when he is operating under difficult circumstances.

The code method is undoubtedly the preferable one for transport airplanes operating in the country, where there are particularly long jumps between bases. The additional range of the transmitter may be vitally necessary in these cases, and, further, the operator can also obtain his radio bearings by communicating with marine vessels as this becomes necessary. For code transmission, the power of the transmitting ground station need not, in most cases, exceed 250 watts, and the transmitting equipment on the airplane may be as small as 15 watts. On the other hand, for voice communication for about the same set of circumstances, the equipment of the transmitting ground station should be provided for 400 watts, which will give a fully modulated wave of 1,600 watts at the "peak power" of the voice. For this voice equipment, the airplane should have a transmitting outfit designed for operation at 50 watts, giving 200 watts of peak power on the voice.

Radio Range.—The terminals in larger cities have many entering air routes, each of which should be outlined by a beacon course. Since it would not be economically possible to install a separate beacon for each route, the system had to be modified to accommodate multiple routes. These conditions have all been satisfied on the radio range system as now in use on the airways, if the number of courses to be served does not exceed four. The *aural type* of radio range was installed by the airways division of the U. S. Bureau of Standards at Hadley Field, N. J., Bellefonte, Pa., and Cleveland, Ohio, for the route shown in Fig. 35.

Two methods have been successfully adopted to differentiate between radio ranges. The first method allocates different frequencies in the band from 285 to 350 kilocycles to each radio range, particular care being taken to separate adjacent beacon frequencies by at least 12 kilocycles. When utilizing the ordinary aircraft receiver using two stages of screen-grid tube, radio-frequency amplification, detector, and two stages of audio-frequency amplification with a six-foot rod antenna, it is possible to tune to a beacon 100 miles ahead or 100 miles behind, when both are operating simultaneously on frequencies separated by 8 kilocycles. The average power output from a beacon installation is 2 kilowatts.

The schematic diagram of a typical radio range is shown in Fig. 36. The master oscillator is a 50-watt tube employing the *Colpitts circuit*. This is amplified by a set of four 50-watt tubes operating in a cross-neutralized, push-pull circuit. The final power amplifier contains two 1-kilowatt tubes of which the plate circuit is tuned. The tuned-plate circuit is coupled by an untuned-link circuit to the primary coils of a goniometer (direction finder), and the key circuit should be inserted at this point. A resistance permits best, and the selection between the two types of antennas must be made after a trial.

To obtain satisfactory efficiency in transmission, the wave length should be the same as the fundamental wave length of the antenna on the airplane. This fundamental wave length is determined by the wing spread of the airplane, and for an airplane with more than one engine cylinder in the motor and with wing spreads of from 70 to 100 feet, the fundamental wave length of the antenna is usually between 50 and 80 meters. At this short wave length, transmission is relatively efficient for both day and night service. On small planes, however, especially those having a motor with a single-cylinder engine and with wing spreads of less than 50 feet, the fundamental wave length of the antenna is usually between 30 and 40 meters. Most of the loss of antenna efficiency on small planes can be overcome by increasing the power of the transmission; but in any case of small or large planes, the upper limit of wave length seems to be about 100 meters when stationary antennas on the airplane are used. The final choice of the most suitable short wave length for two-way communication for airplanes is to select the wave band so that its "low side" is at the point where the skip effect begins to interfere with regular operation and its "high side" is at the point where rapid loss in efficiency of transmission is observed, when the wave length is increased above the fundamental of the stationary antenna. To provide two-way communication for "itinerant" or "sport" airplanes or for transport airplanes that are temporarily off their usual routes, the Federal Radio Commission has set aside the wave length of 97 meters and designated it as the "national calling frequency." All transmitting ground stations are required to keep a watch on this wave length and to communicate with any airplane that calls for assistance.

Voice or Code Operation for Two-way Communication.—An airplane equipped with a motor having a single-engine cylinder can obviously be operated most conveniently if radio communication with the transmitting ground station is by the voice method. There is also the difficulty with all types of airplanes that pilots have not, as a rule, been very successful radio telegraph operators for signaling by code. Transport airplanes equipped with motors having several engine cylinders can, as a rule, carry a radio operator if necessary, and under these circumstances, either the voice or code method of communication can be adopted. Very satisfactory voice communication is possible on domestic transport systems where the transmitting ground stations are spaced about 200 miles apart. The voice method requires more powerful and heavier transmitters both at the transmitting ground station and in the airplane than the code method. The voice method has the advantage that instructions can be sent more quickly and with more certainty and the psychologic advantage that the pilot seems

At night, the skip becomes noticeable at all wave lengths below 80 meters. For this reason, it is impractical to operate a receiving set on a standard wave length for day and night service, if the wave length is less than 80 meters.

For daylight service, the two-way communication for aircraft is in practice confined to the short waves between 80 and 200 meters, and in daylight there is considerable weakening of the transmission when the distance covered is greater than 60 miles. At night, however, relatively longer distances can be covered reliably, the distance being often as much as 1,200 miles. The phenomenon of weakened transmission during daytime is very much the same as that commonly observed in ordinary broadcasting with wave lengths of from 45 to 250 meters, except that with the very short waves, the weakening seems to be somewhat more pronounced. In order, therefore, to obtain continuous two-way communication with airplanes under normal operating conditions for a distance of about 100 miles in both daylight and darkness, it seems necessary to make a shift from one wave length to another twice during each 24 hours, once in the morning and again in the evening. This would be a simple matter if the transmitting ground stations alone were to be considered, but there is greater difficulty encountered when the adjustment from one wave length to the other must be made on the receiving instruments of the aircraft. Either the airplane must be landed at an airport so that a new transmitter and receiver may be installed to send and receive on the new wave length, or a "switch" device for making the desired change during normal flight must be included in the transmitting and receiving sets on the aircraft.

The trailing-wire antenna on aircraft has obviously its points of danger, and some arrangement of the antenna wires which will permit them to be strung between the fuselage and the wings is desirable. This method of attaching the antenna more or less permanently to the fuselage and wings would make it unnecessary to reel in and out a trailing antenna whenever airplanes are to be landed or put into flight. The stationary antenna on the airplane permits also communication between the airplane and the transmitting ground station when the airplane is landed on the ground. This stationary antenna on the airplane has also the advantage that it permits a final test of the radio equipment at the airport before the airplane takes off. Two arrangements of stationary antennas on airplanes are possible. According to one arrangement, a pair of wires can be strung from the fuselage to each wing tip. This antenna when used for transmission sends out a horizontal polarized wave. The other method is to set up a pair of wires as already described from the fuselage to each wing tip and use the frame of the airplane as a counterpoise (page 190). It cannot be predicted from the design of the airplane which of these two systems will operate same wave length, that is, between 200 and 550 meters. For the so-called "sport" requirements, in aviation, it may be sufficient to furnish the pilot with merely half-hour weather reports and provide him with the equipment needed to use the radio beacons for keeping him on his course. For scheduled transportation by airplane or dirigible, however, there should be available to the pilot at all times also a reliable two-way method of communication. Then the position and progress of his aircraft may be followed continuously, and, from time to time, he may be informed of special operating and landing conditions or may be sent instructions which become necessary because of weather changes as well as also instructions in regard to emergency landings in out-of-the-way places. Two-way communication permits, also, the sending of requests from the aircraft for assistance in emergencies and reassurance to the ground station of the safety of the airplane and cargo. For the purposes of two-way communication between aircraft and transmitting ground stations, there appear to be an insufficient number of long-wave allocations available for the transport companies, and, further, the long-wave communication requires very large antennas at both the airports and airplanes, making installation at both ends expensive and unnecessarily hazardous. The Federal Radio Commission has set aside the wave band between 45 and 200 meters for two-way communication for aircraft; and most of the air-transport companies are now using these short waves for this service. It has been contended that communication on these short waves was erratic and that communication could not be started over the necessarily long distances. Suitable equipment has now been developed, however, to eliminate largely these two difficulties. It is a rather definite requirement that the two-way communication for aircraft must give uninterrupted communication for a distance of 100 miles at any time of day or night and at any altitude. This is the reason why ground stations for communication cannot be placed very close together along the existing land airways, which are about 200 miles apart. It is also desirable to do away with the trailing-wire antenna (page 819).

It has been noted that communication between airplanes and the ground stations can be maintained with these short waves much more satisfactorily at great altitudes than when the airplanes are flying low or have been landed. Another interesting observation is that within the range of the short waves (45 to 200 meters) some waves follow the contour of the ground better than others.

At wave lengths between 45 and 200 meters, a skip is noticed, meaning that there is a dead spot about 50 to 75 miles from the transmitting ground station, and this dead spot extends outward for a limited distance in all directions. The shorter the wave length is, the greater will be the distance from the transmitting ground station to the point where the "skip" begins.

charge in the development of radio communication and airplanes to accomplish what had required something like 25 years to bring about in marine services. It must be admitted, of course, that the experience with marine types has been of very great value in their adaptation to aviation, but, the greatest assistance in this development came from recent research work in telephone broadcasting and from the activities of amateurs in short-wave radio transmission and reception.

Land Radio Stations.—The U. S. Department of Commerce has established about 40 land radio stations located along the principal airways in the United States. These ground stations are located in most cases about 200 miles apart and extend across the country from New York City to San Francisco, along the Pacific Coast, in the Mississippi Valley, and along the Atlantic Coast. These land stations of the Department of Commerce use voice transmission and have a carrier output (page 501) of 2,000 watts, giving them a range in daytime of about 125 miles and a range at night of approximately 250 miles. Wave lengths between 800 and 1,200 meters were set aside for aviation purposes by the International Convention in 1927, and the Department of Commerce land stations operate within this range.

The U. S. Weather Bureau has established a new service to collect hourly data on weather conditions so that at frequent intervals radio broadcasts can be sent out from the Department of Commerce ground stations to aviators operating in the vicinity of a station. From some of these stations, weather reports are being broadcast every half hour. These radio services from the ground stations make it possible for any aviator (whether flying for sport or on a scheduled transport) to install a simple radio receiving set; and if precautions are taken to eliminate ignition interference (page 769), he can receive the latest weather information almost anywhere in the country. Since all transmission of this kind is by voice, it is not necessary for the pilot to know a telegraph code, and the actual manipulation of his receiver on the airplane or dirigible is as simple as operating a radio receiving set in his home.

Radio Beacons for Guiding Airplanes by Code Broadcasting.—Radio beacons have been installed by the U. S. Department of Commerce for guiding aircraft in an established path through the air by code broadcasting. By means of a directional antenna at the transmitting ground station, a different combination of dots and dashes is sent out on the two sides of an airway. When an airplane, for example, is proceeding exactly along the correct route, the code letters from the two sides of the airway will blend at the receiving instrument in the airplane or dirigible, so as to make a series of long dashes. An aeronautical pilot listening to these signals can tell, therefore, when he is properly on the airway or, if not on the airway, on which side he is traveling. Every half hour, the radio beacon is turned off at the ground station and weather reports are broadcast by the voice on the pilots of airplanes and airships of weather conditions, emergency landing places, and other information that may be needed for air navigation. In some places, the radio telephone transmitting station is located several miles from a radio beacon "guidance" station, so as to avoid radio interference of two transmitting stations. It is customary, however, to install the microphone of a telephone transmitting station near the radio beacon station at an airport, for the reason that by this method the whole system of radio aids for air transportation is under the control of a single radio operator at the airport whose equipment should include a receiving set for messages from the airplanes and airships which have transmitting outfits.

Special Equipment for Airplanes Using Radio Telephony and Radio Beacons for Air Navigation.—Airplanes having radio aids for navigation should usually be provided with special armored cable for the engine ignition system. This special armored cable should have an extra thickness of insulation.

Although at present radio telephony on most airplanes having such equipment is operative in one direction only, that is, transmission from the ground to the airplane, it is likely that it will not be long before nearly all airplanes are provided with the two-way equipment for radio telephony. A 100-watt transmitting set on an airplane will be able under most conditions of airplane service to communicate with transmitting stations on the ground at any distance up to 50 miles.

Radio Stations for Airplane Navigation.—The use of radio as a means of guiding airplanes in flight is becoming increasingly important as applications become more numerous. In fact, radio communication for airplane navigation is likely within a few years to be a required equipment in the same way that it is required on ocean-going ships. Radio for marine services, however, has been in the process of development for almost 25 years, and its technical and operating procedure have been evolved to fit the needs of the shipping industry.

It is, of course, obvious that radio communication on airplanes is of little value without suitable land stations with proper equipment for such communication. In marine work, for example, land radio stations have gradually been extended all over the world, these stations using apparatus, wave lengths, and operating technique which are more or less standard.

The use of radio for airplanes is comparatively new. It is true that two-way communication of airplanes with land stations had reached some degree of perfection before the World War, but its application to commercial transportation in the air is comparatively recent. For commercial service, it has been necessary to develop radio apparatus of a type different from any that was used before, and a complete system of ground stations had to be established. Thus, in a very short time, it has been encumbent on those in all sparking and prevent inductive action by one circuit on another. For this purpose there are choke coils across the primary-arm magnet, the driving-pawl magnet, and the reset magnet; and there is a condenser across the main-relay coils. There is a combination of a condenser and a resistance across the front-stop contact of the relay tongue, another similar combination is connected across any contact which opens the reset-magnet circuit, and a third similar combination is connected across any contact which opens the secondary-magnet circuit or the magnet circuit operating the driving pawl.

All the adjustments of the selector and the receiver are made by means of sunk spindles which require a key to operate them. Receiver adjustments are provided for coarse tuning of the inductance of the antenna, for fine tuning of the variometer, for regeneration, for filament resistance, and for the plate resistance of the third tube. Selector adjustments are provided for the relay, for tuning the primary arm, and for tuning the secondary arm. A diagram of connections for the complete apparatus is shown in Fig. 34.

RADIO IN AIR NAVIGATION

Radio Aids for Airplanes.—Radio telephony is probably the most important of the applications of radio apparatus for the use of the operators of airplanes and airships, when used to establish communication between an airplane or airship and one or more stations on the ground. The equipment required for this service if the transmission is only in one direction, that is, from the ground to the airplane, is relatively simple, as the only equipment needed in the airplane or airship is the necessary antenna and radio receiving set. A much more complicated equipment is necessary when signals or speech is to be transmitted by radio waves from an airplane to the ground. The other, an equally important use of radio, is in its application in radio beacons for guiding airplanes.

There are two types of radio beacons for use in air navigation: (1) directive radio beacon and (2) marker radio beacon. The directive radio beacon sends out a special type of radio wave by which the airplane and airship pilots are able to follow a designated course in total darkness or in a fog. The marker beacons used in air navigation are small radio transmitting stations which are placed at intervals of about 25 miles along the designated course and are intended to supplement the guidance from the directive radio beacons, serving on the air highways somewhat the same purpose as the ordinary milestones on highways on the ground.

Radio transmitting stations established for the purpose of providing opportunities for radio telephony are not unlike ordinary radio broadcasting stations, although usually of limited power. They are used to inform the