EXPERIMENTAL RADIO

THIRD EDITION

BY

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PUBLISHED BY R. R. RAMSEY

BLOOMINGTON, INDIANA

U.S.A.

Composed, Printed and Bound by
The Collegiate Press
George Banta Publishing Company
Menasha, Wisconsin

Preface to the First Edition

These experiments have been collected from various sources during the past five years and have been given to my students in radio in condensed mimeograph form. Several of these experiments have been devised by the author. A larger number have been taken from the various texts on radio telegraphy and telephony. Reference to the various sources from which theory or experiments have been taken is made in the experiments. It has been my endeavor to make the course in radio at Indiana University on a par with any second year course in physics.

Some experiments, methods of test and practical directions for the construction of apparatus have been inserted for those who have not had college physics or who do not have access to regular physical apparatus. I have found that these practical directions have been of use to my students. This is not a text book. A very small amount of theory has been included except in a few places where the texts are deficient.

R. R. Ramsey

Indiana University
Bloomington, Indiana
December, 1922.

Preface to the Second Edition

In this second edition EXPERIMENTAL RADIO has been revised and enlarged. Besides a number of new experiments, suggestions for the construction of simple radio laboratory apparatus have been added.

EXPERIMENTAL RADIO is not in its final form. In order that it may be improved I shall be glad to receive corrections, suggestions, or criticisms.

July, 1923 R. R. R.

Preface to the Third Edition

In 1923 the first mimeographed edition was published primarily for my own students. Its reception by the radio public, college, commercial and amateur, was such that it was necessary to get out a second edition in a few months. This second edition has been revised with slight changes and additions several times.

The third edition has been enlarged and revised in order to keep up with the rapid changes of Radio. No attempt has been made to give the more complicated tests and methods of measurement. Simple tests are given which will bring out the fundamental principles. References are given which will describe the more elaborate methods.

I hope that this edition, printed in more permanent form, will continue to meet the approval of the radio public.

I am indebted to many friends for helpful criticisms and suggestions.

November, 1927 R. R. R.

REFERENCE BOOKS

Theory and experiments have been taken from the following books. Page references are given in the experiments.

Ballentine—*Radio Telephony for Amateurs.* David McKay.

Bucher—*Vacuum Tubes.* Wireless Press.

Fleming—*The Principles of Electric Wave Telegraphy.* Longmans, Green & Co.

Jansky—*Principles of Radio Telegraphy.* McGraw-Hill.

Lauer & Brown—*Radio Engineering Principles.* McGraw-Hill.

Morecroft—*Principles of Radio Communication.* Second Edition. John Wiley & Sons.

Moullin—*Radio Frequency Measurements.* Charles Griffin Co.

Nema Hand-Book of Radio Standards. National Electrical Manufacturers Association.

Pierce—*Electrical Oscillations and Electric Waves.* McGraw-Hill.

Radio Amateur's Hand-Book. American Radio Relay League.

Radio. Radio Communication Pamphlet No. 40. Supt. Documents, Washington.

Radio Instruments and Measurements, Circular of Bureau of Standards No. 74. Supt. of Documents, Washington.

Robison—*Manual of Radio Telegraphy and Telephony*, U. S. Naval Institute.

Stanley—*Wireless Telegraphy*, Vols. I and II. Longmans and Co.

Starling—*Electricity and Magnetism.* Longmans, Green and Co.
Stone—*Elements of Radio Communication*, D. Van Nostrand Co.
Terry—*Advanced Laboratory Practice in Electricity and Magnetism.* McGraw-Hill.
Turner—*Outline of Wireless.* Cambridge University Press.
Van der Bijl—*Thermionic Vacuum Tubes.* McGraw-Hill.
Watson—*A Text Book of Practical Physics.* Longmans, Green & Co.
Zenneck—*Wireless Telegraphy.* McGraw-Hill.

Periodicals.

Experimental Wireless, London.
Proceedings of the Institute of Radio Engineers, New York.
Q S T, Hartford, Conn.

CONTENTS

List of Experiments

TESTING DRY CELLS

1—Large Cells

In this class all cells used for induction coils or for A batteries to heat the filament of tubes are included.

The Ammeter Test. This test is useful to locate cells which have become exhausted or dried out. Connect the cell to a dead beat ammeter whose internal resistance is about .01 ohms. The maximum deflection is taken as the reading. New cells should give 20 to 30 amperes. Used cells will give lower values. When they show as low as 1 to 2 amperes they should be discarded. 1 ampere means that the internal resistance of the cell is about 1.5 ohms. Whether this resistance is detrimental depends upon the resistance of the circuit to which it is connected. When the internal resistance of the battery is equal to the external resistance of the circuit, one-half of the energy of the battery is used in the battery. If the battery is not working well, replace the cells which show the lowest current—i.e., the highest resistance. These discarded cells can be used with good results as cells for potential as in B batteries.

2—Small Cells. B Batteries

The internal resistance of a B battery cell can be measured as in the case of large cells. This is usually not necessary. The essentials of a B battery are that it's E.M.F. be high and that the cell is not noisy.

Use of voltmeter to test the E.M.F. of the B battery.—If a 22½ volt battery reads from 15 to 22-volts it may be considered to be in fair condition. Connect a high resistance telephone head-set across the battery, care being taken to have good connection. There should be no sound in the telephone except the click made when the connection is made and broken. The loudness of this click on making contact can be taken as an indication of voltage of the battery. If a new battery is at hand, a comparison of the click made by the new battery with that of the old will give an indication of the E.M.F. of the old battery.

If there is a rattle or popping in the telephone when the telephone connections are good the battery is noisy and the poor cell or cells must be removed. This popping sound is caused by a poor connection which makes the current intermittent. It may be a poor soldered joint or it may be inside the cell, probably due to the material of the cell becoming dry and making the conduction uncertain. Measure each individual cell or flash light battery. The cell whose E.M.F., as measured with the voltmeter, is less than 75% of the normal voltage is usually the one which causes the noise in the battery. Remove or short circuit this cell or flash battery.

Experiment 1. Testing large dry cells.

Measure the short circuit current of each cell in a large battery by means of a low resistance ammeter. Measure the E.M.F. of each cell by means of a voltmeter. Compute the internal resistance of each cell, deducting the resistance of the ammeter. Calculate the internal resistance of the battery. [Batteries in series, in multiple and multiple series.] Compare the resistance of the battery with that of the apparatus to which the battery is connected,—i.e. induction coil, or lamp, etc.

Experiment 2. Testing small cells.

Repeat the experiment with small cells, such as flash light or B battery cells.

Estimate the E.M.F. of cells by means of the telephone click method. (The resistance of the phone should be at least 1000 ohms.)

Check with the voltmeter.

Compare new and old $22\frac{1}{2}$ volt batteries. New and old flash light batteries. New and old individual cells.

Take a new and old cell and measure the E.M.F. with a 3 volt voltmeter, 15 volt voltmeter and a 150 volt voltmeter. Why do the readings of the new cell check? Why do the readings of the old cell not check? (A Weston 3, 15, 150 volt model 280 voltmeter is ideal for this experiment.)

NOTE. Short circuiting a cell always tends to ruin the cell. Make the time of connection of the ammeter to the cell short.

MEASUREMENT OF RESISTANCE

There are several methods of measuring resistance which are given in any good physics laboratory manual. Two methods will be described here as being the most important for use in radio measurements. The ammeter-voltmeter method and the wheatstone bridge method.

Ammeter-voltmeter method.—This consists of measuring the current through the resistance with an ammeter and the *Pd* around the resistance with a voltmeter, and solving for the resistance by means of Ohm's Law, $R = Pd/I$. This method is useful in measuring resistance which will carry relatively large currents and have resistances from about 0.1 ohm to 1000 ohms. The resistance of lamps, large rheostats, armatures and fields of motors and generators can usually be conveniently measured by this method. Small coils such as coils in ordinary resistance boxes should not be measured by this method, as there is danger of sending too much current through the coils and burning them out.

The assumptions made in these measurements are that the ammeter has zero resistance and that the current through the voltmeter is zero. These assumptions are only approximately true. In measuring a small resistance such as the resistance of an armature the connection should be made as in Figure 1. The source of current is a D.C. 110 volt switch or a storage battery capable of delivering several amperes of current. R_h, is a regulating rheostat or bank of lamps by means of which the value of the current is regulated, a, b are the points of contact of the voltmeter around the armature, R. In this case the current through the ammeter is the current through the armature which is several amperes, plus the current through the voltmeter which is only a few milliamperes. The voltmeter current in this case can be disregarded. In this case, $R = Pd/I$ is the resistance of the armature. If the connection was made as in Figure 2, then $R = Pd/I$ = Resistance of arma-

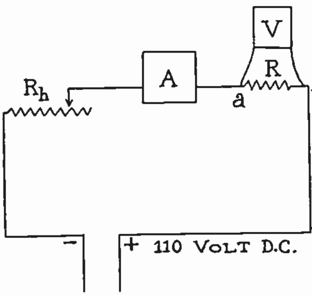

Fig. 1

ture plus the resistance of the ammeter and in certain cases the resistance of the ammeter will be equal to or greater than the resistance *R*. If the resistance is great, connect as in Figure 2. In this case the resistance *R* is great and an addition or error of a few hundredths ohms can be neglected. If connected as in Figure 1 the current through the voltmeter may be much greater than the current through the resistance *R*. Milliammeters and millivoltmeters can be used instead of ammeters, but the errors due to the resistance of milliammeter and the current through the millivoltmeter are liable to be great.

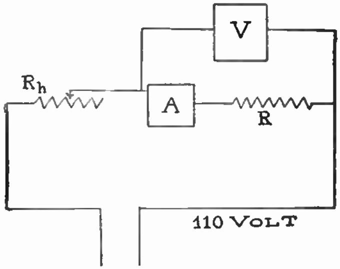

Fig. 2

Caution: Be sure the current is not greater than the maximum range of the ammeter and that the *Pd.* is not greater than the maximum range of the voltmeter.

Experiment 3. Measure the resistance of lamps, tin frame rheostats, etc.

Measure the resistance of two lamps and place them in series and measure, place them in multiple and measure. Note that the resistance in series is not exactly the sum of the separate resistances. This is due to the fact that the temperature of the lamps is less when in series than when measured separately. The resistance of metallic filament lamps increases with temperature, while the resistance of carbon filament lamps decreases with temperature. The resistance of most conductors changes appreciably with temperature.

Wheatstone Bridge: The wheatstone bridge consists of four resistances. The value of one of these resistances is known. The ratio of the resistances of two others is known. The fourth is unknown, or is the resistance to be measured. These four resistances are connected together to form a closed circuit. Diagrammatically the resistances are connected to form a diamond or parallelogram as in Figure 3. R, is the adjustable known. R_1 and R_2 are the ratio arms. The ratio of R_1 to R_2 is known. X, is the unknown. A galvanometer is connected across one diagonal of the diamond and a battery across the other diagonal. The resistance R is changed until there is no current through the galvanometer, then the potential of b is equal to the potential of d. Then $Pd_{ab}=Pd_{ad}$ and $Pd_{bc}=Pd_{cd}$ and $I_1=I_R$ and $I_2=I_X$. Since $Pd_{ab}=I_2R_2$, $Pd_{ad}=I_1R_1$ and $Pd_{bc}=I_XR_X$ and $Pd_{dc}=I_RR$. Then

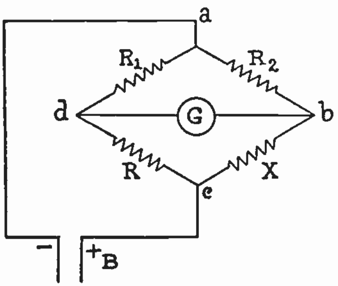

Fig. 3

$$X=\frac{R_2R}{R_1}\cdot$$

Experiment 4. Slide wire bridge.

The bridge has two common forms—the slide-wire bridge and the box bridge. The slide-wire bridge consists of a No. 20 manganin or German silver wire usually 1 meter long, stretched on a board and soldered to two heavy bars of copper or brass. This heavy bar is extended along the back of the board and usually has four openings with binding posts so as to connect resistances. Two of these openings for simple measurements are closed with heavy conductors. The resistance of these heavy bars and straps is considered to be zero.

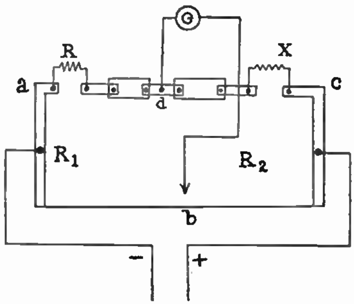

Fig. 4

It will be seen that the resistances R_1 and R_2 are that of sections of the wire. Since the resistance of the wire is uniform, then l_1 and l_2, lengths, can be substituted for R_1 and R_2. In this bridge the known resistance R can be fixed and the ratio of R_1 to R_2 can be changed until the bridge is balanced. For exact measurements it is best to adjust the known resistance R so that the sliding point b is near the center of the wire. Slide-wire bridges can be constructed very cheaply and still give fair results.

BOX BRIDGES

The box bridge consists of three resistances and the unknown. These three resistances are usually placed in the same box and marked terminals and keys placed conveniently. In all bridge work two break keys k_1 and k_2 should be used, one in the battery and one in the galvanometer circuit. Figure 5 is a diagram of one form of box bridge, the letters on the diagram correspond to those on diagram Figure 3. In any bridge work the bridge should be studied by diagraming it and determining the points which correspond to the diamond, Figure 3. Pieces of paper with letters can be fastened to the box until you are able to see the particular bridge in the "diamond form."

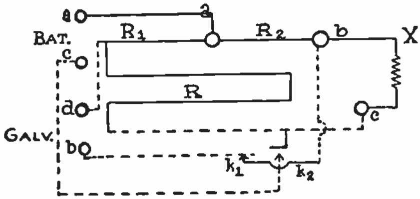

Fig. 5

All box bridges are alike in principle but their outward forms may be very different.

Experiment 5. Use of box bridge.

In using a box bridge connect the unknown in and select some value for the ratio $R_1 = R_2 = 100$ ohms. Let $R = 0$. Press the battery key and then the galvanometer key and note the direction of deflection. This is the direction of deflection when R is too small. Select some large value of R. The direction of deflection will be in the opposite direction if R is greater than X. Then X lies between zero and the large value of R. Make R about $\frac{1}{2}$ of the large value, then from the direction of deflection it is easy to determine whether the value of X is greater or less than the last value. Make R some other value near the intermediate value, noting deflection. By approximating closer and closer, in a short time approximate value of X can be determined.

After the approximate value has been determined, the ratio of R_1/R_2 may be changed so as to obtain more exact measurement.

If the resistance to be measured is a coil containing much inductance care must be taken to close or open the battery key while the galvanometer key is open, otherwise there will be a momentary deflection or kick of the galvanometer even if the bridge is balanced.

Measure the resistance of coils separately and in series and in multiple and check by the formula for series $R=r_1+r_2+r_3+\cdots$ and the formula for multiple $1/R=1/r_1+1/r_2+1/r_3+\cdots$.

If a good bridge is not available a cheap slide wire bridge can be made. If a resistance box can not be had, an ordinary telephone head set may be used for an approximate standard. In a number of commercial phones the variation of resistance from that marked on the phone was not greater than 2%. A telephone head set may be substituted for the galvanometer. Upon opening and closing the key in the galvanometer circuit, telephone circuit in this case, a click will be heard in the phone. Adjust until the click is a minimum. Then the bridge is balanced. If a telephone is used as a resistance standard a galvanometer must be used with steady battery current. A simple galvanometer can be made by winding a flat coil of 50 or 100 turns over a flat board. Remove the board and insert an ordinary pocket compass. Place the coil so the plane of the coil points North.

GROUND RESISTANCE

If a good conducting sphere such as a copper sphere, is placed at the center of a hollow copper sphere and is surrounded with a poor conductor such as earth, the spheres, together with an insulated copper connecting wire, may be considered as perfect conductors and then all the resistance is due to the earth. Let S be a conducting sphere of radius R_1. About the center of S, draw two spheres of radius r and $r+dr$. The resistance of the spherical shell will be

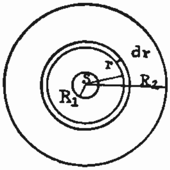

Fig. 6

$$dR=\rho\frac{\text{length}}{\text{Areas of cross section}}=\frac{\rho dr}{4\pi r^2}$$

Then,

$$R=\frac{\rho}{4\pi}\int_{R_1}^{R_2}\frac{dr}{r^2}=\frac{\rho}{4\pi}\ {}_{R_1}^{R_2}\left[-\frac{1}{r}\right]=\frac{\rho}{4\pi}\left(\frac{1}{R_1}-\frac{1}{R_2}\right).$$

If R_2 the radius of the hollow sphere $=\infty$ then

$$R=\frac{\rho}{4\pi}\,\frac{1}{R_1}\,.$$

All the resistance is near the small sphere and if the small sphere's radius is doubled the resistance of the "ground" is reduced one-half.

The same ratio will hold if the copper sphere is half buried on the surface of the earth, and it will be seen that in making good "grounds" a large amount of metallic surface must be exposed to the soil.

In making temporary "grounds" metallic stakes are driven into the ground.

Experiment 6. Measurement of ground resistance.

Drive two stakes into the ground 10 inches deep and 150 ft. apart. Connect the two with a good conducting wire whose resistance is known and measure the resistance with a wheatstone bridge or testing set, which is a box bridge with battery and galvanometer contained in the box, or measure using ammeter-voltmeter method. About 10 inches from the first stake, drive a second stake at each end, connect to the first stake and measure. Repeat with 3 stakes at each end; four stakes and five stakes. Drive the stakes 20 inches into the ground and measure again. Remove the stakes and pour water into the holes and replace the stakes and measure. Or, set up the experiment again in damp soil. How does the resistance vary with number of stakes? With depth of stakes? Repeat with the groups about 10 feet apart. It will be seen that the resistance does not change with distance between groups but that as is shown by theory the resistance can be considered as being located near the stake. Drive several stakes at each end equally spaced on the circumference of a circle 10 inches in diameter to a depth of 10 inches and measure. Drive twice as many

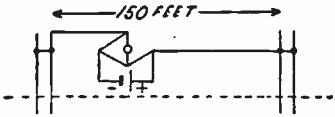

Fig. 7

stakes on a circle 20 inches in diameter to a depth of 20 inches and measure. In this last case the two sets of rings will approximate to hemispheres of radii one and two respectively.

Experiment 7. To measure the resistance of a particular ground such as a connection to a water pipe, or aerial ground connection.

In the open soil some distance from gas or water pipe, drive two groups of stakes 25 or more feet apart. Measure the resistance of the groups. Connect the particular "ground" to one set of stakes and measure. Then connect to the second group and measure again. From the above readings the resistance of the "ground" can be determined.

Let A and B be the two groups of stakes, C the particular "ground" to be measured. Since all the resistance is located near the "grounds" we can speak of the resistance A, the resistance B and the resistance C.

Let R_1 = resistance $A+B$, $R_2 = A+C$, and $R_3 = B+C$

Then $R_2 + R_3 = A + B + 2C$ and $R_2 + R_3 - R_1 = 2C$

In certain soils and at certain times there will be disturbing electromotive forces at the stakes which will be so great as to make measurements with bridges impossible. The ammeter-voltmeter method using a rather high E.M.F. will give better results. Better still use an alternating E.M.F. with A.C. ammeters and voltmeters.

ALTERNATING CURRENT

Since Radio is a special phase of alternating current the student should be familiar with the effect of resistance, inductance, and capacity in alternating circuits. If there is not time to perform all these experiments the instructor should demonstrate some of the following in the lecture room especially those which show resonance.

For these experiments with 60 cycle A.C. various coils, such as large air core coils, transformer coils and high potential condensers of one or more microfarad capacity can be used. For the resonance experiments a condenser of 10 microfarads variable in steps of one microfarad, and a coil of about 4000 turns of No. 18 wire wound on a tube 1½ inch diameter and about 10 inches long with a movable laminated core is needed. Telephone condensers may be used but they are liable to puncture—place a fuse in series.

If we have a circuit with resistance and inductance in series our equation for current is, $I = E/\sqrt{R^2 + L^2\omega^2}$.

Squaring and solving we have, $E^2 = I^2R^2 + I^2L^2\omega^2$.

The square of one term which equals the sum of the squares of two other terms suggests a right angle triangle.

All these quantities are electromotive forces and can be added by the vector method. (Parallelogram of vector method such as is often used with forces.)

In Figure 9 the base of the triangle is laid off equal to the IR drop in potential, the height proportional to the reactance drop of potential and the hypoteneuse is equal to the E.M.F. applied to the coil.

Experiment 8. To measure the inductance, L, of a coil, Impedance Method.

Measure the resistance R or the coil. Use the ammeter-voltmeter method using direct current.

Connect the coil to a source of A.C. of known frequency. Since the frequency, n is known, ω is known, $\omega = 2\pi n$. The connections are the same as in the ammeter-voltmeter method of measuring resistance or as in Figure 8. R is a regulating resistance; L, is the coil whose inductance is to be measured. Take the ammeter and voltmeter readings. Then the voltmeter reading is E. I times the known resistance R is the IR drop and we have the hypotenuse and base of a right triangle to construct the triangle. On a horizontal, lay, off to some convenient scale, ab proportional to IR. At b erect a perpendicular to ab. With a divider construct a circle with a as center and a radius equal to E using same scale as that of IR. Then $ac = E$ and $bc = IL\omega$, from the length bc the voltage $IL\omega$ is scaled out and, $L = IL\omega / I\omega$. The phase angle, $\theta = \tan^{-1} L\omega/R$.

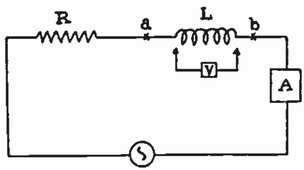

Fig. 8

Measure L of air core coils, transformer coils, lamp resistances, tin frame resistances, etc.

Repeat the experiment with an A.C. current of different frequency.

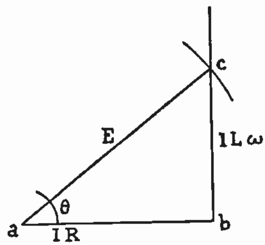

Fig. 9

Note, the phase angles depend upon frequency, while L of an air core coil is independent of frequency. In transformer coils or iron core coils L is not constant but depends upon the permeability of the iron which depends upon current. Any eddy current loss in the core or other parts will make R greater than the value measured with D.C. current.

It will be noted that lamps and tin frame resistances are practically non-inductive for low frequency, 60 cycle.

In solving problems in alternating currents use the graphical method. Lay out the length of lines to exact scale. This method soon gives one an insight to just what is taking place in the circuit and in a great number of cases, calculation by any other method is very tedious.

Experiment 9. To measure the Inductance, L, of a coil by the Three Voltmeter Method.

In a coil, as we have just seen, there are three *Pd*'s, potential differences, which form a right triangle, such as $bb'c$, Figure 11, where bb' is the IR drop of the coil, $b'c$ is the $IL\omega$ of the coil and bc is the voltmeter reading around the coil. If a non-inductive resistance R, is inserted in series with the coil, Figure 10, then since the inductance, L is in the coil alone the three E.M.F.'s of the circuit will form the triangle abc, ab being the IR drop of the resistance R, ac the total E.M.F. and bc is the Pd around the coil.

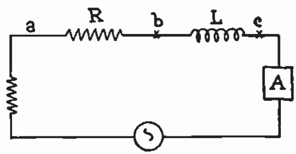

Fig. 10

Measure the Pd_{ac}, Pd_{ab} and Pd_{bc}. Construct a triangle Figure 11, using ab proportional to Pd_{ab} as the base. Set the dividers to equal the length ac proportional to Pd_{ac} and with a, as center draw an arc of a circle. With b, as center, draw an arc of a circle with *bc* as radius which is proportional to Pd_{bc}. The intersections of the arcs give the point *c*. Then draw the lines *ac* and *ab*. From *c*, drop a perpendicular on to *ab*, produced to *b′*. Then *cb′* is $IL\omega$ and *bb′* is IR_1, where R_1 is the resistance of the coil. The angle *cbb′* is the phase angle of the coil. The angle, *cab*, is the phase angle of the complete circuit. It will be seen that adding resistances in series with the coil reduces the phase angle of the circuit, or the current is more nearly in phase with the E.M.F. A large resistance will make the phase angle practically zero. A.C. voltmeters have large non-inductive resistances in series with the galvanometer coils. This resistance not only serves to make the galvanometer direct reading as in D.C. voltmeters, but makes the current through the voltmeter in phase with the E.M.F.

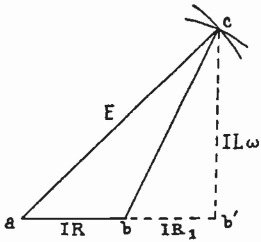

Fig. 11

Experiment 10. Resistances and Inductances in Series.

Connect two coils and three non-inductive resistances in series to an A.C. source, Figure 12. Measure the *Pd.* *ab*, *ac* · · · *bc* · · · making all possible $n(n-1)/2$ connections, 15 readings in this case. Lay off the triangle *abc* Figure 13, as in the previous

Fig. 12

experiment. Then with *a b* and *c* as centers lay off arcs *cd*, *ad* and *bd*, and thus locate the point *d*. In similar manner locate *e*, and then *f*. From *c*, *d*, *e* and *f*, drop perpendiculars on the line *ab* produced. The total length *af′* is the total *IR* drop or the sum of the five separate *IR* drops. The line *ff′* is the total *ILω*, or the sum of the separate (*ILω*)'s. Dividing by *I* and *Iω*, we have that the total resistance of a circuit in series is equal to the sum of the separate resistances and the total *L* of the circuit is the sum of the separate *L*'s. This is true if the coils are so placed so as not to affect each other or if there is no mutual induction between the coils.

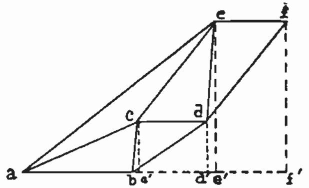

Fig. 13

Place coil No. I on top of Coil No. II and repeat. The effect of mutual induction will be seen.

Experiment 11. Resistances and Coils in Parallel.

In this case the total current is equal to the vector sum of the separate currents.

Connect a noninductive resistance and a coil in multiple. Figure 14. Place an ammeter in each circuit and a third ammeter to measure the total current. Measure the E.M.F. around the points *ab*. With *ab* proportional to Pd_{ab} as a diameter, construct a semicircle, Figure 15. Then I_1 is in phase with the E.M.F. *ab* since I_1 flows through resistance only. With some convenient scale draw aF_1 to represent the current through the resistance.

Then with aF_1 construct the triangle aFF_1 where F_1F is the current in the coil and aF is the resultant current. Complete the parallelogram aF_1FF_2. Then the angle F_1aF_2 is the phase angle of the current through the coil and the angle F_1aF is the phase angle of the resultant current. Then since the IR drop of the coil is in phase with the current in the coil and since the E.M.F. vector right triangle of the coil must be inscribed in the semicircle of which ab is the total E.M.F., then the triangle aP_2b is the triangle and aP_2 is the IR drop and bP_2 is the $IL_1\omega$ of coil L_1. In similar manner aDb is the E.M.F. triangle of the resultant, and aD is the resultant IR drop and bD is the resultant $IL\omega$.

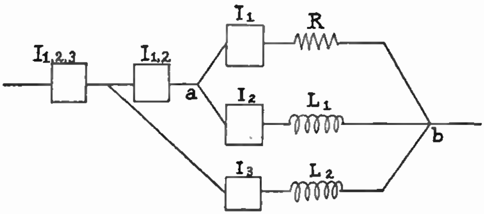

Fig. 14

If a second coil is placed in parallel and its current and resultant of the three is measured, the resultant vector diagram of the three is found as before. The voltage vector triangles are found and we see that in the first two a resistance and an inductance in parallel can be replaced by a resistance and an inductance in series. Any number

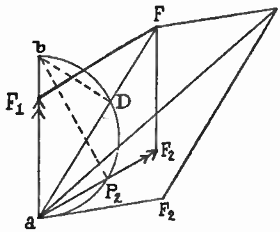

Fig. 15

of resistances and inductances can be replaced by a single resistance and inductance in series. The law of calculating this resultant circuit is not simple and the above method of drawing to scale and calculating is for most purposes the easiest method to handle the case.

CIRCUITS CONTAINING CAPACITY

If we have a circuit with a resistance and an inductance and a capacity in series, then our equations become

$$I=\frac{E}{\sqrt{R^2+(1/C\omega-L\omega)^2}}$$

If L is zero, then

$$I=\frac{E}{\sqrt{R^2+(1/C\omega)^2}}$$

Our reactance in this case is $1/C\omega$ and our phase angle is positive and the current is said to lead the E.M.F. It will be remembered that it lagged in the case of resistance and inductance.

As in the case of resistance and inductance we can write the equation as

$$I=\frac{E}{\sqrt{R^2+(x)^2}}$$

where x is the reactance, I being virtual current, E, virtual E.M.F.

If $L=0$ and $R=0$, we have $I=\dfrac{E}{\sqrt{(1/c\omega)^2}}=CE\omega.$

This equation will apply to a good condenser placed in an alternating circuit. The resistance of a good condenser being small.

Experiment 12. To measure the capacity of a condenser.

Take a large condenser, about 10 microfarads, place it in an alternating circuit and measure E around the condenser and the current through the condenser. Calculate the capacity.

$$C = I/E\omega$$

Care must be taken in this experiment to correct for the current through the voltmeter. The A.C. generator must be one in which the E.M.F. varies as the sine of the angle. Any harmonic will be emphasized by the condenser and the results will not check with theory.

Experiment 13. To measure the capacity of a condenser, —Three voltmeter method.

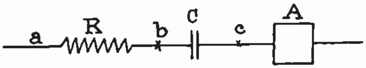

Fig. 16

Place a condenser and noninductive resistance in series Figure 16, and measure the current and potentials, *ab*, *ac*, and *bc* and from the vector triangle as in the case of resistance and inductance in series calculate the capacity. The phase angle *bac* is positive in this case, Figure 17. The angle *abc* should be nearly 90°, since the resistance of the condenser is nearly zero. *ab* is the IR drop across R and *cb* or *cb′* is $I/C\omega$. Measure *cb′* and calculate C. Condensers in large Ruhmkorff induction coils make good capacities for this experiment.

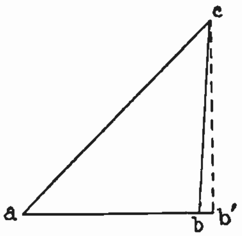

Fig. 17

Experiment 14. Resistance, inductance and capacity in series.

Connect a resistance such as a lamp in series with an inductance coil and a large condenser to an A.C. E.M.F. as in Figure 18.

Measure the *Pd.*, *ab*, *ac*, etc. with an A.C. voltmeter making all possible measurements.

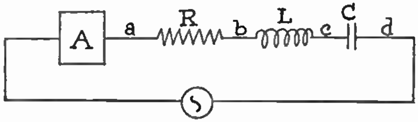

Fig. 18

Construct the vector diagram. Since the phase angle due to inductance is negative, turn the triangle *abc* over as in Figure 19. The diagram may come out with *d* below the line as in

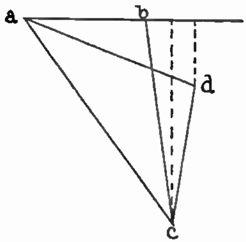

Fig. 19

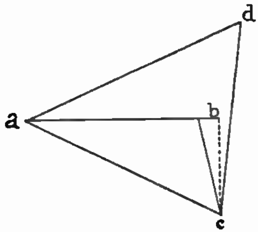

Fig. 20

Figure 19, or it may be above the line, as in Figure 20. The resultant phase angle *bad* is negative. In Figure 20 the resultant phase angle *bad* is positive.

Select coils and condenser such as will give diagrams of both types. The point *d* should be vertically above the point *c*, however, as a general thing the voltmeter being in parallel with the condenser gives the effect of a resistance in series with the condenser.

Experiment 15. Series resonance.

If in the equation

$$I=\frac{E}{\sqrt{R^2+(1/c\omega-L\omega)^2}}$$

L and C are such as to make $1/C\omega-L\omega=0$. Then we have $I=E/R$. This is the maximum value of the current. When this condition exists we have resonance. The capacity and inductance exactly annul each other. In the equation

$$1/C\omega-L\omega=0 \quad C=1/L\omega^2 \text{ or } L=1/C\omega^2 \text{ or } \omega=\frac{1}{\sqrt{CL}}$$

Thus it is possible to make the equation zero by changing C, or by changing L, or by changing ω, Since $\omega=2\pi n$, the frequency being n we have,

$$n=\frac{1}{2\pi\sqrt{LC}}$$

This is the fundamental equation in radio.

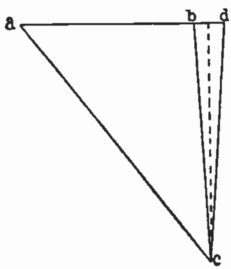

Fig. 21

If a variable condenser or variable inductance coil with movable iron core is available, get the condition of resonance. This can be determined by watching the ammeter as the capacity or inductance is varied continuously in the circuit of Experiment 14. The point of maximum current is the point of resonance.

Measure the voltages ab, ac,

etc. and plot the diagram. *d* should lie on the line *ab* extended. Figure 21.

The condition is so critical that connecting the voltmeter tends to throw the circuit out of resonance thus making it hard to obtain good vector diagrams.

Experiment 16. Inductance and capacity in parallel.

If a coil of large inductance and small resistance and a condenser are placed in parallel in the circuit, Figure 22, then the current I_1 is nearly at right angles to the E.M.F., *ab*. The current through the condenser, I_2 is also 90° with the E.M.F. but the angle is positive. The sum of these currents or resultant is small, or is the vector difference. If the values are varied until the resultant current is a minimum, then we have parallel resonance.

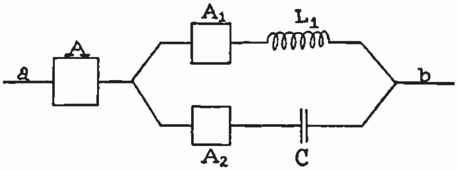

Fig. 22

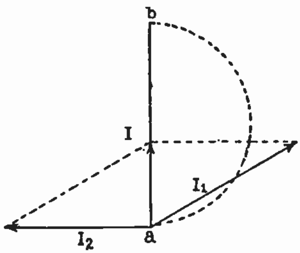

Fig. 23

If neither condenser or coil has resistance, then the two phase angles are exactly 90°, Figure 24, and the two currents are exactly opposite and the resultant current is zero when they are exactly equal, and the impedance in the circuit is infinite. This is the case of parallel resonance. Connect a variable condenser and variable inductance in parallel, with ammeters to measure each current and note the resultant current. This is the "fly-wheel" circuit of radio. Wave traps are made of a condenser and coil placed in parallel in the circuit and tuned to the frequency which is undesirable.

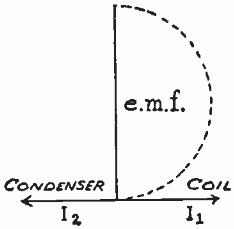

Fig. 24

Experiment 17. To test a 60 cycle high potential transformer.

We shall assume that the transformer is rated as 1 K.W. 60 cycle, 110 volts primary and 10,000 to 25,000 volts secondary. It is practically impossible to test a high potential transformer unless you have access to an electrostatic voltmeter. An ordinary voltmeter takes several milliamperes of current. This current load through the voltmeter is a large percent of full load current. Since 10,000 volts$\times$0.1 ampere is 1000 watts 100 milliamperes is full load value of the secondary current. However, tests can be made for shorts and grounds.

Test for ground to core.—Connect one terminal of the coil to a D.C. 110 volt circuit with a lamp or D.C. voltmeter in series. Connect the other terminal of the 110 volt circuit to the frame. There should be no indications of a flow of current.

Tests for shorts in secondary coil.—Connect the primary to a 110 volt A.C. circuit with an ammeter in series.

Close the switch and note the current. Let the current flow for a short time and open the switch. Note the temperature of the secondary coil. If there is any rise of temperature the coil is short circuited. This assumes that there is no sparking over at the terminals of the secondary coil. If there is sparking, the potential of the primary circuit should be reduced by means of a rheostat or choke coil until there is no sparking over. It is well to note the current in the primary coil, the secondary being open, when the transformer is new. At later times the primary current can be compared with this reading. Any considerable increase of current under the same conditions indicates a short circuit.

Experiment 18. To measure the capacity of a radio condenser.

The theory of the bridge connection is the same as in the case where a ballistic galvanometer is used. When a ballistic galvanometer is used the capacities must be comparatively large (Micro-farads). With the buzzer method small capacities can be compared fairly accurately. B is a buzzer; D is a dry cell; M is a small transformer or telephone coil; T is a telephone receiver; and L is an inductance placed in series with the telephone. The inductace L is not essential but at times it helps to give a sharper minimum sound. C_3 and C_4 are the capacities to be compared, R_1 and R_2 are resistance boxes. These resistances must be non-inductive.

If there is difficulty in getting a balance, interchange the telephone and buzzer connections on the bridge. In changing the resistances, loosen the plug and wiggle it, making and breaking the connection around the resistance coil rapidly. Absolute silence in the room is necessary for accurate balance. The equation for balance is.

$$C_3/C_4 = R_2/R_1$$

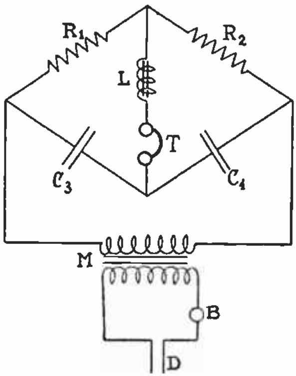

Fig. 25

The derivation of this equation is as follows:

In Figure 25 when the bridge is balanced and there is no current through the telephone, the potential across the resistance, R_1 is the same as the potential across the condenser C_3 or $Pd_1 = Pd_3$. In like manner, $Pd_2 = Pd_4$. The current through the resistance, R_1 is the same as the current through the resistance, R_2. And the quantity of electricity in C_3 is the same as the quantity in C_4.

From the above we have, $I_1 = I_2$ and $Q_3 = Q_4$.

Since, $Pd_1 = I_1R_1$ and $Pd_2 = I_2R_2$ also $Pd_3 = Q_3/C_3$ and $Pd_4 = Q_4/C_4$ we have $I_1R_1 = Q_3/C_3$ and $I_2R_2 = Q_4/C_4$. Dividing the last two equations one by the other term by term, we have $R_1/R_2 = (1/C_3)/(1/C_4) = C_4/C_3$.

Note how the ratio is stated. In stating the ratio the terms are read off in a circle around the diamond of figure 25. This is different from the ordinary resistance bridge used to measure resistances.

In this bridge we have, large capacity times small resistance equals small capacity times large resistance.

When both capacities are small, best results are obtained when the resistances are large.

If a variable capacity is given, measure it at ten positions of the dial.

After the first position is obtained for balance, the resistance in one arm of the bridge can be changed by a small amount and the point of balance can be found by changing the variable capacity and noting the reading of the condenser scale. In this way 10 readings can be taken in a short time.

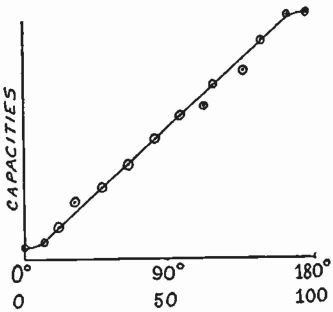

Fig. 26

Plot a curve using capacities as ordinates and scale readings as abscissas.

If the condenser is an old fashioned semicircular plate condenser, this curve should be a straight line except near the extreme ends, as in Figure 26.

Measure the capacity of a Leyden jar and of a fixed radio condenser. Make a glass plate condenser and measure, using the variable as a standard. Measure two capacities separately. Place in multiple and measure. Place in series and measure. Check with the computed values.

Check the value of the glass plate condenser by the formula $C=KS/4\pi d$. Divide by 900,000 to reduce to microfarads.

Starling, p. 325; Watson, p. 530; Stanley, Vol. I, p. 415.

CAPACITY BRIDGE

A bridge for the measurement of capacity can be made of four condensers. The connections are made as in Figure 27.

Condensers, C_1 and C_3 may be two variable condensers which have been calibrated.

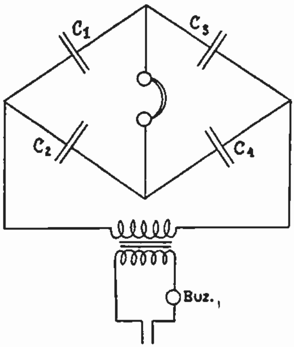

Fig. 27

If they are good semi-circular plate condensers which give a straight line curve, when capacity is plotted against dial settings, and the straight line passes through the zero point of the curve and both condensers are approximately alike, the ratio of the dial readings can be used as the ratio of the capacities.

C_2, can be the standard condenser and C_4 the unknown condenser.

If the standard is a "straight line capacity" condenser, semicircular plates, the capacity is proportional to the dial readings and facilitates calculation.

It might be remarked here that for most experimental purposes the "straight line capacity" condenser is much better than the modern shaped plate condenser.

In the case of the condenser bridge the ratio is $C_1/C_2 = C_3/C_4$. The derivation of this is left to the student.

The standard condenser may be a standard mica condenser whose capacity is .05 microfarads or less. Commercial fixed radio condensers whose capacity is about .001 microfarads may be mounted and measured by the instructor and used as a standard. The measured value being the correct value. The marked value is a very rough approximation to the true value. The standard condenser may be a condenser made of two large sheets of metal and mounted parallel to each other as described later.

Experiment 19. Measure the dielectric constant of oil.

Measure the capacity of an air condenser in air and again when immersed in oil. The ratio of the capacity with oil to that with air will give k, the dielectric constant.

Experiment 20. To make a condenser of tinfoil and photographic glass plates.

Connect the alternate sheets together. The capacity will depend upon the size and number of plates, and upon the thickness of plates. The thinner the glass the greater the capacity. Glass plate condensers can be used for grid condensers and for by-pass condensers. They can be used in parallel with the tuning condenser to increase the wave length range of a receiver. One or more glass plate condensers about .001 m.f. capacity can be arranged to be placed in parallel with a variable condenser .001 capacity. A switch can be made so as to use the variable alone, variable and No. 1, then 1 and 2, etc., Figure 28.

Grid condenser and by pass condenser can be made of tin foil and paraffined paper such as bread wrappers. Four or five square inches of surface is required for a grid condenser.

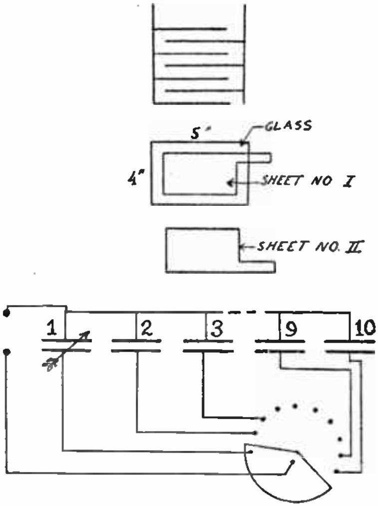

Fig. 28

If the grid condenser is mounted on a thin sheet of hard rubber with the terminals about ½ inch apart lead pencil marks can be made between the terminals for the grid leak. More lead makes less resistance.

Experiment 21. To make a standard condenser.

A standard condenser can be made of two heavy plane brass or aluminum sheets separated by small pieces of sheet glass. Use as little glass as possible to keep the sheets parallel to each other. The sheets should have 10 or more square feet of surface. Calculate the capacity using the formula

$$C=\frac{S}{4\pi d} \text{ Centimeters.}$$

Divide by 900,000 to reduce to microfarads. Unless the surface is large and the distance d small, edge effects may make the actual value greater than the computed value.

Experiment 22. Resistance and Phase angle of a condenser.

In a good air or mica condenser the resistance is very near zero and the current in the condenser is 90 degrees ahead of the electromotive force. The phase angle of the condenser is 90 degrees and the phase difference is said to be zero.

In a poor condenser there may be an appreciable resistance in the connections. The condenser may leak, and there may be a dielectric loss in the condenser. The residual charge of a Leyden jar is due to this dielectric loss. If the jar is charged and discharged very rapidly the glass will get hot showing that there is a dissipation of energy which appears as heat.

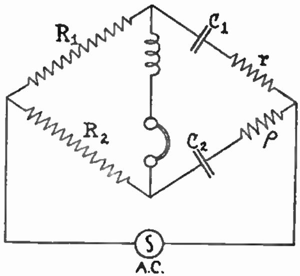

Fig. 29

Some of these heat losses may be in series with the condenser and others may be a high resistance path in parallel with the condenser. A resistance in parallel can always be represented or the effect duplicated by a resistance in series with the condenser. See theory of alternating current.

If a good standard condenser is compared with a paraffine paper condenser by the bridge method the minimum sound in the condenser will not be good. The two currents in the two condensers are not a maximum at the same time. The phase angle of the good condenser is 90 degrees and the other is less than 90 degrees. If a resistance box is inserted in series with the good condenser the phase angle of that branch of the bridge can be made to equal that of the poor condenser.

Connect the condensers to the bridge as in experiment 18. Adjust to the best minimum by changing R_1 or R_2. Insert resistance r in the arm with the standard until the minimum is the best.

Adjust R_1 and R_2 again and then adjust r again. When the best condition is obtained then, $R_1/R_2=C_2/C_1=r/\rho$. Where ρ, is the resistance in the condenser. The phase angle of the condenser is $1/\rho\ C\omega$. Or the phase difference is the reciprocal or $\rho C\omega$. Where ω is $2\pi n$. n being the frequency of the alternating source. For best results a good alternating source of pure wave form should be used instead of the buzzer.

Terry, p. 191.

Experiment 23. To measure the inductance of a coil. Anderson's method.

The method outlined here is one in which the effect of the inductance is balanced by a condenser.

Measure the resistance of the coil by means of a wheatstone bridge and galvanometer. Experiment 5. Connect the coil as in the diagram, Figure 31. Balance the bridge to the nearest ohm. If the resistance, S, of the coil is known, this can be done without a galvanometer. C is a condenser; r, is a resistance box; T, is a telephone; L_1, is an inductance the insertion of which helps in obtaining a distinct balance; M, is a telephone coil and B is a buzzer.

The balance is made by adjusting the resistance r until a minimum sound is heard in the telephone. The same precautions must be taken as to noise in the room as in the Buzzer-telephone method of measuring capacity.

The formula is $L=C(r(Q+S)+RQ)$. For derivation of formula see Starling. It will be noted that if the current

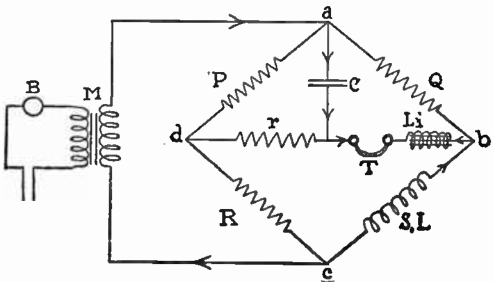

Fig. 30

is increasing as indicated by the arrows in the figure there will be a current through the telephone due to the

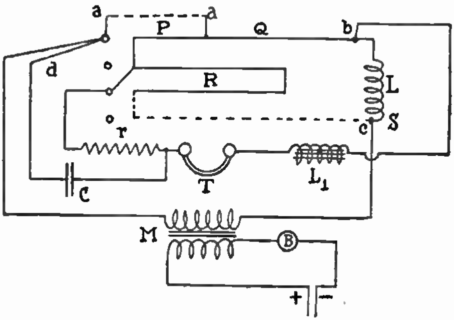

Fig. 31

charge of the condenser. At the same time, there will be a back E.M.F. in S towards b which will cause a current to flow through the telephone in the opposite direction.

The value of the first current will depend upon the resistance r. When r is adjusted until the two currents are equal, there will be a minimum or no sound in the telephone.

Figure 30 is the diagrammatic connection.

Figure 31 is the same connection using a Leeds Northrup box bridge. This method is more accurate when the inductance is greater than 1000 microhenries.

Measure the inductance of a single layer coil and check by the formula $L=4\pi^2n^2r^2l$ centimeter. n=turns per centimeter length. r=radius of coil. l=length of coil in

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H. Nagaoka's factor, K, for closely wound single layer solenoid coils. In the formula for the inductance of a single layer coil, $L=4\pi^2r^2n^2l\ K$, cm. K is given in terms of $2r/l$.

Diameter / length	*K*	*Diameter / length*	*K*
.00	1.000	.95	.700
.05	.979	1.00	.688
.10	.959	1.10	.667
.15	.939	1.20	.648
.20	.920	1.40	.611
.25	.902	1.60	.580
.30	.884	1.80	.551
.35	.867	2.00	.526
.40	.850	2.50	.472
.45	.834	3.00	.429
.50	.818	3.50	.394
.55	.803	4.00	.365
.60	.789	4.50	.341
.65	.775	5.00	.320
.70	.761	6.00	.285
.75	.748	7.00	.258
.80	.735	8.00	.237
.85	.723	9.00	.219
.90	.711	10.00	.203

centimeters. The formula assumes that there is no flux leakage at the ends, or that the coil is long compared to the diameter. The value calculated without the end correction factor will be greater than that obtained with the bridge. The bridge value should be the correct one.

The more correct formula is $L=4\pi^2n^2r^2lK$ where K, is H. Nagaoka's correction factor given in the table on page 34. Other slight corrections should be made for size of wire, etc.

Watson, p. 543; Stanley, Vol. 1 p. 418; Starling, p. 329; Terry, p. 172; Morecroft, p. 194; Bulletin of Bureau of Standards, 8, p. 224, 1912; Circular of the Bureau of Standards, 74, p. 252.

Experiment 24. Measurement of inductance—Maxwell's method.

This method consists of comparing the inductance of a coil with the capacity of a variable condenser.

Place the coil in a wheatstone bridge and balance the bridge for steady current. With the bridge balanced connect an alternating current in the battery position. And a variable capacity around the resistance arm which is opposite the inductance. Figure 32.

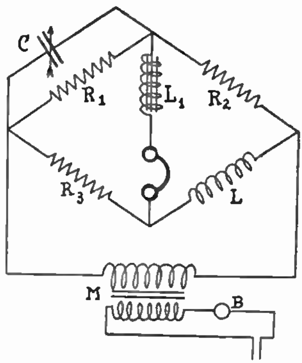


Fig. 32

Vary the capacity until the sound in the telephone, which is in the usual galvanometer position of the bridge is, a minimum.

$$\text{Then, } L = CR_2R_3 = CR_1R_4$$

Since the capacity of the usual variable condenser varies from .0001 to .0005 or .001 microfarads, the resistances must be so chosen that the products CR_2R_3 will be comparable to the inductance, L. With $R_2 = 100$ ohms and $R_3 = 100$ ohms the smallest value that can be measured is $.0001 \times 100 \times 100 = 1$ microhenry. This experiment works best with small coils. Terry p. 169; Starling, p. 326.

Experiment 25. Measurement of mutual inductance.

If two coils are connected in series and so placed that they do not affect one another then the total inductance is the sum of the separate inductances,

$$L = L_1 + L_2$$

If they are close enough together to affect each other, then,

$$L = L_1 + L_2 + M_{12} + M_{21}.$$

Where M_{12} is the mutual inductance or the E.M.F. induced in coil No. 1 by the current change of one ampere per second in coil No. 2, and M_{21} is the E.M.F. in coil No. 2 by the current change of one ampere per second in coil No. 1. Since

$$M_{12} = M_{21} \text{ then } L - (L_1 + L_2) = 2M$$

Connect the coils as in diagram Figure 31 or Figure 32 and place them so that M is in the same direction as L. That is, in order that the current may circulate in the same direction in both coils. Then,

$$L' = L_1 + L_2 + 2M.$$

Reverse the current in one coil. Then

$$L'' = L_1 + L_2 - 2M.$$

Subtracting we have,

$$L' - L'' = 4M$$

Take two coils such as a loose coupler tuning coil, couple as closely as possible and measure L' and L'', and compute M.

Couple the coils as loosely as possible and repeat the measurements. From the values compute the coefficient of coupling in each case. The coefficient of coupling,

$$k = M/\sqrt{L_1 L_2}.$$

The value of k, will vary from unity, close coupling, to near zero, loose coupling. When the value is over .5 it is usual to call it close coupling. When the value of k, is less than .5 it is called loose coupling. L can be measured using either a bridge method or a wave meter method.

Experiment 26. To obtain the characteristic curve of a crystal.

Connect a battery of four or six volts to a high resistance potentiometer, *abc*, Figure 33. Connect *a*, and the slider *c*, to a reverse key and then to the crystal through a galvanometer, *G*. Between *a* and *c* place a voltmeter. Measure the current through the crystal by means of the galvanometer as the potential between *a* and

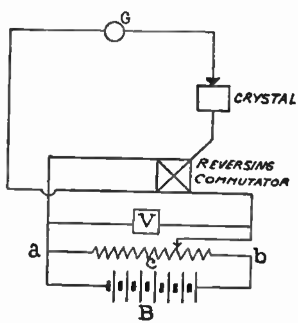


Fig. 33

c is increased. Reverse the commutator and repeat. Call the smaller set of readings negative and plot a curve using potential along X axis and and current or galvanometer readings along the Y axis.

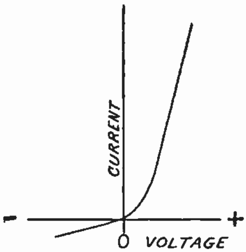


Fig. 34

Set the wire contact on the crystal, C, to a new position and repeat. With the potential positive hunt a spot on the crystal that gives large deflections of the galvanometer and repeat.

The resistance of a crystal can be measured with a box bridge. Measure with current direct and with current reversed through the crystal. Note the difference.

Various kinds of crystals can be tested in this manner. Stanley Vol. 1, p. 427.

THE WAVE METER

The wave meter is the measuring instrument which is peculiar to radio.

The wave meter consists of an inductance and a capacity connected in series with some sort of current indicator. Either the inductance or the capacity is variable.

In alternating current when we have a circuit containing resistance, inductance and capacity we have,

$$I = E/\sqrt{R^2 + (1/C\omega - L\omega)^2},$$

where E is the E.M.F.; R, the resistance; C, the capacity; L, inductance; $\omega = 2\pi n$; where, n, is frequency. If $L\omega = 1/C\omega$, or $n = 1/2\pi\sqrt{LC}$, the current is a maximum, i.e., $I = E/R$ and the circuit is in resonance with the E.M.F. of the exciting source.

Also we have seen that if the circuit is discharged it will oscillate with a frequency $n = 1/2\pi\sqrt{LC}$.

In radio as in light we do not usually speak of the frequency of the oscillation but of the wave length. Since in any medium the velocity of the waves is independent of the source, the wave length depends only on the frequency of the vibrating source, and since electric waves are disturbances in the ether of space, the velocity of electric waves is the same as that of light. $v = 3 \times 10^{10}$ centimeters per second or 3×10^8 meters per second. The more exact value is 2.998×10^8 meters per second. Since in any medium $v = n\lambda$ where, λ is the wave length, we have,

$$\lambda = \mathrm{v/n}$$

$$\lambda = 3 \times 10^8/(1/2\pi\sqrt{LC}) = 3 \times 10^8 2\pi\sqrt{LC} \text{ meters}$$

In the above L is measured in henries and C in farads. When the inductance is expressed in microhenries and the capacity is expressed in microfarads the value of λ is,

$$\lambda = 3 \times 10^8 2\pi\sqrt{L10^{-6}C10^{-6}} = 1884\sqrt{LC} \text{ meters.}$$

If we use centimeters and microfarads we have,

$$\lambda = 59.6\sqrt{LC} \text{ meters.}$$

The U.S. Government is encouraging the use of frequency in kilocycles instead of wave lengths in meters. To get the frequency in any case divide the velocity of light by the wave length. Since, when the inductance is constant, the square of the wave length is proportional to capacity it is usually more convenient to calculate wave length than frequency.

Experiment 27. To calibrate a wave meter—Calculation.

We shall assume that we have a coil whose inductance has been measured as in Experiment No. 23 or 24 and a variable condenser whose capacity curve has been drawn as in experiment No. 18.

Express the inductance in microhenries and the capacity in microfarads. With the inductance and the capacity of the condenser, taken from the capacity curve at some point of the scale, at zero say, supply in the formula $\lambda = 1884\sqrt{LC}$ and solve for the wave length. From the capacity curve take the capacity at 10, supply again, and calculate the wave length.

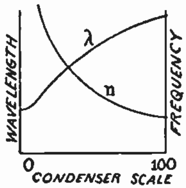


Fig. 35

Repeat for every ten divisions of the condenser scale. From the results plot a curve with condenser scale along the X axis, abscissas, and wave length along the Y axis, ordinates. Calculate the frequency for each 10 degrees and plot a curve, x = condenser reading and y = frequency.

We now have a curve from which the wave length of any circuit which is in unison with our circuit can be read. As a check on the accuracy of this method the wave meter can be compared with a standard. See Experiments 28 and 29. Stanley Vol. I, p. 409.

Experiment 28. To calibrate a wave meter by means of a standard wave meter.

With a standard wave meter the two meters can be brought close together, one can be used as a source or sending station and the other as a detector or receiving station. One is connected as in Figure 36a with a buzzer and the other as in Figure 36b or Figure 36c with a crystal and telephone. See diagrams of method of connecting.

Adjust the meters to approximate resonance. Adjust the crystal receiver to its most sensitive condition and move the meters apart, or loosen the coupling (make the mutual inductance as near zero as possible). Adjust the meters to resonance and read the scale of the condenser of your wave meter and the wave length of the standard. Repeat for several points distributed on the scale and plot a curve as in the previous experiment.

DIAGRAMS OF METHODS OF CONNECTING THE DETECTOR TO THE WAVE METER AND OF USING THE WAVE METER AS A SOURCE OF HIGH FREQUENCY OSCILLATIONS

The most simple method of using a wave meter is to connect the coil, L, and the variable condenser, C, in series with a radio frequency milliammeter or galvanometer. These instruments can be obtained such that 100 milliamperes will give the full scale deflection. The coil is brought near the radio frequency source, such as a transmitting station, and the condenser changed until the reading of the current as shown by the meter is the greatest. Then the reading of the condenser is taken and from the calibration curve the corresponding wave length is found. Instead of the milliammeter a small incandescent lamp such as a flash lamp bulb may be substituted. The readings on the condenser are taken when the lamp is the brightest.

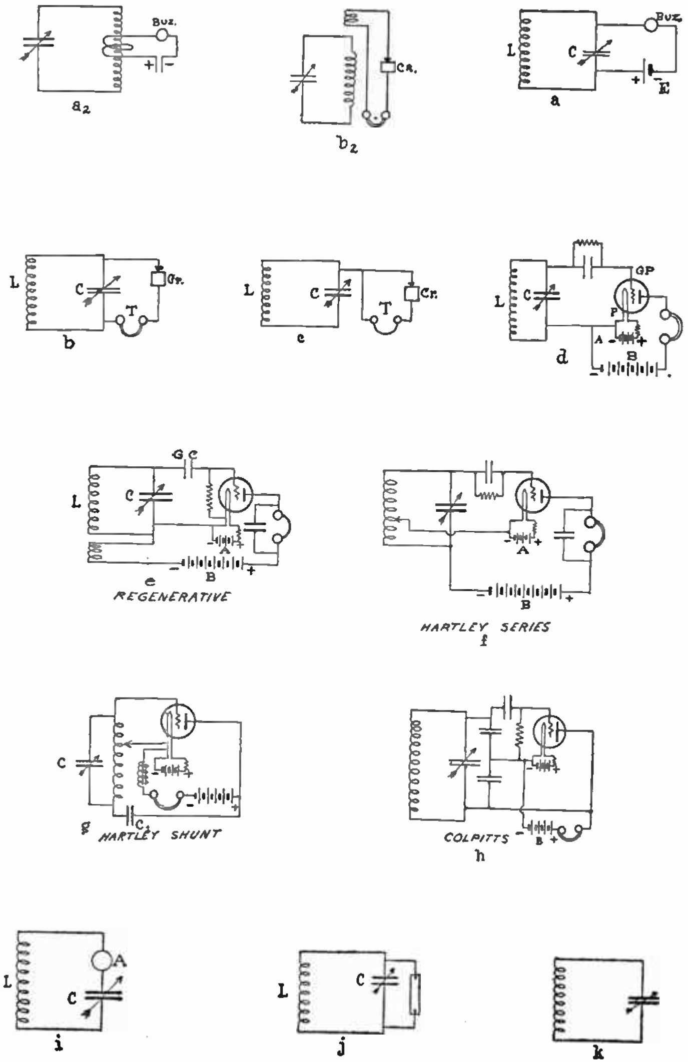
Figure 36i shows the connection. L is the coil, C is the variable condenser and A is the milliammeter or lamp bulb.

A Geissler vacuum tube, can be placed in multiple with the condenser. The current in the wave meter is the greatest when the tube glows the brightest. Figure 36j shows the diagrammatic connection.

When the current in the oscillating circuit is not very great there will not be enough current in the wave meter to give a deflection of the milliammeter or to cause the lamp or bulb to glow. A telephone and crystal can be used as an indicator of current. One will recognize this connection as being essentially the secondary of a two coil loose coupler crystal receiver. This will work for damped waves, but not for continuous waves, Figure 36b.

The wave meter can be used as a generator of damped waves by placing a battery and buzzer around the condenser as in Figure 36a. This is essentially the connection of the primary of the oscillating transformer of a damped wave or spark transmitting station. The dry cell and the buzzer take the place of the transformer and spark gap.

Figure 36a is a sending circuit. L is the coil; C, the capacity; Buz., a buzzer, and E, a battery. The frequency is $n=1/2\pi\sqrt{LC}$. The group frequency is that of the buzzer. Figure 36b is a receiving circuit; Cr is a crystal detector and T, a telephone. Figure 36c is the same as Figure 36b except that the telephone and crystal do not change the wave length of the circuit as much as they do in Figure 36b. The signals will be more intense with Figure 36b. Figure 36d is a vacuum tube detector circuit. Figure 36e is a "regenerative feed-back" or oscillating circuit. This can be used for the reception of


Buz.
a2
Cr.
b2
L
C
Buz.
E
a
L
C
Cr.
T
b
L
C
Cr.
T
c
GP
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P
A
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G C
L
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B
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REGENERATIVE
A
B
HARTLEY SERIES
f
C
C1
g
HARTLEY SHUNT
COLPITTS
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h
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i
L
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Fig. 36

either damped or undamped waves, and as a generator of undamped waves. Figure 36f is an auto feed back circuit, in which the feed back coil is a portion of the main coil. This circuit is known as the Hartley Series Circuit. In this both the D.C. and A.C. components of the plate current pass through the lower part of the coil, L. Figure 36g is known as the Hartley shunt circuit. In this circuit the A.C. component of the plate circuit passes through the condenser C_1. Figure 36h is a capacity feed-back circuit. The wave length depends upon the combined capacity of the condenser, C, and the two condensers which are in series. Figure 36i shows the wave meter with a lamp bulb or milliammeter in the circuit. This can be used when the circuit to be measured contains a large current. Figure 36j contains a Geissler tube for an indicator. Figure 36k is the coil and condenser connected alone. This circuit is used when the resonance click method is used with an oscillating receiver. In the regenerative or oscillating circuits the telephone should be by passed with a condenser, capacity .0005 to .001 microfarads. This by pass is for the radio frequency component of the plate current. In the Hartley shunt circuit the telephone should not be by passed. This circuit requires a choke coil in series with the battery.

When the resistance of the coils is large the resistance may be so great the buzzer will not operate. The buzzer may be connected to two or three turns of wire wound about the coil and connected as in Figure 36a_2.

The telephone and crystal may be connected to a coil of few turns and placed near the tuned coil as in Figure 36b_2.

See Bureau of Standards Circular 74, p. 104; or Signal Corps Radio, p. 393.

Experiment 29. Resonance click method of using a wave meter.

The wave meter is connected as in Figure 36k. An oscillating tube receiver is tuned on a distant sending station and the wave meter is brought near the receiver. When near enough the wave meter will absorb enough energy to cause the receiver to cease oscillating. This will cause a click in the phone. Loosen the coupling until the click occurs when the wave meter is exactly tuned, the click occurring at the same point on the condenser when decreasing as when increasing the capacity.

At certain times the Bureau of Standards transmits standard wave lengths and by using this method the wave meter can be tested or calibrated. For schedule consult Radio Service Bulletin (25 cents per year), Supt. of Documents, Washington, D.C.

If two or more standard wave lengths are received, one near the lower range and another near the upper range of the wave meter, and the square of the wave length, λ^2, is plotted against condenser readings, a straight line will be obtained. From this line the wave length at various points is taken and a calibration curve is plotted. This assumes that the condenser is a straight line capacity condenser, semi circular plates.

This involves the principles of Experiment 30. This method can be used in Experiment 35.

Experiment 30. To measure the capacity of a coil, the natural wave length of the coil, and to correct a wave meter.

All coils and even straight wires have a certain amount of capacity. This is usually considered to be so small that it is neglected. In coils used with condensers of small capacity this becomes a source of error.

We shall assume that the inductance of the coil is known and that the condenser is calibrated properly. In the equation $\lambda = 1884\sqrt{LC}$ we see that λ^2 varies with C or $\lambda^2 = (1884^2 L)C$. Thus $1884^2 L$ is the slope of the straight line obtained by plotting, λ^2 along the Y axis and, C along the X axis. Capacity in microfarads is to be plotted instead of condenser scale readings.

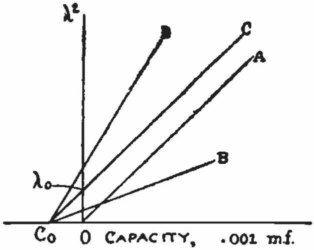


Fig. 37a

Calling C_0 the capacity of the coil we see that the true equation is $\lambda^2 = (C + C_0)1884^2 L$. Our data when plotted gives us a straight line through zero while the true line should cut the X axis to the left of zero by an amount equal to C_0.

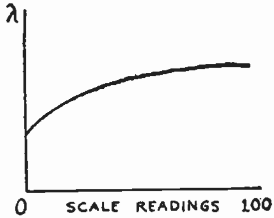


Fig. 37b

It will be seen that the error due to C_0 is greatest for small values of the condenser readings. When the capacity of the condenser is 100 times C_0 the error of capacity is 1% while when the capacity in the condenser is equal to C_0 the error is 50%.

A second wave meter whose maximum wave length is equal to the wave length near the lower end of the curve of your wave meter can be used to correct for C_0. The second wave meter need not be accurately calibrated. The error of inductance will cause the slope of the straight line to be wrong. The error due to capacity of the coil will be small as long as large values of capacity in the condenser are used.

We shall assume that the maximum range of the second wave meter corresponds to 10 or 20 on the dial of the condenser of the meter being corrected. Take several readings of the wave length as given by the smaller wave meter at points ranging from 0 to 10 on the larger wave meter. Plot these readings on the same sheet as the λ^2, C curve, these will give a straight line which will cut the X axis at C_0.

This line will not be parallel to the first line unless the second wave meter were accurately calibrated. But the line will cut through C_0 since we have assumed that we have used large values of capacity in the smaller wave meter. Since we have assumed that the inductance of the first wave meter is correct the slope of the first line is correct. Draw a straight line through C_0 parallel to the first line and this is the correct λ^2C line since the slope is correct and it passes through C_0. The intercept on the Y axis gives λ_0^2, or the natural wave length of the coil, i.e., the wave length of the circuit when there is no condenser in the circuit.

From this corrected line the values of λ^2, and C can be taken off and from this data a corrected curve for the wave meter can be plotted. Note that the convenient curve to use is the λ, condenser reading curve while we have been plotting λ^2, capacity.

USE OF THE WAVE METER

The wave meter can be used to measure the wave length of a sending set, to measure the wave length of stations that are received, to measure the inductance of coils, to measure the capacity of a condenser, and, when provided with hot wire ammeter or galvanometer, it can be used to measure the decrement of a sending set, the resistance of a circuit, and the phase angle of a condenser.

Experiment 31. Measurement of capacity. Capacity and inductance of the wave meter being known.

The following four experiments, 31, 32, 33 and 34 are very much alike in theory and one experiment overlaps the other. The four experiments meet the four possible conditions met in practice and on this account the four experiments are listed.

This experiment assumes that we have two unknown condensers, one being variable, and an unknown inductance as well as the wave meter. Let, C, be the unknown fixed condenser, C_1 the known wave meter condenser, C_2 the variable condenser, L_1 the wave meter inductance, L_2 the second inductance. The value of C must be less than the maximum value of C_1.

Connect as sender and receiver as in first and second diagrams for wave meter connection, Figure 36a and b. Replace C_1 with C, the second wave meter being C_2L_2.

Adjust to resonance, by varying C_2 then $CL_1 = C_2L_2$.

Replace the fixed condenser with C_1 and tune by changing C_1, keeping C_2 unchanged, then $C_1L_1 = C_2L_2$ and $C = C_1$ the value of which is read from the curve.

Replace C_2 with C and tune to resonance by adjusting C_1, then, $L_2 = C_1L_1/C$.

Since L_2 is now known C can be replaced by other unknown condensers and their capacity determined.

Experiment 32. To measure the capacity of a condenser. Wave meter calibration given.

A wave meter with the calibration curve being used. This involves having a known inductance.

Make the known inductance and unknown capacity into a wave meter and use one wave meter as a sender and the second as a receiver. See Methods of Connection of Wave meter for diagrams of connections, Figure 36a and 36b.

Adjust the crystal for its most sensitive position and loosen the coupling until the telephone responds for sharp resonance.

$$\text{Since } \lambda = 1884\sqrt{LC}$$
$$C = \lambda^2/(1884)^2L$$

C will be expressed in microfarads if L is expressed in microhenries. This experiment is very closely allied to the corresponding experiment of measurement of Inductance, Experiment 33.

Experiment 33. To measure the inductance of a coil.

First having the wave length calibration curve given. This method requires the use of a known condenser. Place the known condenser in series with the inductance and thus make another wave meter. Use one of the meters as a sender and the second as a receiver, and adjust to unison with very loose coupling. See Figure 36 for connections. Adjust the crystal to its most sensitive condition and loosen the coupling until the telephone responds only at sharp resonance.

$$\text{Since } \lambda = 1884\sqrt{LC}$$
$$L = \lambda^2/(1884)^2 C$$

L will be expressed in microhenries if C is in microfarads.

Experiment 34. To measure the inductance of a coil, the capacity and inductance of the wave meter being known.

This involves the measurement of capacity as well as inductance and is explained in the experiment Measurement of Capacity of a Condenser, the Capacity and Inductance of the Wave meter being known (Experiment 31).

In these experiments it is assumed that the range of the wave meter will include the range of the unknown capacity and inductance combination.

Experiment 35. To calibrate a wave meter using over tones.

If a standard wave meter or other standard wave length is available it is possible to calibrate any other wave meter using overtones. The two wave meters are connected to tubes so as to oscillate, using the Hartley or other oscillating circuit. Figure 36f. A telephone in either circuit, preferable in the circuit of higher wave length, will respond to the "beat" tone when the lower wave length circuit is in resonance with the fundamental, first second, etc. overtone of the higher wave length of the circuit; or to wave length of λ, 2λ, 3λ, etc. Where λ, is the wave length of the lower wave meter.

Thus if given a wave meter whose range is 200 to 600 meters it is possible to calibrate a wave meter whose range is 600 to 1800 meters using the second overtone. The range can be higher if the response to the higher overtones is good. Having the 600 to 1800 meter calibrated a third meter can be calibrated whose range is 1800 to 5400 meters by using the second as the standard.

If the standard is known to be accurate at one particular point or wave length, only, a wave meter can be calibrated by having the meter respond to λ, 2λ, 3λ. A sending station which always uses a definite known frequency can be the standard. Then if the condenser capacity is proportional to the condenser readings, that is if the capacity is measured at a number of points and these points give a straight line when capacity and scale readings are plotted, the square of the wave length, λ^2, is proportional to the condenser readings and the three or four points will lie on a straight line when the square of the wave length is plotted against the condenser scale readings. From this straight line the value of λ^2 can be taken and the value of λ at 20 or more points can be obtained.

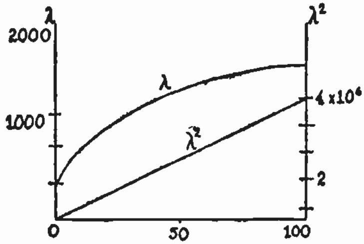


Fig. 38

It is well to plot λ^2 capacity curves when using the overtone method as it is easy to detect any error. If an approximate calibration is first obtained the danger of mistaking the overtone is much less.

In this experiment the value of the old fashioned semicircular plate condenser will be noted. Since the capacity is proportional to the dial readings the square of the wave length is proportional to the dial readings and when plotted a straight line is obtained. The intercept on the X-axis is proportional to the capacity of the coil. This will be true for each and every coil used with the condenser.

With the shaped plate straight line frequency or straight line wave length condenser assuming the plates are shaped right the curve will be a straight line, only when the coil has a certain capacity. If the condenser is so shaped as to give a straight line with one coil it will not give a straight line with a second coil of different self capacity.

Experiment 36. To calibrate a wave meter using standard frequencies from the Bureau of Standards.

We shall assume that the wave meter consists of a variable condenser and an inductance coil, and that the condenser has been tested as in Experiment 18 and that it has been found that the capacity of the condenser is proportional to the scale readings.

Use a regenerative receiver which can be made to oscillate at will. A loud speaker connected to the receiver will be found to be advantageous. The wave meter may be excited by means of a buzzer or it may be connected as a low power tube generator using an ordinary amplifying tube with about 60 volts on the plate. The connection may be the Hartley circuit. See specifications for coils and generator in Notes and suggestions for Laboratory Apparatus.

It will be a great help if the wave meter or receiver has been approximately calibrated before the test. This will enable one to find WWV, the Bureau of Standards station.

When WWV has been found listen to the preliminary announcements and then set the tube oscillating and tune until the beat tone is zero frequency or disappears. Then adjust the wavemeter to the same wave length and record the readings of the condenser. Experiments 28 and 37. It is well to record the readings on the receiver noting the amount of coupling and the readings of the aerial circuit as well as those of the primary circuit.

The Resonance Click Method can be used, Experiment 29. However, this is not as accurate as some other methods.

If the generator does not cover the same band of waves as those sent out the method of Experiment 35 can be used.

After the readings have been taken it is well to plot λ^2 and condenser readings. This should give a straight line. If any point fall off this line any considerable amount it is evident that an error in reading or recording has been made. If the readings of receiver as well as wave meter have been recorded the receiver and wave meter can set up as per the record and as a usual thing the error of reading, or record will be apparent.

After the straight line has been plotted the exact calibration curve or data can be taken from the straight line. Experiments 30 and 35.

It will be evident that the calibration will be exact for the particular connections which were used in the calibration.

Use the same tube with the same *B* battery and the exact relative position of the various parts, condenser coils and connections.

For schedule from WWV see Radio Service Bulletin, Supt. of Documents, Washington, D.C. (25 cents per year.)

It will be well to practice this method by tuning to the carrier wave of the various broadcasting stations. The wave length may be taken from the lists of stations as found in the radio magazines.

Experiment 37. To measure the wave length of distant sending station.

Adjust the receiver until the station is heard clearly. Gradually loosen up the coupling, keeping the station as clear as possible. Make the coupling as loose as possible without losing the station. Connect a buzzer to the wave meter and bring it near the receiver; adjust the wave meter to resonance without changing the receiver. Make the coupling of the wave meter to the receiver as loose as possible. Read the wave length from the wave meter calibration. If the coupling is not loose there may be two points of resonance. Read the wave length for both points. To find which is the correct value, cut a few turns out of the primary of the receiver, decrease the inductance and if the stations can not be heard in the receiver the longest wave length is the correct value.

If the wave length of the stations is known, this method can be used to calibrate a wave meter. If the wave meter consists of a coil of a few turns and an ordinary 43 plate condenser the square of the wave length and condenser readings when plotted will give a straight line through zero. From this line the wave length at any reading of the condenser can be found.

Stanley, Vol. 1, p. 426.

Experiment 38. To measure the natural wave length of an aerial.

Connect an inductance of a few turns in series with the aerial and a buzzer or shunted buzzer around the coil, Figure 39. Bring a wave meter near the aerial and measure the wave length. Cut out one turn of wire and measure again. Repeat until a very few turns are left, one if possible. Plot turns of wire along *X* and wave length along the *Y* axis. This will be almost a straight line. Extend the line back to zero turns, the intersection on the *Y* axis will give the value of λ_0.

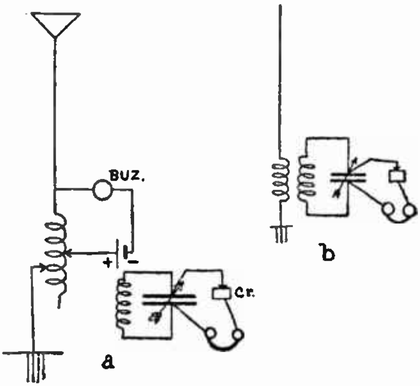


Fig. 39

A short wire stretched at some little distance from the aerial and a calibrated receiver can be used, Figure 39.

2nd Method. A spark gap can be placed in series with the aerial and a strong buzzer or small induction coil is connected around the spark gap, Figure 40. The wave meter is brought near the aerial and readings taken. In this case there will probably be a noise in the wave meter phone due to the

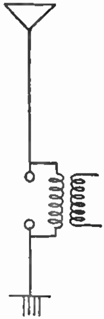


Fig. 40

field of the induction coil. One must distinguish between that and the noise due to high frequency. The intensity of the coil induction will remain constant while that due to the wave will vary and be a maximum when tuned on the wave.

It may be necessary to use a short wire and calibrated double coil receiver. Both primary and secondary circuits of the receiver must be tuned and the coupling made loose.

3rd Method. Place a large condenser in series and connect the spark gap of a buzzer around the capacity and measure with a wave meter, Figure 41. If the condenser is large it will have no effect on the wave length.

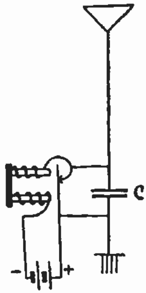


Fig. 41

Experiment 39. To measure the capacity of an aerial.

The capacity can be measured the same as the capacity of any condenser, using the bridge buzzer method, Experiment 18.

The capacity can be measured by means of a wave meter. Measure λ_0, Experiment 38, then place a capacity in series and measure again.

$$\text{Since } \lambda_0 = K\sqrt{L_0C_0} \text{ and } \lambda_1 = K\sqrt{(C_0C_1)/(C_0+C_1)L_0}$$
$$C_0 = C(\lambda_0{}^2 - \lambda_1{}^2)/\lambda_1{}^2$$

Experiment 40. To measure the inductance of an aerial with a wave meter.

Measure λ_0, Experiment 38, and place a known inductance in series and measure again.

Since $\lambda_0 = K\sqrt{L_0C_0}$ and $\lambda_1 = K\sqrt{(L_1+L_0)C_0}$

$$L_0 = \left(\frac{\lambda_0^2}{\lambda_1^2 - \lambda_0^2}\right)L_1$$

The capacity and inductance of an aerial is distributed in the aerial. The measurements at high frequency will not be exactly the same as that measured at low frequency.

Stanley, Vol. I, p. 421.

VACUUM TUBE CHARACTERISTICS

There are four characteristic curves which show the operating properties or characteristics of the three electrode tube. They are the Filament, the Mutual, the Plate, and the Grid characteristic curves.

Experiment 41. Filament characteristic, filament current, plate current.

Connect the tube as in the diagram, Figure 42. Use a 22½ volt dry battery on the plate. (Do not measure the E.M.F. of the battery with a voltmeter more than is necessary.) Connect a 6 volt storage battery to the filament, using an ammeter and variable resistance in series. Instead of a filament ammeter a voltmeter may be placed across the filament from $F-$ to $F+$, Figure 42. The filament potential can be changed from the maximum rated filament potential down to lower values. If a low filament

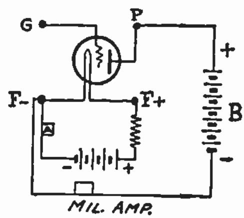


Fig. 42

potential tube is used place a 1.5 volt dry cell or a 2 volt storage cell in the filament circuit.

A Weston voltmeter can be used in place of the milliammeter.* Resistance in the plate circuit does not change the current much. (Weston Model 280 voltmeter takes 15 milliamperes for full scale deflection.) Vary the filament current from maximum down to near zero and measure the plate current. Plot curve X = filament current, or filament potential, Y = plate current.

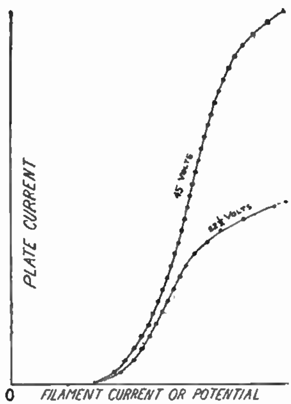


Fig. 43

Reverse the 22½ volt battery and try again. Repeat with a 45 volt battery on the plate.

Experiment 42. Mutual characteristic, plate current, grid potential characteristic.

Connect the tube as in the diagram. For the variable potential on the grid use a high resistance potentiometer around a 22½ volt B battery or a potentiometer across the terminals of a 110 volt D.C. lighting

* Any voltmeter can be used in which the voltmeter resistance is small compared to the tube resistance. The deflection can be multiplied by the proper constant to give the current in milliamperes. If the resistance, R_v, of the voltmeter is known, the constant is $1/R_v$. (The current when the meter reads one volt on the scale is $1/R_v$ amperes.)

circuit. See that the potentiometer in the 110 volt circuit does not get hot.

Keep the potential of the plate and the current or potential in the filament circuit constant. Change the potential of the grid from zero to positive by steps of a few volts and read the current in the plate circuit until the plate current ceases to change rapidly. If the tube is a soft or gas tube the current in the plate circuit suddenly may become very large. Do not continue.

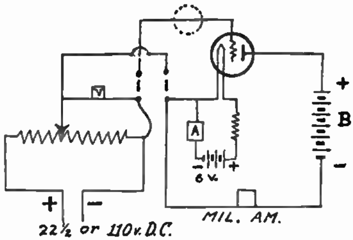


Fig. 44

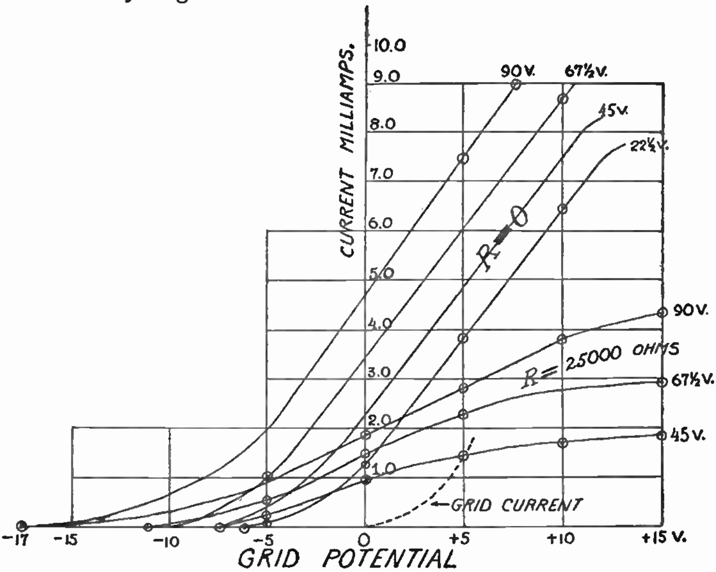


Fig. 45

The grid potential is measured by the voltmeter between the slider and the end of the potentiometer.

Change the potential of the grid to negative values by reversing the commutator. Take readings until the plate current is zero.

Repeat with a different current in the filament circuit. Never use more filament current than the rated value given by the makers of the tube.

Repeat with 45 volts in the B Battery. Repeat with 67½ volts and 90 volts. Insert a resistance in the plate circuit and repeat.

The data for measuring the amplification constant of the tube can be taken with this experiment. See Experiment 49. The reverse key may be a simple one made of four pools of mercury in a block of wood as diagrammed in Figure 44. The connections are made between the pools by means of two parallel wires in the vertical position as shown in the diagram. To reverse the connections the wires are lifted and placed across the pools in the horizontal position.

A reverse key may be made of a double pole double throw electric switch by connecting as in Figure 58.

Bucher Vacuum Tubes, p. 26, 37; Stanley, Vol. 2, p. 19, 23: Turner, p. 94; Jansky, p. 224; Lauer & Brown, p. 150; Morecroft, p. 478.

Experiment 43. Plate characteristic.

Plate current, plate potential. The connections for the plate characteristic is practically the same as that for the mutual characteristic, Figure 44.

In this the grid potential is kept constant and the plate potential, B battery, is varied and the corresponding plate current is read. When a number of these are taken we have a set of curves as in Figure 46.

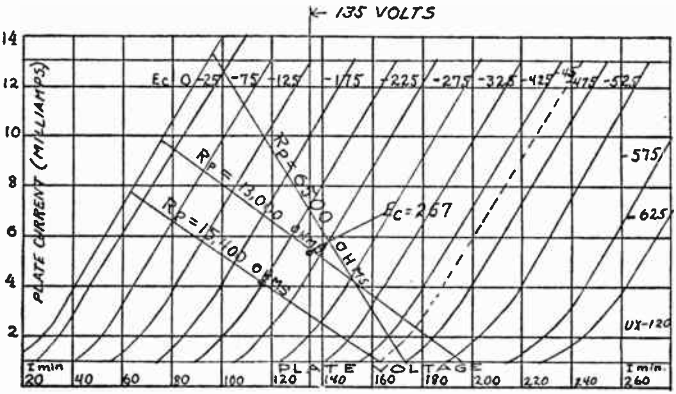


Fig. 46

These curves can be used to determine the amplication of the tube with a resistance coupling as in a resistance amplifier. Suppose the tube is connected to a resistance, R_p, of 6500 ohms in the plate circuit. The tube is to be worked at an average plate potential of 135 volts with an average plate current of 7 milliamperes. Since we have the equation $Pd = E - IR \cdot E$, the B battery potential must be $135 + .007 \times 6500 = 135 + 45 = 180$ volts. The straight line marked $R_p = 6500$ is drawn through the point, 0, 180 and the point, 7, 135. This line gives the plate potential on the plate when the current has any particular value.

Thus when the grid is -22.5 the current is 7 milliamperes, and the plate potential is 135 volts. If the grid increases to -17.5 volts the current is 8.4 milliamperes and the potential is 126 volts. If the grid potential decreases to -27.5 volts the current decreases to 5.6 milliamperes and the potential of the plate increases to 144 volts. The total change of the grid potential is 10 volts and the total change of the plate potential is 18 volts. The amplification is 1.8. The total change of plate current is $8.4-5.6=2.8$ milliamperes.

If we consider the grid to be actuated by an A.C. E.M.F. the grid potential is $5/\sqrt{2}$ volts, the plate variation is $9/\sqrt{2}$ volts A.C. The A.C. current in the plate is $1.4/\sqrt{2}$ milliamperes. The power is EI, which is $9\times.0014/2$ $=.0063$ watts.

With 13000 ohms in the plate circuit and about 225 volts, B, battery the voltage amplification is greater but the power output is less. The average potential on the plate being practically the same.

Experiment 44. Grid characteristic. Grid current, grid potential.

Connect as in Figure 44, except that a sensitive micro-ammeter or galvanometer is placed in the grid circuit. with $22\frac{1}{2}$ volts on the plate, vary the grid potential and read the grid current. Repeat with 45 volts on the plate. Plot a curve using grid current or galvanometer deflections along the vertical and grid potential along the horizontal.

Particular care should be taken in locating the position of the zero current point of the curve. Figure 47.

THE VACUUM TUBE AS A DETECTOR

In the plate current grid potential characteristic curve of the tube it is seen that it consists of a curved line at the ends and a straight part in between. The curved part at the foot of the curve will be noted. The Figure 48, represents the

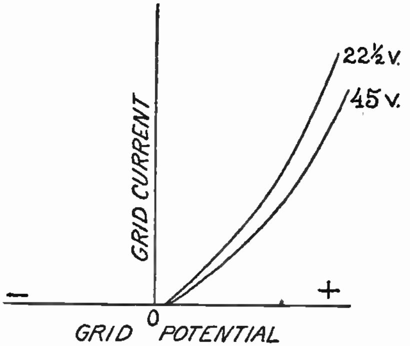


Fig. 47

foot of the curve. If by means of a battery or potentiometer the potential of the grid is brought to the point *a*, which corresponds to the point *b*, of greatest curvature of the curve. Then if an alternating potential is placed upon the grid so as to cause the grid potential to vary between *c* and *d*, the

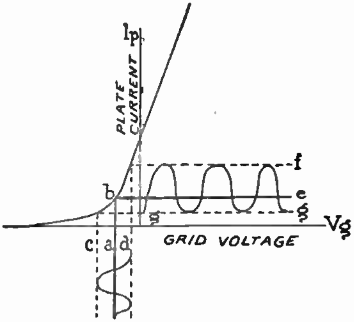


Fig. 48

plate current which was constant at *e*, will vary between

g and f. But since the curve is not straight the upper loops of the plate current will be greater than the lower loops and the average current through the telephone will be increased. If this effect is due to a damped train of waves each train will cause a click in the telephone. A series of trains will cause a musical note. The rectified component of the current through the telephone or the signal current is equal to

$$\frac{v^2}{4} \cdot \frac{d^2 i_p}{d V_g^2}$$

Turner, p. 111; Bucher Vacuum Tubes, p. 32, 46; Stanley, Vol. II, p. 41; Morecroft, p. 519.

Experiment 45. The vacuum tube as a detector.

Connect the detector tube up as in the experiment to obtain the I_p, V_g curve. Place a sensitive galvanometer in the grid circuit and take readings of the grid current as well as of the plate current when the grid potential is changed. Pay particular attention to the lower part of the curve, i.e. from the point where the current is zero up to the straight line part of the curve. Plot both curves on the same sheet, using V_g as abscissas for both curves and I_p in milliamperes, and I_g in scale deflections as the two values of ordinates. If the figure of merit of the galvanometer is known, the exact value of the grid current can be used, but this is not necessary. The plate potential should be

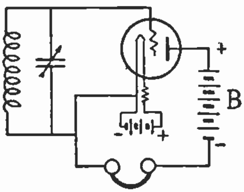


Fig. 49

16 to 22½ volts. Consult the specifications for the particular tube used.

If these curves have been run for the tube before this it is not necessary to run them again. Secure the curves and refer to them frequently.

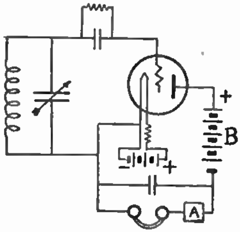


Fig. 50

It will be noted that the point on the X axis where I_g is zero corresponds to some point well up on the lower curved part of the I_p curve.

If the mean value of the grid potential corresponds to the point of greatest curvature of the I_p, V_g curve, we have positive rectification, i.e. the lower half of the sine curve is smaller than the positive half. This sort of detection corresponds to that which is made use of in the crystal detector. If a grid condenser is placed in the grid circuit and the average potential of the grid is held near the point of greatest curvature of the grid current grid potential curve we will have negative rectification, or grid current detection.

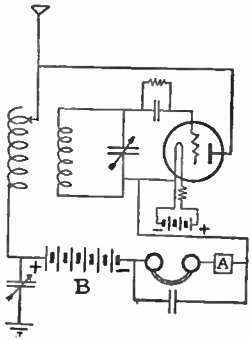


Fig. 51

When using a grid condenser, a resistance of a megohm or more must be placed from the grid to the filament or around the grid condenser to allow the accumulated charge to leak off. The value of the grid condenser is usually from

.0001 to .0005 microfarads. The grid leak must be adjusted to suit the tube used. See Experiment 20 for directions for making condensers and Experiment 62 for grid resistance.

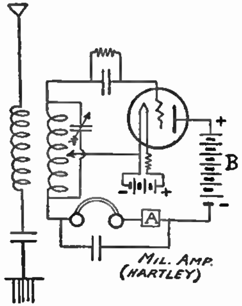


Fig. 52

Connect up two wave meters, one as a buzzer sender and the other as a receiver with a crystal detector, Figures 36a and 36b. Loosen up the coupling by increasing the distance between the two or by turning the coils at right angles until the signals can just be heard, when the crystal is adjusted to the most sensitive condition.

Replace the crystal by a detector tube connected as in Figure 49 and observe the intensity of the signal heard and compare with that heard with the crystal.

Place a milliammeter or voltmeter in series with the telephone. Place a by pass condenser, .0005 to .001 microfarads, around both the phones and meter. A .0005 m.f. variable condenser can be used. Observe the action of the meter when the signals are the loudest. By means of the reading of the plate current as given by the milliammeter the position of the working point on the characteristic curve can be determined. Adjust the

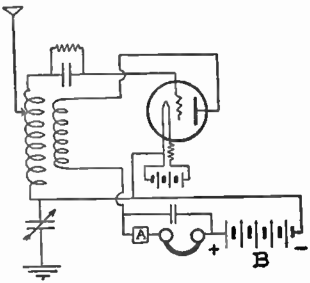


Fig. 53

position to the point of greatest curvature on the plate current grid potential curve and note the intensity of the signals.

Place a grid condenser with grid leak in series with the grid circuit as in Figure 50 and note the relative intensity. Adjust the plate current to the value which corresponds to the point of greatest curvature on the grid current, grid potential curve. It will be noted that the grid condenser acts as a negative *C*, battery. The amount of this action depends upon the resistance of the grid leak.

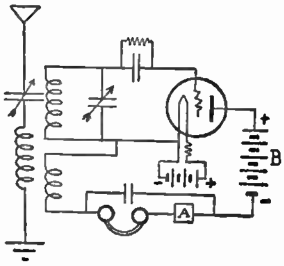


Fig. 54

The greater the resistance of the grid leak the greater the negative *C*, battery effect. This action can be controlled by adjusting the grid leak. The grid leak may be a commercial fixed grid leak. In this case it will be necessary to adjust by replacing with another of a different value. The grid leak may be made of lead pencil marks on a hard rubber strip connected around the grid condenser. More lead pencil marks makes the resistance less. To increase the resistance use an eraser. After adjusting measure the resistance of the leak and the capacity of the grid condenser if variable.

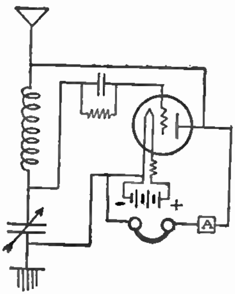


Fig. 55

Adjust to the best condition and note the relative intensity.

Change the connection of the receiver into a regenerative receiver. The Hartley circuit Figure 52 or the tickler coil circuit Figure 54. Adjust the amount of regeneration and note the intensity of the signal from the buzzer. It will be noted that the signal is increased very much by the regenerative circuit.

The receiver can now be coupled to a coil connected to an aerial and signals received from commercial or broadcasting stations.

Since most of the radio telegraph stations sending code are continuous wave stations it will be necessary to couple the regenerative receiver up so as to cause the tube to oscillate and use the self heterodyne method of reception. The connection to the aerial can be inductively coupled to the aerial as in Figures 52 and 54, or the aerial can be conductively coupled as in Figures 51, 53, and 55. When inductively coupled to the aerial and the coupling is made very loose the wave length of the sending station can be measured if the receiving coil and condenser has been calibrated as a wave meter. This is particularly true if the Hartley circuit is used.

With conductive coupling the capacity and inductance of the aerial is added to that of the wave meter and the readings have no value. The wave can be measured by bringing a wave meter, which is actuated by a buzzer near the receiver. Figure 55 is the ultraaudion circuit which is very efficient and requires little apparatus.

If a telephone station is received the regeneration must be made small enough to cause the circuit to cease oscillating. This can usually be done by diminishing the filament current. Turn the tube down until it ceases oscillation. The most sensitive position is at the point where the tube is just about to oscillate. It is instructive to practice setting up the various circuits.

It will be noted that this experiment is largely qualitative.

In your report give the advantages and disadvantages of the various circuits. Give the call and wave length of stations received. Explain the action of the milliammeter.

Bucher Vacuum Tubes, p. 46; Stanley, Vol. II, p. 41.

Experiment 46. Heterodyne method of detecting spark stations and C.W. stations.

If the detecting circuit is subjected to a high frequency E.M.F. the wave length of which is near that of the signal to be detected, or if the detecting tube is oscillating, see later for oscillating circuits, a spark station will produce a peculiar sound something like that of escaping steam.

This method is usually much more sensitive than that of the straight detector circuits. 1000 times is claimed in Turner's Outline of Wireless, p. 123.

The objection to this is the poor tone quality, and all spark stations sound alike. A spark station gives a wave form of very poor quality compared to C.W. stations. The beat tone produced by the composition of the spark wave and the wave from the detecting tube circuit is very irregular. Part of the increased sensitivity of this method is due to the fact that the circuit is regenerative.

With this method stations can be heard with the tube oscillating that cannot be heard when the tube is not oscillating. This method must be used for continuous wave stations.

Experiment 47. To measure the relative detecting efficiency of vacuum tubes.

When the grid potential is made to correspond to the curve part of the I_p, V_g curve and the grid is subjected to an alternating potential the average value of the plate current is increased. If the curve is straight the average value will be the same as that when the potential is constant.

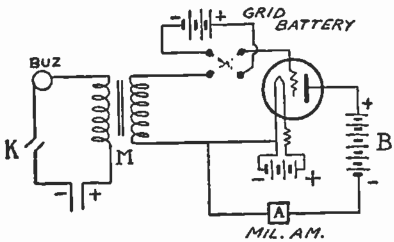


Fig. 56

Connect a telephone induction coil, M, to the grid circuit of the tube, Figure 56. To the primary of the coil connect a dry cell or a two volt storage cell with a buzzer in series. To the plate circuit in series with the B, battery connect a sensitive milliammeter or dead beat galvanometer. In the grid circuit place a grid battery so that the potential of the grid may be made any convenient potential. Four good dry cells will usually give enough grid potential. A potentiometer with a voltmeter to measure the value of the grid potential at any setting of the potentiometer can be used. See Figure 58.

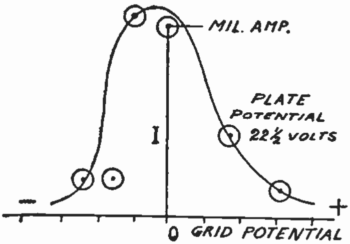


Fig. 57

Heat the filament with the normal current. Read the value of the plate current. Close the key in the buzzer circuit and read the current again. The difference between the two readings is proportional to the detecting efficiency of the tube. Change the value of the grid potential and repeat. With most detectors the tube works best near zero grid potential or a volt or two negative.

Start with the grid four cells negative and take readings, repeat with 3 neg.; 2 neg.; 1 neg.; 0; 1 pos.; 2 pos.; 3 pos.; 4 pos.

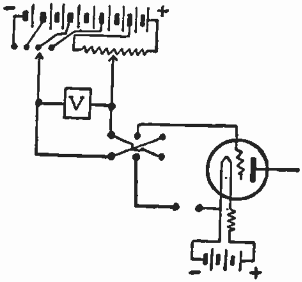


Fig. 58

Plot the grid potential and the difference of plate current.

Change the plate potential and repeat.

By comparing curves the proper value of the plate battery and of grid potential can be determined for the best detecting conditions of the tube.

With a grid condenser in the grid circuit the plate current will diminish when the buzzer operates. This diminution is proportional to the detecting efficiency. Repeat the experiment with the grid condenser in the circuit.

If a milliammeter is not at hand a Weston voltmeter can be used reading the deflection of the needle in arbitrary units. The resistance in the volt meter is small compared to that in the tube. Note. The proper value of the grid leak resistance is essential for success with a grid condenser. This is adjusted by trial. When the best condition is obtained measure the resistance of the grid leak. See Experiments 20, 62, and 93 for methods of making grid condensers and grid leaks.

A telephone can be used and the intensity of the signals can be estimated if a milliammeter or galvanometer is not available.

Special C, Battery Potentiometer. A special C, Battery can be constructed as in the diagram, Figure 58. Several dry cells are connected in series. The first cell is connected to a carbon-potentiometer of some 200 or more ohms resistance. A key should be inserted in this circuit so as to disconnect the cell from the resistance when not in use. The terminals of the other cells are brought to a series of contacts arranged on the circumference of a circle. A rotating switch is arranged so as to make contact at any desired point. The contact switch changes the potential on the grid by the value of one cell at a time. The potentiometer will give fractions of a cell's voltage. A voltmeter connected across the terminals of the potentiometer will give the voltage on the grid. If the resistance of the voltmeter is great compared to that of the carbon resistance the potential on the grid will be approximately the same with the voltmeter connected or disconnected. This can be determined in any case by taking readings with the voltmeter connected and disconnected. If the readings are the same there is no appreciable error. If there is a difference then the readings must be taken with the voltmeter connected. A double pole double throw switch connected as a reverse key is shown in the diagram Figure 58.

Experiment 48. To compare the relative efficiency of various methods of detection.

The theory and general principles of this experiment is much the same as that of Experiment No. 45. Experiment 45 is qualitative while this experiment is quantitative.

Connect a buzzer to a wave meter so that it may be used

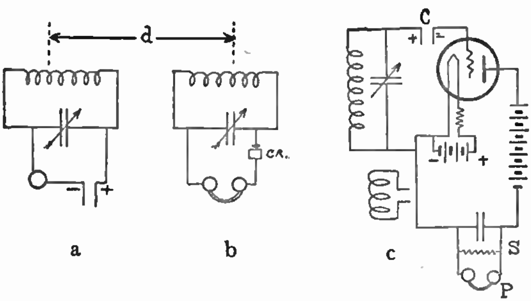


Fig. 59

as a generator of damped waves. Use a 2 volt storage battery instead of a dry cell in the buzzer circuit. The buzzer must be capable of running a long time without any variation of the high frequency current in the wave meter. Connect a crystal and a telephone to a second circuit as in Figure 59b adjust the crystal to the most sensitive condition. Loosen the coupling by increasing the distance, d, or by rotating the coil until the sound is just audible. Keep both tuned to the same wave length. It will be better if it is possible to place the receiver in a sound proof room with the transmitter in another room.

Replace the crystal detector with a vacuum tube detector keeping the coil in the same position. The connections are diagramed in Figure 59c. By means of a resistance, S, in shunt with the telephone decrease the sound until it is just audible. Then since $I_p = I(S/(S+P))$, and $I/I_p = (S+P)/S =$ the detecting efficiency of the tube compared with the crystal detector. $I =$ total current, $I_p =$ current through the phone, the least audible current; $S =$ the resistance in the shunt; and $P =$ the resistance of the phone. See experiment 88. The C battery, the battery in the grid circuit, should be adjusted until the response is the loudest.

Remove the C battery and in its place put a grid condenser with a grid leak resistance. Adjust the condenser and leak resistance until the response is the best and measure as before.

Place a regenerative coil in the plate circuit and repeat again. Couple the regenerative coil for the best response.

Couple the regenerative coil until the tube oscillates and repeat again.

The value of the plate battery should be changed until the best value is found. In some soft tube the value of the plate potential is very critical. The grid potential can be changed conveniently if a potentiometer is placed across the terminals of the filament.

An audibility meter is convenient to use instead of the shunt around the telephone.

The experiment can be extended by using a different type of tube. It will be found that the best adjustments of plate and grid voltage for one tube may not suit a second tube.

Van der Bijl p. 349.

Experiment 49. The tube as an amplifier.

Turner, p. 94, 98; Bucher Vacuum Tube, p. 51; Stanley, Vol. II, p. 51.

Select a hard tube and run the grid potential plate current characteristic curves at several voltages from the lowest up to the highest at which the tube will not "flare over", (Ionization by Collision), Experiment 44. The curves may be considered to be a series of parallel straight lines if the upper and lower ends are neglected.

Plate current 1 Milliampere. a = 7.

V_p	22.5	45	67.5	90	112.5	
V_g	+ 3.5	0	-3	-6.3	-10.	
V_p+aV_g	45	45	46.5	45.9	42.5	

The straight part of the curve can be represented by the equation $I_p=A+B(V_p+aV_g)$ where I_p is plate current, V_p is the plate voltage, V_g is grid potential, a is the voltage amplification constant, and A and B are constants to be determined.

$dI_p/dV_g = aB = G$, the grid potential plate current conductivity or the mutual conductance.

$dI_p/dV_p = B = P$, the plate potential plate current conductivity.

$$a = aB/B = G/P.$$

From the slope of the grid potential, plate current curves, G can be calculated. If the various values of the

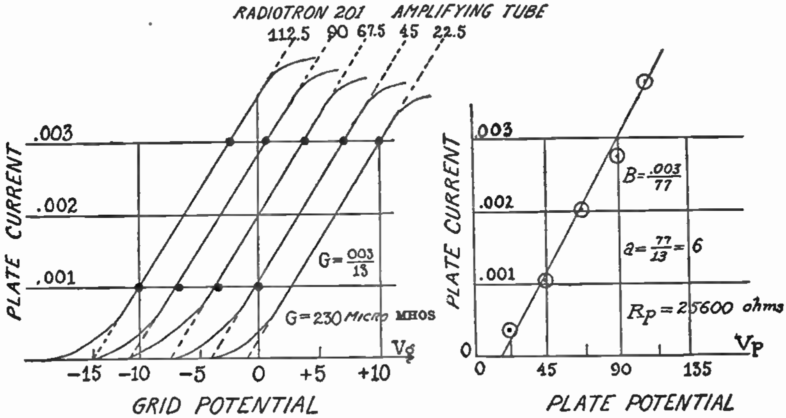


Fig. 60

plate current where the curves are cut by some vertical line, such as the line grid potential equal zero, are taken and a plate current plate potential curve is plotted, a straight line is obtained from the slope of which P can be obtained.

From these values of G, and P, a, the amplification constant, can be had. After a is determined, the quantity $V_p + aV_g$ for any constant value of I_p should equal a constant. Fill in the table from the values taken from the curve, where I_p = Constant value. Determine G the mutual conductances and $1/G = R_g$, the mutual resistance.

Determine P and $1/P = R_p$, the resistance of the tube.

Note: The characteristic curves of the "treated" filament tubes do not approximate to a straight line as nearly as do the tungsten filament tubes. Figure 60 are curves taken with a tungsten filament 201 tube. Figure 45 is taken with a 201A tube.

Experiment 50. Measurement of the amplification constant.

The tube is connected, Figure 61, to a resistance or potentiometer by means of which the ratio of the potential applied to the plate to that applied to the grid can be changed. When there is minimum noise in the telephone in the plate circuit we have, $a = R_2/R_1$.

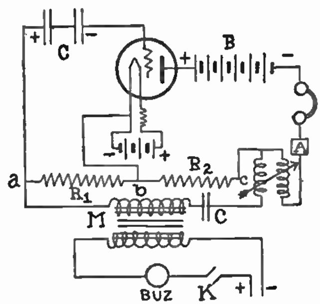


Fig. 61

By referring to the I_p V_g, curve of the tube the proper value of the potential of the B battery and of the C battery, (the battery in the grid circuit), can be obtained. It is often convenient to make the B battery such that the C battery can be zero. In the curves given in Experiment, 49, B should be 60 volts with zero grid potential. A condenser of large capacity can be placed in series with the secondary of M. A variometer connected as in the figure corrects for phase change. The condenser and variometer can be omitted.

Use two resistance boxes for the potentiometer. R_1 should be 10 to 100 ohms.

A D.C. milliammeter or galvanometer can be sub stituted for the telephone if a battery of 10 volts and key is inserted in place of the telephone coil. Adjustment is made until there is no change of deflection when the key is closed or opened. The filament current should be the normal rated current. Change the filament current to a lower value and measure again. Measure several tubes using rated current and potentials.

Lauer & Brown, p. 160; Van der Bijl, p. 194; Stanley Vol. II, p. 348; Morecroft p. 899.

Experiment 51. Determination of the resistance of the tube.

1st method. The resistance of the tube can be determined from the curves since the resistance is the reciprocal of the conductivity. Or $R_p=1/P$. Experiment 49.

2nd method. The resistance can be measured by inserting a known high resistance in series with the milliammeter in the plate circuit.

Since $E=I_1R_p$ when the inserted resistance is zero and $E=I_2(R_p+R)$ when R is inserted.

$R_p=RI_2/(I_1-I_2)$.

Experiment 52. Measurement of the resistance of a tube, bridge method.

Connect as in the Figure 62. This will be seen to be a simple bridge circuit for measuring resistance. Since A.C. is used with a telephone the batteries in the arms can be disregarded. R_1 and R_2 are the ratio arms and R is the rheostat arm of the bridge.

$$R_x = \frac{R_2 R}{R_1}$$

Lauer & Brown, p. 161; Van der Bijl, p. 203.

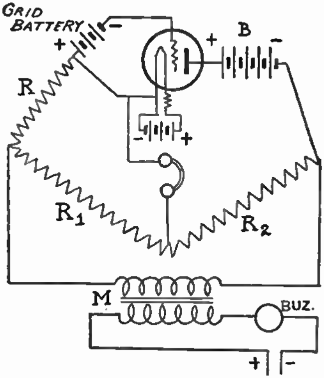


Fig. 62

Experiment 53. To measure the plate capacity and the grid capacity of tubes.

The capacity between the various elements of a vacuum tube has a distinct value and becomes of great importance in short wave work.

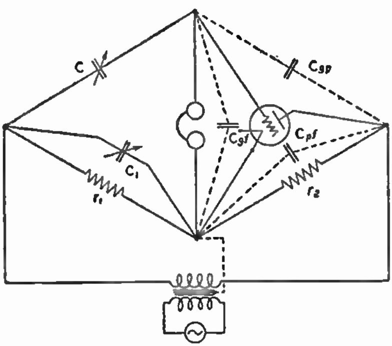


Fig. 63

Diagram of connections for measuring grid-plate capacity of a tube. Diagram taken from NEMA Handbook.

The capacity can be measured the same as that of the capacity of a small condenser. The measurements should be made when the tube is mounted as it is when used as a detector or as amplifier.

For the plate capacity treat the tube as a condenser whose terminals are filament and plate. For the grid capacity, use terminals filament and grid. The heating battery should not be connected. It is of interest to take measurements with the filament cold and then hot. If the tube is in a socket part of the capacity is due to the socket. Diagram Figure 63 gives connections. C_1 compensates for C_4f.

The bridge method can be used, or the wave meter method. The capacity is small and the distributed capacity of the coil should be taken into account if the wave meter method is used.

Experiment 54. To measure the mutual conductance of a tube.

The mutual conductance of a tube is usually defined as the amplification constant divided by the resistance of the tube.

This will be seen to be the same as the constant, G, of Experiment No. 49. This is dI_p/dV_g, the change of the plate current divided by the change of the grid potential.

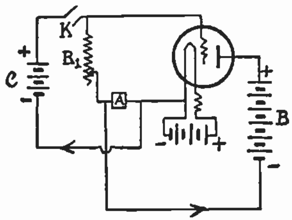


Fig. 64

The mutual conductance can be determined as in Experiment No. 49. It can be determined by getting the amplification constant and the resistance of the tube and dividing. The mutual conductance can be measured directly by the following method. The tube is connected with a milliammeter in the plate circuit as in the Figure 64. A second battery C, of small potential is connected to the grid circuit so that the current from this battery flows through a resistance R_1 so that the potential of the grid is changed by an amount IR_1 when the key, K, is closed.

Since $dI_p = dE_p/R_p = a\ dE_g/R_p$, $dI_p/dE_g = a/R_p = G_m$, $G_m = dI_p/dE_g = dI_p/I_1R_1$. Then if $dI_p = I_1$, $G_m = I_1/I_1R_1 = 1/R_1$.

Connect the battery, C, so that the current through it will flow backward through the milliammeter when the key is closed. The plate current flows forward through the milliammeter. Then if the resistance, R_1 is adjusted so that there is no change of deflection when the key is closed we have the change of the plate current equal to the current from the battery, C. Then $I_1 = dI_p$ and $G_m = 1/R_1$. Reverse the battery C and adjust again.

The battery should be adjusted so that the current I_1 through the milliammeter is of the order of one milliampere. It is assumed that the tube is operated on the straight part of the characteristic.

The mutual conductance of the tube should be large in a good tube. This will be seen to mean that the amplification constant of the tube is large and the resistance of the tube is small. The mutual conductance is usually expressed in micromhos. The mutual conductance of 201 tubes is about 400 micromhos. The value will depend on plate potential and filament current. Determine G_m of several types of tubes and compare with the values calculated by other methods.

Van der Bijl p. 202.

Experiment 55. The vacuum tube as an oscillator.

When the grid of a tube is made positive the plate current is increased. If the plate current is passed through a coil of wire such as *F*, in the Figure 65 and this coil is coupled to the coil, *L*, so that the mutual inductance is such as to increase the grid potential while the current is increasing the change of the grid potential will be much greater. When the grid potential is reversed the effects will be reversed. Energy is fed into the oscillating circuit, *LC*, from the plate circuit. If there is more energy given to the circuit than is used up in the circuit, radiated as heat say, then the circuit, *LC*, will oscillate and the current in *LC*, will increase until the energy used up in the circuit is equal to that fed into it.

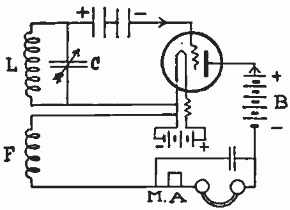


Fig. 65

There are several different connections which will serve as oscillator circuits. All radio telephone and C.W. circuits come under this class.

The following general directions should be followed in order to obtain the maximum current in any particular case.

(1) Uncouple the two coils, *i.e.* change the connections so that the circuit will not oscillate.

(2) Adjust the grid potential by means of a battery so that the plate current is ½ of the maximum plate current, see grid potential plate current curve. Some circuits require a grid condenser in the grid circuit. The value of the grid condenser and the resistance of the grid leak must be adjusted so that the average potential of the grid has this value. This must be done

while the circuit is oscillating. See experiment 93 for grid resistance.

(3) Gradually couple up the coils until oscillation begins, and then a little more as a margin of safety. When the tube begins to oscillate there will be a peculiar click in the phone. If a milliammeter or voltmeter used as a milliammeter is in series with the phone there will be a sudden kick of the pointer. A by-pass condenser must be around the phone and milliammeter.

(4) Keeping the product CL constant, *i.e.* wave length constant, adjusting as in (3) on each occasion until the oscillatory current is a maximum. The amplitude of oscillation, is,

$$I_1=\sqrt{V_0I_s/2R}$$

Turner p. 134

These directions must be followed in principle as the exact order of proceedings will differ with the particular circuit. The above directions will apply to the circuit of Figure 65.

Connect up two such circuits. (It will be noted that this is the wave meter circuit shown in Figure 36e, Diagrams of Methods of Connection of Wave Meters.)

When the two circuits are almost in unison there will be a shrill tone heard in the telephone. This note will get lower in pitch and disappear when the circuits are exactly in resonance.

Measure capacities and inductances using this method of "detection" instead of the buzzer crystal method. Compare wave meter calibration with this method. Two students working together can compare results of previous work. Experiments 31, 32, 33, 34, 28, and 35.

Experiment 56. Characteristic of an oscillating tube.

When a tube is set into oscillation there will be, in general, a change in the D.C. current of the plate circuit. This is due to the rectified component of the R.C. current. When the tube is oscillating near the lower end of the plate current, grid voltage curve there is positive rectification, and when near the top of the curve there is negative rectification.

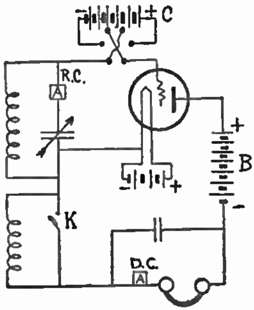


Fig. 66

Connect as in the Figure 66 placing a regenerative coil in the circuit. A loose coupler with a feed-back coil will answer the purpose.

Place a by-pass condenser around the milliammeter and telephone in the plate circuit. Tune with the variable condenser in oscillating circuit. The *C*, battery, the battery in the grid circuit, is composed of a few low resistance dry cells. If old dry cells, high resistance, are used there will be an effect such as that obtained with a grid condenser in the circuit.

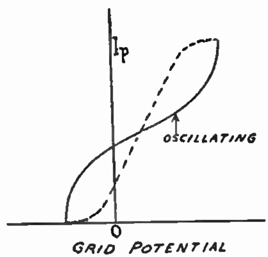


Fig. 67

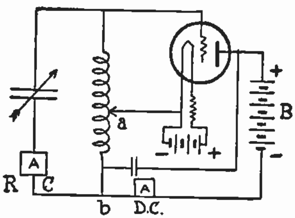
When the coils are coupled loosely so that the tube does not oscillate the curve obtained is the same as the plate current grid potential, curve, Experiment 44. Take the plate current grid potential, curve and then close the coupling until the tube begins to oscillate and repeat the observations. Or couple the coils until the tube begins to oscillate and "kill" the oscillation with a short circuit around the feed-back coil. Plot the "oscillating" plate current on same sheet with the I_p, V_g curve, Figure 67.

Read the radio frequency current by means of the hot wire ammeter, R.C., in the oscillating circuit and record. Plot a curve, X=grid potential, Y=high frequency current. If small tubes are used the R.C. current may be too small to give a reading.

The feed back coil may be connected to an aerial and relative intensity of signals from C.W. stations and spark stations, pure and heterodyned can be observed.

Experiment 57. Adjustment of an oscillating circuit.

Take a hard tube and run the characteristic curves, connect the tube up to an oscillating circuit as in the diagram, Figure 68. Place a D.C. milliammeter in the plate circuit and a hot wire ammeter in series with the condenser. The D.C. instrument will measure the plate current plus the rectified component of the R.C. current. The hot wire instrument will measure the R.C. current in the oscillating circuit. Regulate the grid potential by means of a low resistance



λ CONSTANT
Fig. 68

battery in the grid circuit. Make the grid potential such as to make the plate current small, some place on the lower half of the characteristic curve. Connect the filament connection at the bottom of the coil, at the plate connection, and read both meters. Move the filament connection up a turn or two and read. Take readings with the filament connection at regular intervals along the coil.

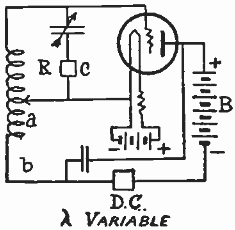


Fig. 69

As the filament connection is moved the relative number of turns in the plate coil and grid coil is changed. Thus the values of M, the mutual inductance, and self inductance is changed. Plot a curve X = number of turns of wire between the filament connection, a, and the plate connection on the coil, b, and Y = the D.C. current. Also a second curve where Y = the R.C. in the hot wire ammeter.

Make the grid potential near the middle of the characteristic curve and repeat. Then repeat with the grid potential near the top of the curve. Plot curves for each case.

In the first case the plate current will be increased when the oscillation is vigorous. In the last it will be diminished while in the second it will remain practically constant.

The intensity of the oscillation will depend upon the value of inductances. There is a certain ratio which will give the best result. This is shown by the hot wire instrument. The current in this circuit may be much greater than in the plate current. The value in this circuit depends upon the resistance, *i.e.* $I = E/R$. If a wave meter with a low resistance meter in the circuit is brought near the oscillating circuit the current in the wave meter may be greater than that in the main circuit.

Experiment 58. The oscillating tube and parallel resonance.

The oscillating tube can be considered to be a particular case of parallel resonance, Experiment 16.

Connect the tube with the tuning coil and condenser in the plate circuit. In the grid circuit connect tickler coil, Figure 70.

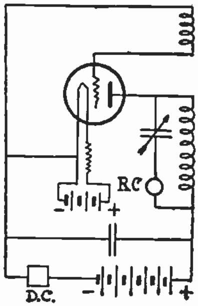


Fig. 70

The grid circuit can be considered to be a device which varies the plate current and which takes little or no energy. The plate current can be considered to have two components a constant D.C. current and an alternating radio current the frequency of which is governed by L and C in the tuned circuit. The R.C. current in the plate circuit then is the resultant of the two currents, one the condenser current and the other the current through the coil. These two currents are practically the same in numerical value and almost in opposite phase.

Let the vertical dotted line represent the direction of the E.M.F. If the resistance is considered to be all in the coil the condenser current is represented by *oc* which has a positive phase angle of 90° in advance of the E.M.F. The current through the coil lags behind the E.M.F. by an angle represented by the angle *pol*. The current through the coil is represented by *ol* whose magnitude is approximately equal to *oc*, and nearly opposite to *oc*. Both are equal to the current as measured by the radio ammeter in series with the condenser. The vector difference is *op* and is equal to the radio frequency current flowing into the plate.

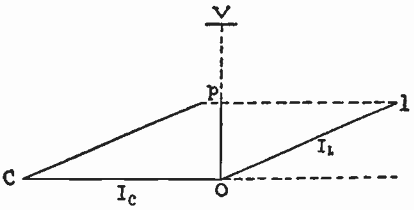


Fig. 71

The plate current can be estimated by the reading of the D.C. ammeter. See Experiment 107. The D.C. meter reads the average current in the plate, which is approximately the maximum R.C. current.

The virtual current is the max./1.41. Lay out the vector diagram, having *oc* and *ol* equal to the radio milliammeter reading, and *op* equal to 1/1.41 of the D.C. ammeter reading.

The tangent of $pol = L\omega/R$ and the tangent of $plo = R/L\omega = op/ol =$ plate current divided by the resonant current.

Measure the resistance of the circuit by the resistance variation method, Experiment No. 80. Measure the wave length with a wave meter and the inductance of the coil L. (If the condenser C has been calibrated the value of L can be calculated from the wave length). Then $R/L\omega$ should equal the ratio of the currents.

Notice, use precaution in measuring the resistance in Experiment No. 80.

This check will be rather rough but a thorough understanding of the principles gives one an insight into the theory of oscillation.

This experiment can be extended by placing the tuned circuit in the grid circuit and proceeding as above.

Experiment 59. The tube oscillating at low frequencies.

If an audio frequency transformer is used as the inductance the tube can be made to oscillate at low frequency and the tube becomes a low frequency alternator. The frequency depends upon the inductance of the coil and upon the capacity of the condenser used. With some audio amplifying coils using a 43 plate variable condenser the frequency is low enough to be counted. Connect the condenser to the terminals of the secondary coil. Figure 72. Connect the same two points to the filament and to the grid of the tube. Connect the primary of the coil in the plate circuit with a *B* battery and a telephone. If the tube does not oscillate reverse the connections of the primary coil.

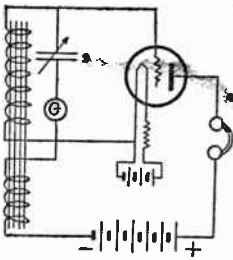


Fig. 72

The tone in the telephone will be a very low note, perhaps low enough so that the individual oscillations can be counted. Change the capacity of the condenser and note the change of the frequency. A galvanometer can be placed in the oscillating circuit and the alternations be made visible to a class.

To Measure the Inductance of an Audio Transformer.

Place the transformer coil in the circuit of a tube so that the tube will oscillate at a frequency which can be counted.

The time of vibration, $T_1 = 1/n = 2\pi\sqrt{LC}$.

Add a certain amount of capacity and $T_2 = 2\pi\sqrt{L(C+c)}$, where c is the added capacity. Then,

$$T_2^2 - T_1^2 = 4\pi^2 Lc \text{ And,}$$

$$L = (T_2^2 - T_1^2)/4\pi^2 c$$

Count the number of vibrations in a certain time, 1 minute say, and determine T, the time in seconds of one vibration. C must be expressed in farads. Then L will be in henrys. The two coils can be connected in series and connected to the tube using the Hartley connection. Then,

$$L = L_1 + L_2 + 2M.$$

See Experiment 66.

Experiment 60. Measurement of the amplification constant. Use of an electrostatic volt meter or electroscope.

It will be noted that when the grid voltage is changed the plate current is changed. The potential between the terminals of the plate and filament is that of the B battery or is constant unless there is an appreciable resistance inserted in series with the battery. With a resistance in series the dV_p, is equal to the change of the $Pd.$, potential difference, at the terminals of the resistance. Since $Pd = Ir$, $-dV_p = dI_pR$, where R is the inserted resistance.

Since $I_p = A + B(V_p + aV_g)$, $dI_p = BdV_p + aBdV_g$

$$= PdV_p + GdV_g$$

$$-dV_p = R(PdV_p + GdV_g)$$

$$-dV_p = dV_g RG/(1+RP) = dV_g (G/P) \ R/(R+1/P),$$

$$-dV_p = dV_g aR/(R+R_p)$$

Since $G/P = a$, and $\frac{1}{P} = R_p$.

If R is made large in comparison to R_p, then the quantity $R/(R+R_p)$ approaches unity, and then dV_p/dV_g is equal to a, the amplification constant. The actual potential between the plate and filament must be several volts or the current must be one or two milliamperes so there are practical difficulties in making R great. If $R = R_p$ the actual measured amplification will be one-half of a, the theoretical value.

If $R = 4R_p$ the value is .8 of a, and the actual potential across the plate will be 1/5 of the B battery.

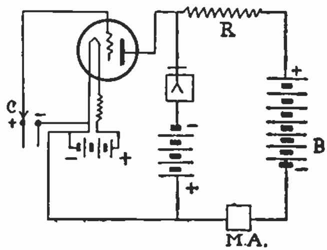


Fig. 73

Connect a high resistance in series with a B battery of one or two hundred volts and connect an electrostatic voltmeter or an electroscope across the plate terminal to the filament, Figure 73. Change the potential of the grid a volt or two and measure the change in the plate potential, from the known value of $R + R_p$ and the readings calculate a.

Note that this is the principle of the resistance amplifier.

If the potential between the plate and filament is too small to use the electroscope, a B battery can be used to increase the potential between the case and the leaf system of the electroscope. Connect the positive terminal to the filament and the negative to the case of the electroscope. See Experiments 62 and 93 for method of making resistances. However it is better to use a good grade of commercial resistances, those that are constructed for resistance amplifiers.

For construction of an electrostatic voltmeter see Notes on Laboratory Apparatus.

TWO STAGE RESISTANCE AMPLIFIER

The same principle can be used in a two stage resistance amplifier. Make the connections as in the diagram, Figure 74. The same precautions as to the relative values of the tube resistance and inserted resistances must be taken. The values of the B batteries must be increased as R is increased. The grid leak resistance R_1 must be such as to keep the operating point of the second tube near the middle of the grid potential plate current curve.

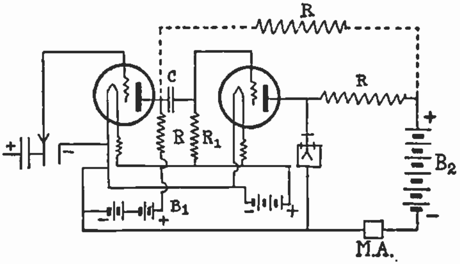


Fig. 74

Either one or two B batteries are used. The dotted line in the diagram gives the connection when one battery is used. The C battery is one or two cells which can be connected at will.

Experiment 61. A method of measuring the amplification of two or more stage audio amplifiers.

This is an adaption of the potentiometer method of measuring the amplification constant of an electron tube, Experiment 50.

The negative terminal of the filament is connected to the middle point, *b*, of a potentiometer made of two ordinary resistance boxes, Figure 75. This negative terminal may

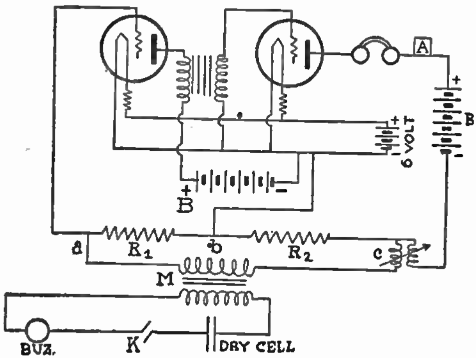


Fig. 75. Two Stage Audio Amplifier.

be connected to the earth also. An alternating E.M.F. generated by a buzzer working through a telephone induction coil is connected to the terminals, *a*, *c*, of the potentiometer. The point, *a*, is connected to the grid of the first tube and the point, *c*, is connected through a suitable *B* battery and telephone to the plate of the last tube.

The tubes are connected together with audio frequency coils. Care must be used in connecting the coil. The coil must be so connected that when the potential of the grid of tube No. 1 is made positive the potentials of the second and of all other tubes are positive. When the grid potential of the first tube is made positive the plate current of all tubes must increase. A second B battery must be used for the plate potential of all tubes except the last.

When the potential of the point, a, is positive the current runs from a to c through b. The potential of c will be negative. The potential of b being zero.

If the potential of the grid of tube No. 1 is raised, the current in the plate circuit of the last tube is increased unless the plate potential is decreased. When the plate potential is diminished enough to keep the plate current constant there will be no sound in the telephone, or a minimum of sound.

If the resistance R_1 is set at some convenient value, 10 ohms, say, and then R_2 adjusted to minimum sound, then the ratio of R_2 to R_1 is the amplification constant of the amplifier.

$A = R_2/R_1 =$ Change of plate potential divided by the change of grid potential. If the amplification constant of the tubes have been determined then the amplification constant of the audio coil can be determined. $A = a_1C_1a_2C_2a_3 \cdots a_n$.

Where $a_1, a_2, \cdots, a_n$ is the amplification constant of the various tubes, and $C_1, C_2, \cdots$, is the amplification constant of first, second, etc., coils. A mutual inductance can be inserted as in the diagram and correction made for change of phase angle.

Best results are obtained with two tubes and one coil. The plate potential must be such as to let the tubes operate on a point near the middle of the plate current, grid potential curve. *C* batteries of suitable values may be inserted in the grid circuits of the tubes if necessary.

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Experiment 62. Measurement of the amplification of a three stage resistance amplifier.

In a resistance amplifier an uneven number of tubes must be used. If the grid potential of the first tube is increased the plate current increases and the potential of the plate diminishes, causing the potential of the grid of the second tube to diminish, and the plate current of the second tube to diminish. This will cause the potential of the second plate to increase the the grid potential of the third tube will increase and the current in the plate circuit of tube three will tend to increase.

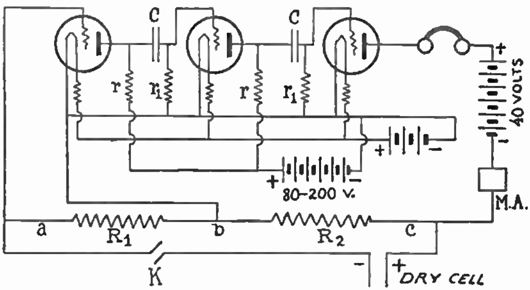


Fig. 76

The resistance in the potentiometer, Figure 76, can be adjusted until there is minimum sound as in the first case. A milliammeter can be inserted in place of the telephone, and a battery of a few volts can be placed around *a*, *c*. A key, *K*, in the battery circuit is opened and closed and the resistance adjusted until there is no change of deflection.

In this resistance amplifier the actual amplification will be less than the product of the amplification constants of the three tubes. If the resistance, r, is four times the resistance of the tube, then the amplification is 4/5 that of the tube alone. The potential of the B battery must be large. If the tube is to work with 40 volts potential on the plate then the battery must be 200 volts if r, is four times the resistance of the tube.

The grid condensers and the grid leak resistances r_1 must be adjusted so that the tubes operate near the middle point of the grid voltage, plate current characteristic curve.

The resistances can be made as described below but it is not advisable to do so if good metalized resistances are at hand. With 201A tubes, r should be about 25,000 ohms; r_1, $\frac{1}{2}$ megohms to 2 megohms. The condensers, C, can be from .1 mf. to 1. mf. A buzzer connected as in Experiment 61 works better than the dry cell.

The resistances r and the grid leaks r_1 can be made of card board soaked with india ink. These strips can be mounted on glass tubes. The resistance should be measured by bridge or other suitable method. The exact length and width of the cardboard is a matter of trial. Try 1 inch by $\frac{1}{2}$ inch at first.

In expressing the gain or amplification of an amplifier it is becoming customary to give the amplification in terms of transmission units (TU). The (TU), N in any given case is ten times the logarithm (base 10) of the ratio of the output to the input expressed in watts.

$N = 10 \log_{10} P_2/P_1$, where P_1 is the input and P_2 is the output. Thus an amplification ratio of 100 is 20 TU.

If input and output are expressed in current, $N = 20 \log_{10} I_2/I_1$.

Experiment 63. Practical method of measuring the amplification of the various stages of an audio amplifier.

If one has an amplifier with jacks in the plate circuit of each tube the amplification from stage to stage can be measured using the shunted telephone method. Experiment No. 88.

The amplifier and receiver can be tuned to some given station, one which will remain constant for some time, either local buzzer or distant station, and the telephone placed in the detector tube circuit and shunted until the sound is just audible. The resistance of the shunt is recorded. The same procedure is carried out with each tube in succession. In order to measure the amplification of the second stage it will be necessary to reduce the amplification of stage No. 1. The receiver and amplifier must be in the best adjustment before this first tube is turned down.

Then from the theory of the shunted telephone the current, I, in each case is determined in terms of the least audible current, I_p, which is assumed to be constant in each case. We have $I = I_p(S-P)/S$, then the amplification of the first stage is $a = I_1/I_d$, where I_1 and I_d are the currents in the plate circuits of the first amplifying tube and the current in the plate circuits of the detector tube respectively.

The ratio of the other tubes can be determined in the same way.

If one tube is found which gives a low amplification it will be well to test it by running the plate current grid voltage curves. The grid voltage or plate voltage may not suit that particular tube.

Experiment 64. To construct an amplifier.

In the construction of an efficient amplifier it is important that the normal, zero, condition of the plate current be near the middle point of the plate current grid potential characteristic.

This can be accomplished by changing either the plate potential or the grid potential. With grid potential zero

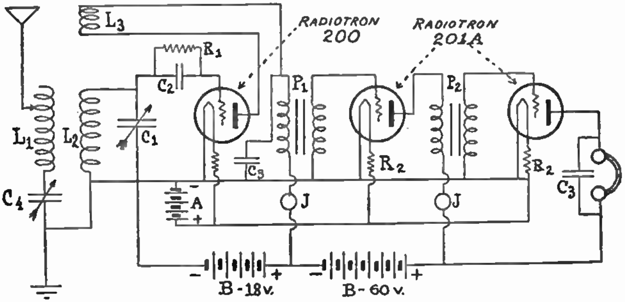


Fig. 77. Detector and Two Stage Amplifier.

a normal radiotron amplifying tube requires from 45 to 62.5 volts. There are many freaks among these tubes so in order to be sure the curves should be run for all tubes.

The audio amplifier is the one that is in most common use. It is the easiest to use. Audio amplification can be carried out with the regenerative receiver. It takes about two or three stages of radio amplification to equal the regenerative detector, if one used the radio amplifiers on the market. A good radio amplifier tends to eliminate static and noises.

The diagrams are adapted from those given by the Radio Corporation of America for radiotron tubes. Other tubes and coils can be substituted for these.

In Figure 77, L_1, primary coil of tuning transformer. L_2, secondary coil of tuning transformer. L_3, "tickler" coil for regenerative amplification. C_1 secondary variable condenser. C_2 grid condenser. C_3 telephone condenser. R_1, grid leak. R_2, filament rheostat. A, 6-volt storage battery; B, standard 22½ volt plate batteries; P, transformer; J, jacks placed in the plate circuits of the tubes

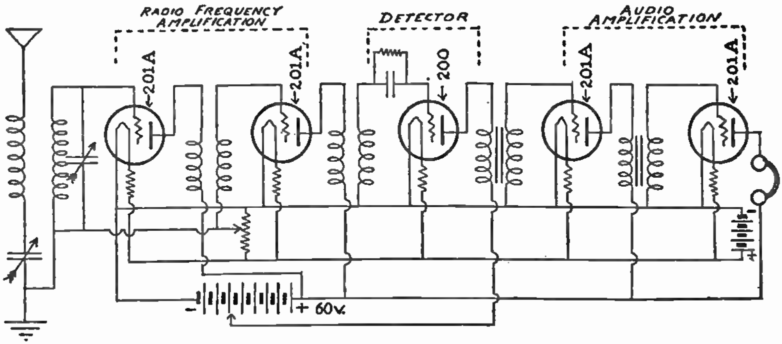


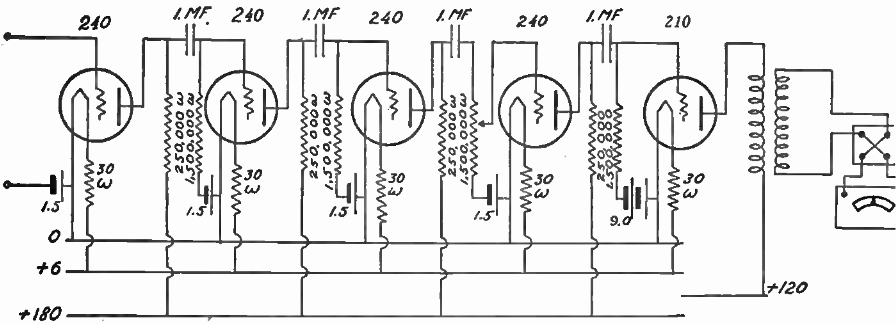
Figure 78. Circuit for radio frequency amplification and two stages audio amplification.

so that the phone can be inserted in each plate circuit at will. For details of receiver coils see Experiment 113.

Radio Frequency Amplifier. Radio frequency amplification is theoretically the best method. However owing to the capacity of the tubes it is not a success with short waves. The capacity effect in the tube tends to make the tubes oscillate and works in opposition to the inductive effects of the coils of the radio frequency amplifier. The usual radio frequency amplifying coils use a stabilizer which may be a high resistance or other means of reducing the efficiency of the coil. This effect of the stabilizer is so great that the wave is very broad and is in tune for a large band of frequencies. For method of making radio transformers see Experiment 69.

Experiment 65. To construct a resistance coupled amplifier.

The diagram of connections is shown in Figure 79. This diagram supposes the use of high mu tubes. The resistance of tubes with high amplification constant is



FIRST 2 TUBES TO BE PROTECTED FROM MECHANICAL, ACOUSTIC AND ELECTRICAL DISTURBANCE

Fig. 79.

usually high. The diagram shows a thermo couple in the output circuit. A loud speaker can be substituted.

Before constructing a resistance amplifier the theory of Experiments 60 and 62 should be studied. A resistance circuit is aperiodic and has no resonance frequencies and is supposed to amplify all frequencies alike. However, the impedance of condensers depends upon frequency, being greater for low frequency. Also at high frequency, radio frequency, the accidental capacities in the set are large enough to pass the signal. Thus the signal does not take the route intended and is lost. On this account resistance amplifiers are used for audio frequencies and rarely for radio frequency amplification.

Experiment 66. Testing audio frequency amplifying coils.

The audio frequency amplifier consists of two coils wound on an iron core the same as an ordinary transformer.

Measure the resistances using a box bridge, Experiment 5. Measure the inductance of the coils. Compare with a large condenser, 1/3 microfarad, using Anderson's or Maxwell's method, Experiment 23.

Measure L_1, L_2, and M. See mutual inductance, Experiment 25.

Calculate the theoretical voltage amplification.

$$L_1 \equiv n_1^2, \quad L_2 \equiv n_2^2, \quad M \equiv n_1 n_2$$

$$E_1 = L_1 di_1/dt, \quad E_2 = M_2 di_1/dt$$

$$\text{Amplification, } A = E_2/E_1 = M/L_1 = n_2/n_1 = \sqrt{L_2/L_1}.$$

This assumes that the coils are perfect and that the resistance of the coil is very small.

The relative amplification of two coils can be tested by using them one at a time in a two stage amplifier the amplification constant of the two tubes being known. If the two tubes are alike and the coil gives a one to one amplification the amplification of the two stage amplifier will be a^2, where a is the amplification constant of one tube. Then $A = A'/a^2$, where A' is the measured amplification of the two stage amplifier. Experiment 50.

Experiment 67. Test of an audio frequency transformer.

National Electrical Manufacturers Association Method, "NEMA Method."

The following diagram and method is taken from the NEMA Handbook of Radio Standards, Third Edition.

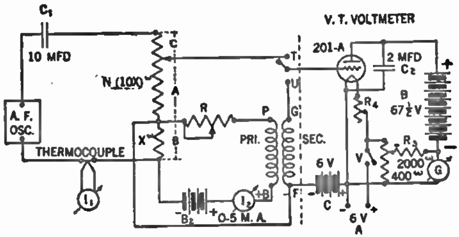


Fig. 80

The primary of the transformer is connected to an audio oscillator by means of the resistance, B, which is in series with a potentiometer, AC, whose resistance is 10 times the resistance, B, Figure 80. These resistances may be non inductive resistance boxes or a calibrated potentiometer.

The secondary of the transformer is connected to a tube voltmeter.

The galvanometer or milliammeter, G, serves as an indicator for the tube voltmeter. The switch is then turned to the position, T, and the slider on the potentiometer is adjusted until the tube voltmeter indicates the same potential. Then the amplification of the transformer is given by the ratio of the resistances, $a = A/B$.

The audio oscillator should be free from harmonics and have a frequency range of 30 to 7000 cycles per second and be capable of delivering from 10 to 25 milliamperes through the resistances in the potentiometer circuit. The thermocouple in this circuit has a range of from 5 to 25 milliamperes.

In series with the primary is a battery D.C. milliammeter, and regulating resistance. This battery is to furnish a D.C. current through the primary equivalent to the usual plate D.C. current. It is recommended that readings be taken at 30, 45, 60, 100, 200, 500, 1000, 2000, 3500, 5000, and 7000 cycles. The results should be plotted on semi logarithmic paper. The results can be expressed in Transmission Units. See Experiment 62.

Experiment 68. Principle of the neutrodyne.

Measurement of the Amplification Ratio of a Transformer. An audio frequency transformer or any other kind of a transformer is connected as in the diagram, Figure 81.

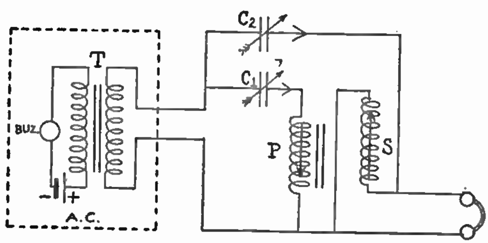


Fig. 81

C_1 and C_2 are condensers, one of which should be variable. The ordinary 43 plate variable condensers will do. P and S are the primary and secondary of the coil to be measured. The secondary must be connected "reversed" as in the diagram, Figure 81. T is a telephone coil connected to a buzzer so as to give an alternating E.M.F. A telephone is connected around the secondary S.

The capacities of C_1 and C_2 are adjusted until the sound in the telephone is a minimum. Since the capacity of the condensers is small the impedance in the two coil circuits is all due to the condensers, and I_1 is proportional to C_1 and I_2 is proportional to C_2. This can be seen from the equation,

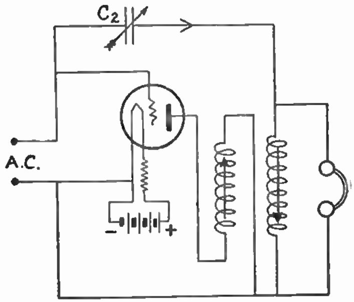


Fig. 82

$$I=\frac{E}{\sqrt{R^2+\left(\frac{1}{C\omega}-L\omega\right)^2}}=CE\omega$$

Since there is no current through the telephone,

$$M dI_1/dt=L dI_2/dt \text{ or } MI_1=LI_2$$

Since M is proportional to $n_1 n_2$ and L is proportional to n_2^2, $n_1 I_1=n_2 I_2$.

Then $n_2/n_1=I_1/I_2=C_1/C_2=A$, the amplification ratio of the two coils.

If C_1 and C_2 are variable condensers, semi circular plates, which are exactly alike (same make) then the readings of the dials can be substituted for the value of the capacities.

C_1 may be the capacity of a tube, and C_2 may be a "Neutrodyne condenser," then we have as in the Figure 82.

If the coil is a neutrodyne coil and if instead of the telephone we place a second tube to act as an amplifier and detector and if instead of our buzzer alternating current we place a third tube, which is connected to the first tube with a neutrodyne coil, and if this tube is used to amplify the alternating current received by an aerial we have the regular neutrodyne hook up. See Figure, Experiment 69.

Experiment 69. Neutrodyne receiver.

Professor Hazeltine in 1923 made public a method of neutralizing the capacity of the tubes by means of a small

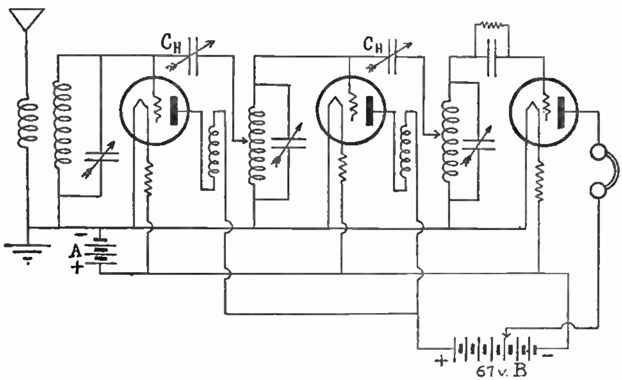


Fig. 83. The Three Tube Neutrodyne Radio Amplifier.

condenser placed between the grids of the tubes. This condenser is marked C_H in the diagram for radio amplifier, Figure 83. It is made of a small metal tube one inch long which is slipped over the ends of No. 12 or 14 insulated wires which are about $\frac{1}{4}$ inch apart. These two wires are connected to the grids of the two tubes. The coils consist of a primary 13 turns of No. 24 D.S.C. wire wound on a tube $2\frac{3}{4}$ inch diameter and 4 inches long. The secondary coil consists of 55 turns of No. 24 D.S.C. wire wound on a tube 4 inches long and 3 inches diameter. The primary is placed inside of the secondary. The coupling is so close that both coils can be tuned with a variable condenser placed in the secondary coil. The receiving coil may be one of these coils. The coils are placed $6\frac{1}{2}$ inches apart at an angle of 60° with the horizontal. It is better to set the coils with the centers all in a straight line and the axes of the coils mutually perpendicular one to another. The coils of the neutrodyne transformer must be connected "reversed." See Experiment 68.

To adjust the condensers the amplifier is tuned to a loud signal and the filament of the first tube is turned out. The signal will still be heard through the capacity of the cold tube. The first condenser, C_H is adjusted until the signal is not heard. C_H then neutralizes the capacity of the first tube. The first filament is heated and the second tube is turned down and the second neutrodyne condenser is adjusted. The neutrodyne condensers were originally connected from grid to grid of the tubes. The neutralizing condensers then had to be smaller than the capacity of the tube. Connected as in the diagram the capacities are about equal. Some circuits use a third coil in place of the lower part of the secondary coil.

For details see Wireless Age April, 1923 p. 7. Q S T April 1923, p. 54 Radio News, May 1923, p. 1949.

Experiment 70. The two control four tube neutrodyne radio frequency reflex set.

This set is a combination of several fundamental features in set building the mastery of these is well worth the time taken to construct the set.

REFLEX AMPLIFICATION

In reflex amplification a tube is used first for radio amplification and again for audio amplification. For general principles of connection see diagram, Figure 84. The radio

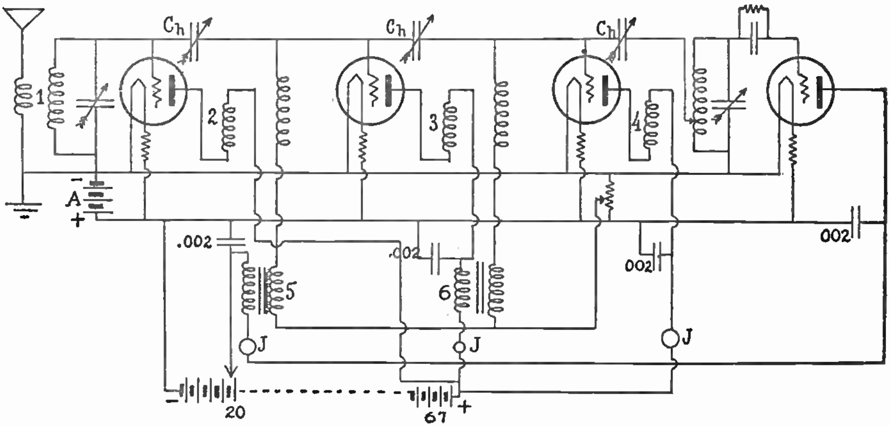


Fig. 84

coils may be tuned or untuned. Reflexing generally makes the tuning broad. Radio frequency choke coils should be placed in series with the primary coils of the audio transformers.

The usual neutrodyne set employes three tubes and three condensers by means of which the three coils are tuned. Tuning three circuits to the same frequency at the same time is somewhat tedious. The middle coil may be replaced with an untuned radio frequency coil. This of course decreases the amplification to some extent but since the controls are reduced to two the tuning is much simplified. The radio amplification can be increased by using a fourth tube and another untuned radio frequency coil.

Coils 1 and 4 in the diagram, Figure 84, are the usual neutrodyne coils. See Experiment 69. These are tuned with 23 plate variable condensers. Coils 2 and 3 are untuned radio frequency coils. These may be purchased or may be made by winding two flat coils each containing about 40 feet of No. 36 to No. 40 copper wire wound in two circular channels cut in a hard rubber rod 1 ½ inch diameter. These channels are separated by about 1 millimeter of hard rubber and are from 1 to 1½ millimeters wide. The inside diameter is about ½ inch. The outside diameter is at least 1 inch. Coils 5 and 6 are audio frequency coils.

Neutrodyne condensers, C_h see Experiment 69, are placed between the secondaries of coils 1, 2, 3, and 4. In coil 4 a tapmay be made on the thirteenth turn from the filament end of the secondary.

The primary of coil 5 is placed in the plate circuit of tube No. 4. The secondary of this coil is placed in series with the secondary of coil No. 2. Coil No. 6 is placed in series with coil No. 3. The telephone or loud speaker is placed in series with the primary of coil No. 4.

Jacks, *J*, may be placed in series with the primary of coils 5 and 6 as well as in the plate circuit of tube No. 3. With the jacks in place a telephone may be inserted in the plate circuit of tubes 4, 2, and 3, at will. 0.002 mf. condensers must be placed around the primaries of coils 5 and 6 as well as around the telephone to by-pass the radio frequency current. Coil No. 1 may be replaced with a coil aerial if so desired.

When properly constructed this set has the desirable features of the neutrodyne set and is easier to tune. The amplification is enough to work a loud speaker and the quality is free from the distortion caused by excessive iron core amplification.

The neutrodyne coils may be made as directed in Experiment 69 or they may be wound on one tube. The primary is placed on the tube and a layer of paraffined card board is placed over this and the secondary is wound over this. If the wire is well insulated spider web coils can be made by winding two wires in parallel until the required number of turns for the primary is placed on the coil and then continuing with one wire until the secondary is finished. The coils may be made in the form of the "low loss" coils or the figure eight coils which are described in many of the radio magazines.

When adjusting the neutralizing condensers it will be necessary to remove the audio frequency coils. Build the set as per the diagram, test all the circuits and then remove the audio frequency coils and connect the taps made in the circuits and adjust the condensers with the telephone connected in the detector tube plate circuit. This method of adjusting the neutralizing condenser applies to all reflexed neutrodyne receivers. Short circuiting the primary and secondary of the coils will not do. The coils must be removed.

Experiment 71. Superheterodyne amplification.

In the superheterodyne amplifier the signals are received and detected with a tube connected to a receiving coil which is very much if not identical to one of the ordinary receivers. Coupled to this is a second tube which is connected to a regenerative circuit so as to oscillate at a lower or higher frequency than that of the signal being received. The plate circuit of the first tube is connected to a radio frequency transformer which is tuned to the beat note produced by the difference of the frequency of the two circuits. Then follows several stages of amplification at the low frequency or long wave length of the beat note. This is detected by a detector tube and usually there is one or two stages of audio frequency amplification.

While tuning, the frequency of the oscillator is changed as the frequency of the receiver is changed so as to keep the difference of frequency constant. If the signal is 300 meters wave length or 1000 kilocycles frequency and the oscillator is set to 333 meters or 900 kc. the beat note is 100 kc. or 3000 meters. The amplification transformers are tuned to 3000 meters. If the signal is 500 meters or 600 kc. the oscillator is tuned to 600 meters or 500 kc. and the beat note is the same as in the first case.

The diagram, Figure 85, shows an eight tube superheterodyne receiver. The lower tube, by itself, is the oscillator. The first tube, to the left, is the first detector which picks up the signals from the loop. The following four stages are intermediate frequency stages which are tuned to the beat note. The fifth tube is the intermediate frequency detector. The second, third, and fourth tubes are amplifying tubes. The last two stages are audio frequency amplifiers.

Some sets use five intermediate stages instead of four. In some sets the loop is made regenerative by connecting the middle of the loop to the filament and one side of the

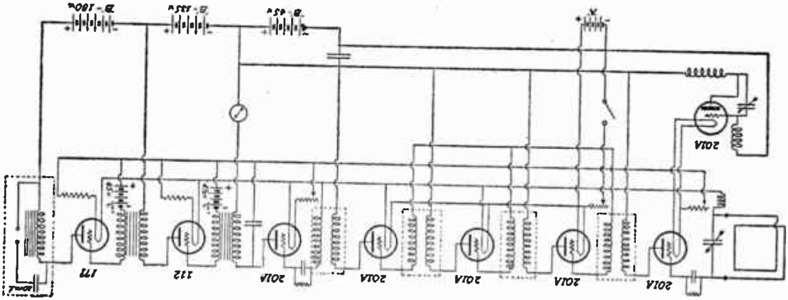


Fig. 85

tuning condenser to the plate of the detector tube by means of a small variable condenser.

This will be recognized as the Hartley shunt circuit.

This regenerative circuit may oscillate and create a disturbance the same as a single tube regenerative circuit. A superheterodyne connected to an aerial is often a nuisance to the neighborhood if allowed to oscillate.

The coils can be made and tuned with a fixed condenser or they may be untuned coils with the peak adjusted to the intermediate frequency. The coil connected to the last detector is tuned. This coil is some times called a filter.

The intermediate frequency coil can be made by turning a cylinder of wood two and a half inches in diameter. In the cylinder turn two channels one fourth inch wide and one inch deep. Leaving in the center a cylinder one half inch in diameter. The two channels are one fourth inch apart.

In one of these channels wind 850 turns of No. 36 insulated wire for the primary and in the other channel wind 1000 turns of No. 36 wire for secondary coil.

The filter coil can be wound on the same wooden form with 500 turns for primary and 600 turns for secondary. The secondary is tuned to the natural wave length of the other coils with a condenser. Capacity about .00025 MF.

Adjustment of the Intermediate Frequency Amplifier of A Superheterodyne Receiver.

The superheterodyne coil is connected between two tubes, the first being an amplifier tube and the second a detector tube with a grid condenser and leak. The connection can be made the same as the connection of tube five and tube six in the superheterodyne connection, Figure 85.

A telephone is placed in the plate circuit of the detector tube and a coil of one or two turns is placed in the grid circuit of the first, or amplifying tube.

This coil is wound around or coupled with the coil of a wave meter whose range is from 1000 meters to 9000 meters according to the particular heterodyne coil used. This wave meter can be made of any of the coils listed, under Laboratory Apparatus and a good variable condenser, maximum capacity .001 microfarads preferred.

It is not necessary to know the exact wave length. A buzzer is connected to the wave meter as in Figure 36a. The buzzer is started and the condenser varied until the maximum sound is heard in the telephone. If the maximum is too intense for comfort loosen the coupling between the wave meter coil and the coil in the grid circuit.

If the intensity of the sound is estimated and recorded with the condenser readings a rough resonance curve can be plotted much like Figure 90. This curve will be found to be rather broad indicating that the coil is in tune for a band of waves.

Test out all the coils this way except the filter coil, (the coil which has a condenser connected to it.)

All coils should give the same curve. If there is much difference the coils are not matched and will not work well together.

The filter coil should be tested in the same manner except a variable condenser is placed across the secondary coil. The wave meter condenser is set to the reading corresponding to the maximum intensity obtained with the other coils and the condenser in the filter circuit is tuned for maximum response.

In estimating the intensity and plotting, this resonance curve will be found to be comparatively sharp.

As a usual thing the point of maximum intensity should correspond to a capacity of .00025 microfarads. The usual directions recommend a fixed condenser of that value across the filter coil.

If the coils are well matched the maximum response of all coils should be at the wave which corresponds to that of the tuned coil when a fixed condenser with the recommended capacity is placed across the secondary.

WAVE LENGTH OF CIRCUITS WHICH ARE CLOSELY COUPLED

In the use of the wave meter we always assume that the wave meter is loosely coupled to the second circuit, or that the mutual inductance of the two circuits is small or that the coefficient of coupling is small. In certain cases this is not true and then as a general thing, we have two frequencies or wave lengths to deal with.

The following is based on Fleming, The Principles of Electric Wave Telegraphy, p. 211.

Let T_1 and T_2 be the fundamental periods of the two circuits. We shall assume that they have been tuned to the same wave length.

Then, $T_1^2 = 4\pi^2 C_1 L_1 = T_2^2 = 4\pi^2 C_2 L_2$

And, $\theta^2 = 4\pi^2 M \sqrt{C_1 C_2}$

Since $T'^2 = T_1^2 \pm \theta^2$

$$T'^2 = 4\pi^2 C_1 L_1 \pm 4\pi^2 M \sqrt{C_1 C_2}$$

Let $k = M/\sqrt{L_1 L_2}$

k, being the coefficient of coupling,

$$T'^2 = 4\pi^2 C_1 L_1 \pm 4\pi^2 (M/\sqrt{L_1 L_2})(\sqrt{C_1 C_2}\sqrt{L_1 L_2})$$

$$T'^2 = 4\pi^2 C_1 L_1 \pm 4\pi^2 k \sqrt{C_1 L_1}\sqrt{C_2 L_2}$$

Since $T_1 = T_2$, $C_1 L_1 = C_2 L_2$

Then, $T'^2=4\pi^2(C_1L_1 \pm kC_1L_1)$

$$T'^2=4\pi^2C_1L_1(1\pm k)$$

$$=T_1^2(1\pm k)$$

Since wave length equals velocity times period,

$$\lambda=VT,$$

$$VT'=VT_1\sqrt{1\pm k}$$

$$\lambda'=\lambda\sqrt{1\pm k}$$

Since $\lambda=1884\sqrt{LC}$, $\lambda'=1884\sqrt{LC(1\pm k)}$. When k is greater than zero λ' will have two values. Both of which are different from λ. Where k is made small the mutual inductance M is small and λ' approaches λ. Thus one sees the necessity of using loose coupling when measuring with a wave meter.

In a perfect transformer, no leakage of magnetic flux, we have L_1 proportional to n_1^2, where n is the number of turns of wire, L_2 proportional to n_2^2, and M proportional to n_1n_2.

Then $k=1$ and $\lambda'=1884\sqrt{CL(1\pm k)}=1884\sqrt{2CL}$ or zero. If we substitute

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

in $\lambda'=1884\sqrt{L_1C_1(1\pm k)}$ we have,

$$\lambda'=1884\sqrt{C_1k(L_1\pm M\sqrt{L_1/L_2})}$$

From the above it will be seen that only when the two circuits are identical, *i.e.*, $C_1=C_2$ and $L_1=L_2$, can the equation be written

$$\lambda' = 1884\sqrt{C(L \pm M)}$$

Experiment 72. To plot the resonance curves of circuits which are more or less closely coupled.

Morecroft, p. 95. Bur. of Stand. 74, p. 49. Pierce, p. 73.

Two circuits may be coupled in three ways, inductively coupled, conductively coupled, and capacitively coupled.

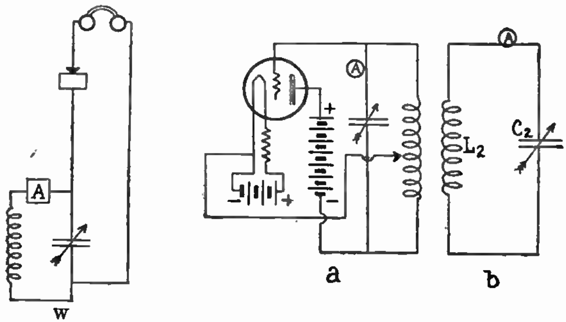


Fig. 86

The three Figures 86, 87, and 88 show the method of coupling. Figure 86 is inductively coupled and shows a power tube connected as a generator using the Hartley circuit. The wave meter, *W*, contains a radio milliammeter. Tune circuits *a* and *b* to the same wave length and then couple the two circuits rather closely and read the value of the current in the wave meter, *W*, as the setting of the wavemeter condenser is changed. Plot a curve with current in the wave meter as ordinates and wave length or capacity of the wave meter as abscissas. Repeat with loose coupling of circuits *a* and *b*. The wave meter, *W*, must be loosely coupled to the two circuits. The presence

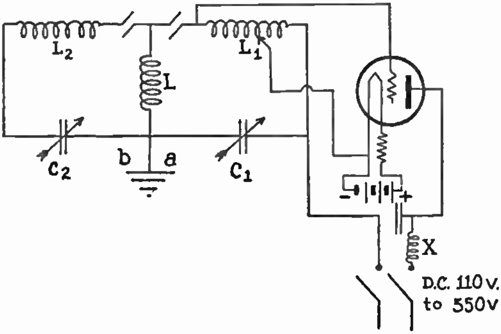


Fig. 87

of the wavemeter should not change the current in either *a* or *b*.

If a tube generator is not at hand a generator buzzer may be used instead. In this case a telephone and crystal must be used in the wave meter. By estimating the relative intensity of the sound in the telephone the position of the peaks of the curves can be located and the general form of the curves can be determined.

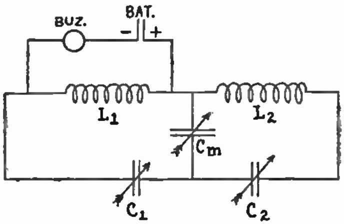


Fig. 88

More accurate results can be obtained by using the shunted telephone as explained in the experiment on the use of the telephone as a current measuring instrument. Experiment No. 90.

In coupled circuits the wave length,

$$\lambda_1(+) \text{ or } \lambda_2(-) = \text{constant}\sqrt{LC(1 \pm k)}$$

$$= \lambda\sqrt{1 \pm k}, \lambda_1(+), \lambda_2(-) = 1884\sqrt{LC(1 \pm k)}$$

where k is the coefficient of coupling. For inductive coupling $k = M\sqrt{L_1L_2}$.

The above theory indicates that when the coupling is close there are two frequencies, or wave lengths at which it is possible for the coupled circuits to vibrate. With buzzer or spark gap excitation the wave meter will indicate that two modes are present at the same time. With a tube generator the wave length will be one only at any one time. By changing the condenser in circuit, b, the circuit may be caused to change from one to the other. Assume both a and b are tuned to wave, λ, and coupled close and that the circuit is vibrating at $\lambda(-)$. Diminish the capacity in circuit b. The current in b will increase until it suddenly diminishes. Move condenser in b back to the original setting and the circuit will be found to be vibrating at the longer wave $\lambda(+)$.

Experiment 73. Plot the resonance curve using conductive coupling.

For conductive coupling, Figure 87,

$$k = L/\sqrt{(L_1+L)(L_2+L)} = L/(L_1+L)$$

when $L_1 = L_2$. For capacitive coupling, Figure 88, $k = C_1/C(C_m+C_1)$, when $C_1 = C_2$. Thus one sees that, k approaches zero as M approaches zero in the first case, as L approaches zero in the second case, and as C_m approaches infinity in the third case. Calculate k from the value of λ_1 and λ_2. For inductive coupling $k = (\lambda_1^2/\lambda) - 1$ or $= 1 - (\lambda_2^2/\lambda)$.

Connect as shown in diagram, Figure 87. Follow the general plan as outlined in Experiment 72. The coupling is loosened by diminishing the inductance of L. The coils L_1 and L_2 must be placed so that the mutual inductance of L is zero. Calculate k.

Experiment 74. Plot the resonance curve using capacitative coupling.

Follow the same general plan as above, connecting as in Figure 88. The coupling of the coils, must be such that the mutual inductance is zero. The coupling of the circuits is loosened by increasing C_m. Calculate k.

It will be interesting to repeat these experiment when the two circuits are not exactly tuned to the same wave length.

Experiment 75. To tune a spark sending station.

The sending station, Diagram Figure 89, consists of a primary circuit consisting of an oil condenser or a number of Leyden jars the primary coil of an oscillation transformer and a spark gap. The secondary circuit consists of the secondary of the O.T. in series with the aerial and if necessary a loading inductance, and a condenser in series. The modern radio regulations have practically outlawed all spark stations. It will be necessary to use a dummy aerial consisting of a condenser and coil giving the same constants as the regular aerial. The condenser is connected to the secondary of a high potential transformer. The primary of this transformer is connected to an ordinary source of alternating current, usually 110 volts 60 cycles. The spark gap may be an open gap, a rotary gap, or a quenched gap. The quenched gap tends to keep the primary circuit from reabsorbing the energy from the secondary circuit. The rotary gap also tends to do the same thing as well as to regulate the number of discharges of the condenser.

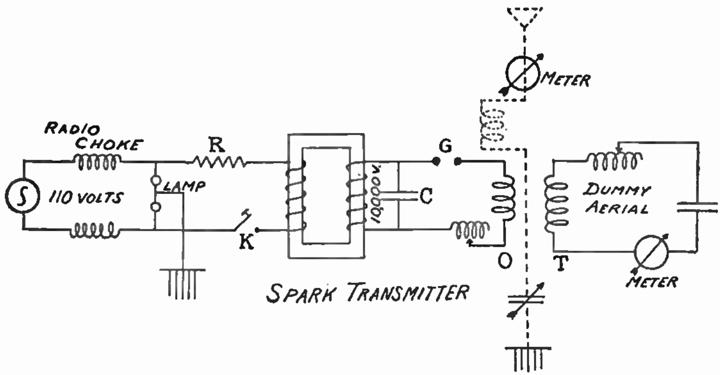


Fig. 89

Use reduced power by placing resistance in the 110 volt A.C. circuit. There is no use in "tearing up the ether" and thus making the station a nuisance to those who are receiving. Measure the natural wave length of the aerial by placing a simple spark gap in the aerial circuit and connect the secondary around the spark gap of the transformer. The spark gap must be long enough so as not to short circuit the transformer. Note this connection is outlawed. Measure the wave length with a wave meter.

The natural wave length can be measured by tuning the aerial with a number of secondary turns of the O.T. in series and then cutting out one and measuring the wave length turn by turn until nearly all the turns are cut out. Plot a curve wave length and turns in the O.T. and extend the curve to zero. This curve will be a straight line. Loosen the coupling of the O.T. Connect variable inductances in the primary and secondary circuits. Couple a wave meter as loosely as possible to the aerial and measure the wave length or wave lengths at which the aerial is oscillating. Vary the capacity and inductance in the primary of the O.T. until a sharp wave is secured. Then gradually change the inductance in the aerial circuit so as to change the wave length towards the required wave, 175 meters to 200 meters, at the same time follow up with the primary circuit keeping both circuits approximately tuned to the same wave length. When the required wave is reached use as large capacity as possible in the primary circuit and small inductance. (There is some question as to whether this is the best condition. It would seem that this is the best condition for the so called "shock" transmitter.)

While tuning the circuit it will be of interest to measure the decrement of the various conditions.

Data for the resonance curve can be taken at this time.

Adjust the gap and coupling to make the wave sharp. Insert the rotary gap and note the sharpness and decrement. Use the quenched gap and repeat. It will be found that the coupling can be much closer with the rotary and the quenched gap.

Finally, after the adjustments have been made, place the normal voltage on the transformer and note the current in the aerial.

For these adjustments, if the aerial current is too small to be read accurately with the aerial ammeter, an improvised wave meter consisting of a few turns of wire and a variable condenser and a hot wire galvanometer can be used. The coil may be placed near the aerial and the condenser and galvanometer may be placed near the observer, connection being made with lamp cord. This wave meter can be calibrated by comparison within a standard wave meter. Due to the capacity and leakage of the lamp cord this meter will not be as accurate as a standard. If the coil is stationary the current in the aerial will be proportional to the current in the wave meter.

Note in taking curves do not hold the key down continuously as the condensers will heat. Also watch the motor and generator bearings.

Turner, p. 36; Stanley, p. 222.

Experiment 76. To plot the resonance curve of a damped wave transmitting station.

Use a wave meter with a hot wire or thermo junction milliammeter or a high frequency galvanometer. Couple the wave meter so that the current when in resonance will give a good deflection on the instrument. Diminish the capacity of the variable condenser until the current is a small value. Read and record the current for various settings of the condenser as the capacity is increased through maximum current down to a low value. Plot cendenser readings or capacity along the *X* axis and current squared along the *Y* axis, the form of the curve will show whether the circuit is tuned right or not. A sharp curve is desirable, Figure 90. With an open gap it is interesting to plot several curves with various degrees of coupling. See Experiment 75, Tuning Aerials. In case the circuit gives a sharp curve introduce resistance in the circuit and take the curve again. Explain.

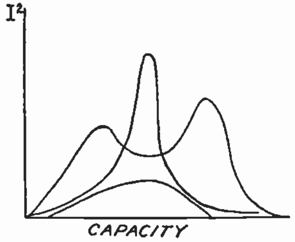


Fig. 90

Stanley, Vol. 1, p. 426; Lauer & Brown, p. 68; Turner, p. 21, 28.

RADIO FREQUENCY RESISTANCE

In general the resistance of a wire or circuit is greater for alternating current than it is for direct current. This is due to the fact that the inductance of a long hollow wire or tube is less than that of a solid wire of the same length and of the same cross section. In high frequency circuits the impedance of the wire is less when the current flows through the outside of the wire or through the "skin." Although the impedance is less the resistance is greater. In very high frequency the outside of the wire carries all the current and the resistance is the same as that of a thin tube of the metal whose outside diameter is the same as the outside of the wire. This is known as the "skin" effect. One should remember that the energy (heat) used up or dissipated in the wire is proportional to the resistance and not to the inductance.

The difference between the D.C. and the A.C. resistance of a wire is greater the higher the frequency, the larger the diameter of the wire, the greater the permeability of the wire, and the greater the conductivity of the material of which the wire is made. In large wires of copper at high frequency the difference is great. In small wires such as German silver, manganin, or nichrome the two values are nearly the same.

See Zennock, Wireless Telegraphy, p. 398; Morecroft, p. 143; Bur. of St. 74, p. 310.

Assume that a wire is made up of two conductors of equal cross section, one a tube and the other a wire which will fit snugly into the tube. The solid wire or core will have more inductance than that of the tube. These two circuits are analogous to two circuits which are placed in parallel. Assume that these circuits are formed of two coils of equal length of wire. The resistances of the two are the same. Assume that one coil is wound non-inductively and that the other is an ordinary coil. When placed in parallel in a D.C. circuit the resistance being the same, the current in each will be the same, the heat developed in each will be the same, and the resistance of the combination will be one-half that of one coil. When placed in an A.C. circuit the non-inductive circuit will carry more current than the inductive circuit. When the frequency is great the inductive circuit can be removed without appreciably changing the total current. The resistance in this case approximates to the resistance of the non-inductive coil. In high frequency circuits the core of the wire can be removed without changing the conductivity of the circuit since the skin or tube carries all the current.

It is wrong to say that a stranded wire is a better conductor for high frequency because it has more surface. It is better if it has more outside surface. If a stranded wire is composed of bare wires in contact the conductivity for radio currents is about the same as that of a solid wire of the same cross section. Usually the resistance of the stranded bare wire is greater than that of the solid wire.

If each small strand is insulated from the others and so stranded that each wire occupies all positions in the wire, then the conductivity is improved. The high frequency resistance approaches the D.C.

The following table gives the frequency expressed in wave lengths and the diameter of the wires, such that the A.C. resistance differs from the D.C. resistance by 1%. Fifty-six hundredths (.56) of this diameter reduces the error to 0.1%.

Material	Conductivity in c.g.s. units	λ 6000	(Maximum diameter in millimeters) 1200	600	120	60	λ 12	λ 6 meters	λ 1.2 meters
Manganin	2.4×10^{-5}	2.4	1.1	.75	.34	.24	.11	.075	.034
Iron									
$\mu = 1000$	10×10^{-5}	.033	.015	.010	.0046	.0033	.0015	.0010	.00046
$\mu = 100$	10×10^{-5}	.099	.044	.031	.014	.0099	.0044	.0031	.0014
Copper	57.5×10^{-5}	.49	.22	.15	.069	.049	.022	.015	.0069
Constantin	2×10^{-5}	2.6	1.2	.83	.37	.26	.12	.063	.037
Platinum	10×10^{-5}	1.2	.57	.37	.17	.12	.057	.037	.017
Carbon, arc.	$.025 \times 10^{-5}$	23.6	10.6	7.5	3.4	2.36	1.06	.75	.34
Concentrated $CuSO_4$	4.6×10^{-11}	175.	78.	55.	25.	17.5	7.8	5.5	2.5

resistance. The inductance of the strand is greater than that of a solid wire. The inductance cuts little figure in the conductivity of radio circuits. We annul the effect of the inductance with a condenser. In any case the radio resistance of n small wires woven or stranded is greater than $1/n$ times the resistance of one small wire.

Copper clad iron wire is good for aerials provided the skin of copper is thick enough.

Experiment 77. To compare the D.C. and the A.C. resistance of a sample of wire.

Take two samples of the wire of equal length and place them in the two legs of a differential air thermometer formed as an H, the cross connection being in the form of a U.

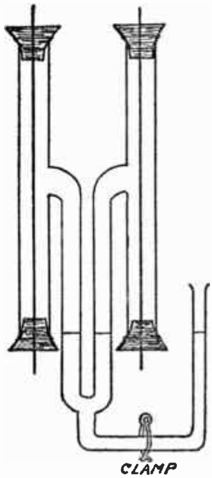


Fig. 91

This H is blown from glass as in the Figure 91, each leg being exactly alike in every particular. The wires are passed through corks and made air tight with wax except for one small pin hole in each leg. The connecting U tube is made with inside diameter about two millimeters and a small amount of water is drawn into the tube.

When finished the tube is placed with the U vertical and when in temperature equilibrium the pin holes are closed. One wire is connected into a high frequency circuit, *R.C.*, with a hot wire ammeter. The other wire is connected to a D.C. circuit with ammeter. If the heating effects of the two wires are unequal the liquid will be of unequal height. Adjust the currents so the pressure is the same on each side.

Then $I_1^2R_1=Ki_2^2R_2$ where R_1 and R_2 are the D.C. resistance of conductors 1 and 2 respectively, K the ratio of the A.C. resistance to the D.C. resistance, and I is the D.C. current in conductor one and i_2 is the A.C. current in conductor two. Interchange the connections and adjust again to equality of pressure. Then $I_2^2R_2=Ki_1^2R_1$ where I_2 is the D.C. current in 2 and i_1 is the A.C. current in 1. From the above

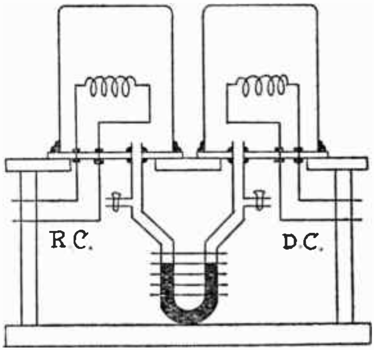


Fig. 92. Drawing showing the differential thermometer. The heat developed in the coil in the left hand beaker by the radio frequency current is balanced by the heat developed in the coil in the right hand beaker by the direct current. The equality of the height of the water in the U-tube indicates when equilibrium is established.

$$KR_2/R_1=I_1^2/i_2^2 \text{ and } KR_1/R_2=I_2^2/i_1^2 \text{ hence } K=I_1I_2/i_2i_1.$$

By taking the two sets of readings the inequalities of the two sides of the apparatus are eliminated. No. 20 iron wire works well in this apparatus. Figure 92 shows apparatus for the comparison of D.C., and R.C., resistance of coils.

Compare small wires and large wires of copper, of iron, German silver and other alloys.

Starling, p. 367; Fleming, Proc. Phys. Soc. Lond. 23, p. 103, 1911.

Experiment 78. To measure the resistance of wire or coil using radio frequency current.

Substitution Method. Use an oscillating circuit with a power tube, such as in the diagram, Figure 93. Insert the unknown resistance in the circuit at *R*. Note the current in the radio ammeter, *A*, when the frequency is the desired frequency as indicated by a wave meter. Remove the unknown resistance and insert a radio frequency resistance box and adjust the resistance until the ammeter reads the same as in the first case when the frequency is the same as the first. Then the resistance in the resistance box is equal to the unknown.

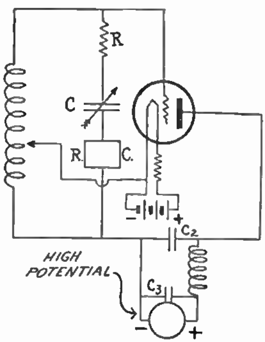


Fig. 93

This measurement should be made several times and the average used.

This assumes that the E.M.F. of the generator remains constant.

The same method can be used with a wave meter coupled loosely to the generator. A milliammeter or radio galvanometer must be in the wave meter circuit. By watching the ammeter in the generator one may be sure that the generator remains constant.

Experiment 79. To measure the resistance of a radio circuit.

Resistance Variation Method. The resistance of a radio circuit, such as a wave meter, can be measured by coupling the circuit loosely to a radio generator and then inserting known resistance into the circuit. Figure 94.

Connect a coil, variable condenser, milliammeter or radio ganvanometer and a radio resistance box in series, making a wave meter circuit. Couple the circuit to a high frequency generator. The coupling should be loose enough so that changing the current in the wave meter will not change the current in the generator.

With the resistance in the box zero, read the current in the milliammeter. Insert a resistance R_1 in the box and read again. Care must be taken to see that the circuit is in resonance in each case. In the first case $I_1=E/R$. In the second, $I_2=E/(R+R_2)$. Then $R=R_1I_2/(I_1-I_2)$. When I_2 is made one half of I_1 then the resistance in the box is equal to R the resistance of the wave meter. This is known as the half deflection method.

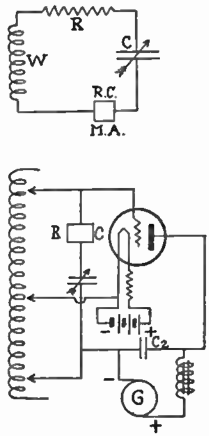


Fig. 94

Note. The Current must be read. If a galvanometer or a so-called "wattmeter" is used the square root of the deflections must be used in the place of the currents.

If the coupling is close the resistance measured will be the resistance of the wave meter plus the effective resistance of the generator.

With close coupling, coefficient of coupling, $k=1$, halving the current in the wave meter will halve the current in the generator and the measured resistance will be the sum of the two resistances if the inductance in the two circuits are equal. This is the same as measuring resistances when using ordinary transformers. From the resistance, R, and the current I_2, calculate the electro motive force in the circuit. Calculate the potential across the condenser.

Experiment 80. To measure the resistance of an oscillating circuit or tube generator.

The connection can be made as in Figure 94 for the substitution method. Any other tube generator circuit will do. An R.C. meter and an R.C. resistance box is inserted in series with the oscillator's tuning condenser. The resistance in the box can be increased until the current as read by the meter is reduced to one half, then the resistance of the circuit is equal to the resistance in the box, the initial resistance in the box being zero. This is true if the E.M.F. of the circuit is constant. Care must be used in using this assumption. If the E.M.F. is constant any amount of resistance can be inserted into the box and the resistance of the circuit can be calculated. However experience shows that as the resistance in the box is increased there is a value at which the circuit ceases to oscillate. It is quite evident that the radio frequency E.M.F. has changed.

A suggested procedure is to use the half deflection method. Assume the resistance to be equal to the resistance R, in the box. Make a second measurement in which the resistance in the box is changed from zero to $2R$ and calculate the value of the resistance of the circuit. If both results are substantially the same the resistance, R, is the true resistance. [Caution: Do not overload the resistance box.]

If the two values differ substantially the true result can not be determined. The circuit must be made to oscillate more vigorously and measured again.

Experiment 81. To measure resistance of a circuit with the impedance variation method.

The circuit is coupled to a generator as in Experiment 79. The current is read when the circuit is in resonance. Then the capacity of the wave meter is changed until the square of the current is one half of the first current squared. The current is reduced to .707 of the first value. If a galvanometer or "watt meter" is used the deflection is halved.

In the first case $I^2 = E^2/(R^2 + (1/C\omega - L\omega))^2 = E^2/R^2$. Since $L\omega = 1/C_r\omega$, $1/2\ I^2 = E^2/(R^2 + (1/C\omega - 1/C_r\omega)^2)$.

Then $R = (1/\omega)(C_r - C)/CC_r$.

If the square of the current is not exactly halved then

$$R = [(1/\omega)(C_r - C)/CC_r]\sqrt{I_1^2/(I_1^2 - I_2^2)}$$

Where, I_1 is the current at resonance and I_2 is the current when the capacity is C.

The resistance of any radio circuit can be measured in this way and then an unknown resistance can be inserted and the sum measured.

Then the resistance of the unknown is the difference of the two results. As a general thing the resistance will change with frequency.

Experiment 82. To measure the resistance of an aerial.

The resistance of an aerial can be measured by the half deflection method. If a radio frequency ammeter is placed in the aerial and the current is measured when the circuit is in resonance, i.e., when $I = E/R$. Then if R, is increased until the current is $\frac{1}{2}$, the resistance in the first case is equal to the amount added to R, in the second case.

This assumes the frequency is the natural frequency of the aerial and that the added resistance is such that the high frequency resistance is the same as the low frequency resistance, and that there is no inductance or capacity in the resistance box. These assumptions are seldom true unless a good radio frequency resistance box is at hand, but the result may be looked upon as a good estimate.

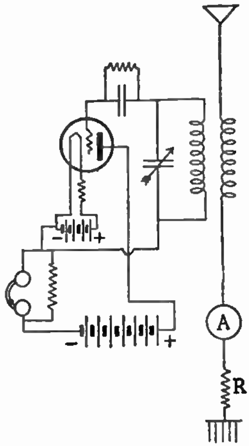


Fig. 95

Hot wire ammeters are not very sensitive, so the current must be large which is true only in a sending aerial. An approximate measurement of a receiving circuit can be made by using phones and a vacuum tube circuit. Adjust the primary and secondary until signals from some convenient station come in the loudest using loose coupling.

In this case both primary and secondary are in resonance with the sending station and the primary $I = E/R$. Shunt the phone until the signals are just audible. $I_p = IS/S+P$. Then calculate the resistance of S, so that the current through the phone is two times I_p or $S_2 = (2S_1P)/(P-S)$, Experiment 88.

Insert this value in the shunt and insert resistance in the aerial at R until the signals are just audible, then the resistance of the aerial is equal to the inserted resistance. This assumes that the amplifying ratio of the tube is constant.

Do not use an oscillating or a regenerative circuit. These circuits introduce an E.M.F. in the circuit. The E.M.F. should be the received signal. The resistance of an aerial can be separated into its component parts by measuring the resistance at a number of wave lengths and plotting a curve.

See Lauer and Brown, p. 85; Radio, p. 313; Radio Inst. and Meas., p. 81.

Experiment 83. To measure the resistance of a radio condenser.

The resistance of a large condenser can be measured at low frequency by the method given in Experiment 22. This method is not accurate enough to measure the resistance of a radio condenser.

Substitution Method. The usual method used is to measure the resistance of a radio circuit by the Resistance Variation Method, Experiment 79, or by the Impedance Variation Method, Experiment 80, and then insert a standard condenser whose resistance is known, or usually its resistance is assumed to be zero, and measure the resistance of the circuit again and the difference of the two results is assumed to be the resistance of the condenser. If the standard is a good "low loss" air condenser the resistance is of the order of a tenth ohm and as a usual thing can be neglected.

The resistance of a condenser may be a resistance in series such as resistance in the terminals or connections or it may be dielectric loss which can be assumed to be in parallel with the condenser. The resistance may be due to eddy currents or other effects. All these can be represented by a resistance in series with the condenser.

Fig. 96. At left, diagram showing a perfect condenser in series with a resistance; at right, showing how the actual resistance of a condenser may be in series or in parallel with a condenser.

The resistances are represented in Figure 96.

In measuring with this method care must be taken to have the circuit in tune with the oscillator and the coupling should be very loose. There should be no reaction on the oscillator when the circuit is tuned to the oscillator.

Thermometer Method. The resistance of a radio condenser can be determined by the thermometer method. This is very much like Experiment 77.

The condenser is placed in a thermometer bulb made of a pyrex beaker sealed to a sheet of glass with bees wax. A second bulb is made exactly like the first. These two are connected to a U-tube which passes through holes drilled in the glass plates and sealed with wax. In the U-tube a small amount of water serves as a pressure indicator. Rubber tubing with pinch cocks, or glass stop cocks are fastened to T, tubes on each side of the U-tube. These cocks serve to equalize the pressure in the bulbs. Electrical

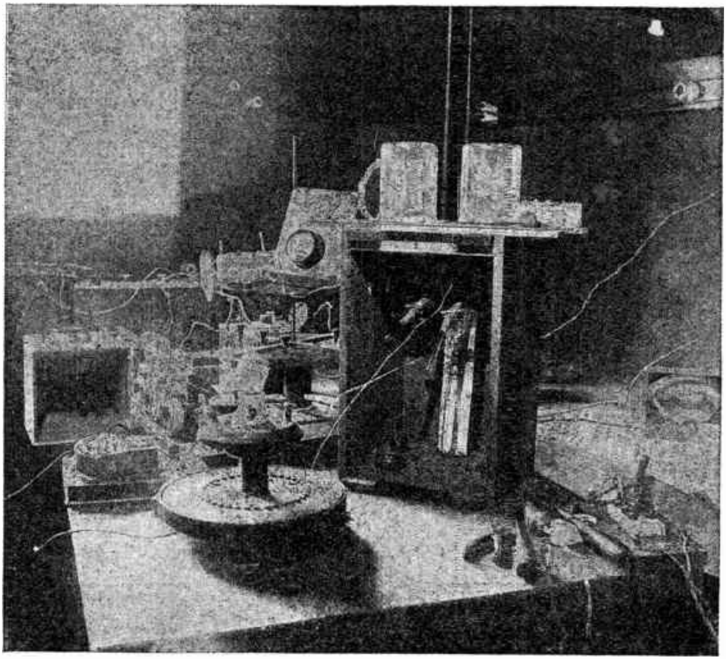


Fig. 97

connections are sealed in holes drilled in the glass plate.

The Apparatus is practically the same as shown in Figure 92. The Plate, Figure 97, shows a photograph of the apparatus with air condensers in the bulbs.

The resistance of the condenser is compared with a short piece of resistance wire, two or three ohms, which is placed in one bulb. The condenser under test is placed in the other bulb. To make the thermal capacity of the bulbs equal a second condenser exactly like the first is placed in the bulb with the resistance wire.

The procedure is as follows. The condenser is made a part of a high frequency circuit coupled to an oscillator. The resistance wire is connected with a D.C. source. A suitable R.C. ammeter is placed in the R.C. circuit and a D.C. ammeter is placed in the D.C. circuit.

A preliminary run is made to get an approximate value of the currents and to test for leaks in the sealed joints. The stop cocks are opened and the apparatus is allowed to come to thermal equilibrium which is attained in an hour or two. Then the stop cocks are closed and the radio frequency current is started. The D.C. current is adjusted so as to keep the pressure in both bulbs equal. This adjusting of the D.C. current is continued until the pressure remains in equilibrium for several minutes with both currents constant. Then since the heat produced in the two bulbs are the same, $i^2r = I^2R$, small letters referring to the R.C. circuit and the capitals to the D.C. circuit. Then the condenser resistance, $r = RI^2/i^2$. Several determinations should be made and the mean value used.

The condensers and coil should be interchanged in the bulbs and another determination made to correct for any inequality of the bulbs or surroundings.

Measure the resistance of the condenser at several dial settings and with different frequencies.

Experiment 84. To test for dielectric absorption.

In making radio apparatus it is important that the material used for forms should not absorb any of the energy of the high frequency current. These tests may be made in a very simple manner. The only apparatus needed is a loose coupler receiver, one in which the space between the coils can be made rather large. Hinged coil couplers are good.

Tune the receiver to some sending station and couple the coils very loosely. Have the coils far apart. Insert the material to be tested between the primary and secondary coil of the receiver and note the intensity of the signals or music. If there is any absorption of the material the intensity will diminish.

Test wooden boards, sheets of mica, formaca, paper tubes, and various material in sheet or tube form.

Test coils. It will be found that with good coils such as honey comb coils with relatively few turns of wire there will be no absorption, while a coil with a large number of turns will completely absorb the incoming energy. A short circuited coil will absorb or choke out the energy.

A few tests will show why a large coil with many taps is not efficient on the shorter wave ranges. The efficiency of radio frequency choke coils can be treated in this manner.

Materials should be tested in the summer when they are moist. A paper tube may test all right in the winter and be poor in the summer.

DECREMENT

The measurement of the decrement of the sending station is one of the important measurements in radio.

Decrement is the same as the logarithmic decrement in ballistic galvanometer work. The decrement is the logarith of the ratio of the first amplitude to the second amplitude. In galvanometer work we follow the English method of counting the first amplitude on one side and the second on the other side. In United States radio we take both amplitudes on the same side. Decrements as measured by the U. S. method is greater than that measured by the English method. A sending station with a large decrement is hard to tune out of the receiving circuit.

As an illustration use coupled pendulums. When one of the pendulums starts to oscillate it gradually imparts its energy to the pendulum that is tuned to the first. The other pendulums are not affected very much. In order to set up a large vibration in the tuned pendulum the first must make several vibrations. If the first pendulum makes only one or two vibrations, and then is held still all the pendulums are vibrating to some extent and the one which is tuned to the first is not vibrating much more than those that are not tuned. Thus if the pendulum is to make a few vibrations and transmit any energy at all it must have an enormous initial amplitude and all pendulums are affected about the same.

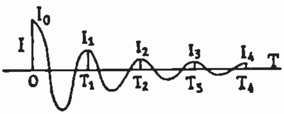


Fig. 98

The same with a sending station if it is much damped; it must have a large amount of energy in the first amplitude and all stations are affected about the same amount. Tuning the receiving circuit does little good in cutting the station out.

In the equation of a damped wave,

$$I=I_0e^{-\alpha t}\sin\omega t$$

Where $\alpha=R/2L$, we have $I_1=I_0e^{-\alpha T}$ and $I_2=I_0e^{-2\alpha T}$ for the first and second maximum values of current and $\alpha T=\log I_1/I_2=d$.

Then $d=RT/2L$. Where T is the period of the oscillation.

The frequency of such an oscillation is

$$n=\frac{1}{2\pi}\sqrt{\frac{1}{LC}-\frac{R^2}{4L^2}}$$

if R, the resistance is small then $n=1/(2\pi\sqrt{LC})$, which is the same as obtained in an alternating circuit with resistant inductance and capacity.

The equation of which is

$$I=\frac{E}{\sqrt{R^2+(1/C\omega-L\omega)^2}}$$

In the above equation, the current is a maximum at resonance when

$$1/C\omega=L\omega$$

or

$$I=E/R$$

The equation can be squared and we have

$$I^2=\frac{E^2}{R^2+(1/C\omega-L\omega)^2}$$

$$I_r^2=\frac{E^2}{\mathrm{R}^2+(1/C_r\omega-L\omega)^2}=\frac{E^2}{R^2}\text{ where}$$

I_r is the current at resonance and C_r is the capacity that makes the decremeter in resonance. Then $L\omega=1/C_r\omega$.

If the capacity is changed until $I^2=1/2.\ I_r^2$ then

$$1/2 I_r^2 = \frac{E^2}{R^2 + (1/C\omega - 1/C_r\omega)^2}$$

The current square would have been halved at resonance if R^2 had been doubled,

Then $2R^2 = R^2 + (1/C\omega - 1/C_r\omega)^2$ and

$$R = \frac{1}{\omega}\left(\frac{C_r - C}{CC_r}\right)$$

$$T = \frac{1}{n} = \frac{2\pi}{\omega} = 2\pi\sqrt{CL}, \text{ and decrement, } d = \frac{RT}{2L}.$$

$$d = \left(\frac{1}{\omega}\ \frac{C_r - C}{CC_r}\right)\left(\frac{2\pi}{\omega}\right)\frac{1}{2L} = \pi\frac{C_r - C}{C_r}\ \frac{1}{\omega^2}\ \frac{2}{2CL}$$

$$d = \pi\frac{C_r - C}{C_r}$$

thus the decrement can be obtained by determining the two values of the capacity.

Having the resonance curve where the current squares is plotted the values of C_r and C can be taken off.

The decremeter consists of a wave meter which has a variable condenser and a milliammeter or other high frequency current measuring instrument. Since the calibration curve of a variable condenser is a straight line the scale readings can be substituted in the formula for the actual value of the capacities. The ratio of scale readings will be the same as the ratio of the capacities. In Circular No. 74 Bureau of Standards, Radio instruments and Measurements, p. 198, a scale is given which can be attached to any ordinary variable condenser. This scale enables one to read off the decrement directly.

The scale mentioned above can be photographed and placed on the condenser. While photographing the scale can be reduced or enlarged to fit the particular condenser.

Lauer and Brown, p. 74, has the same scale.

After determining the decrement of the station the number of oscillations per spark can be computed.

It is assumed that the circuit has quit oscillating when the amplitude of the oscillation has dropped to 1% of the initial amplitude or $I_n = 1/100\ I_0$.

Since decrement,

$$d = \log_e\left(\frac{I_0}{I_1}\right) = \log_e\frac{I_1}{I_2} = \frac{1}{n}\log_e\frac{I_0}{I_n}$$

$$n = \log_e\left(\frac{I_0}{I_n}\right) \Big/ \log_e\left(\frac{I_0}{I_1}\right)$$

$$n = \log_e(100)/d = 4.6/d$$

Thus if the decrement is 0.2, the largest value allowed, $n = 23$ oscillations per spark.

Decrement will be seen to depend upon the amount of resistance in the circuit. Thus decrement is in a sense an indication of the resistance.

Since the decrement can be determined from the resonance curve, decrement is also an indication of the sharpness of tuning. A circuit might have small resistance and be closely coupled so as to give a large decrement reading.

In the days of the spark station it was assumed that the decrement of a C.W. station was zero. The resonance curves from C.W. stations were very sharp in comparison to the spark station.

The term decrement is now applied to C.W. stations, and circuits. Since $d = RT/2L$ and $T = 2\pi\sqrt{LC}$, $d = \pi R\sqrt{C/L}$.

Thus decrement, or logarithmic decrement can be considered to be a constant of a simple radio circuit, being π times the product of resistance by the square root of the ratio of the capacity to the inductance of the circuit. (Nema Hand book of Radio Standards.)

Experiment 85. To measure the decrement of a sending station.

Make up a decremeter of a coil of wire so wound that the distributed capacity will be small, a hot wire meter, and a variable condenser. Make the connecting wires as short as possible. Do not use lamp cord or twisted wire. This introduces capacity and leakage.

A coil of six or seven turns of No. 18 wire on a frame 50 centimeters square, the wire placed about 1 centimeter apart makes a good decremeter. Choose the number of turns so as to have the capacity readings above the middle of the condenser scale. Small capacity makes the potential on the condenser great and there is danger of a brush discharge. This leakage is a waste of energy and acts the same as if resistance were inserted in the decremeter.

Bring the decremeter near enough to get a good deflection when in resonance and read the capacity. Change the capacity until the current squared is $\frac{1}{2}$ the initial current squared, i.e. $I = .707$ of maximum; read the capacity. Calculate the decrement from the formula.

$$d = \pi(C_r - C_2)/C_r = \pi(C_1 - C_r)/C_r$$

There are two values of C one less than C_r and another greater than C_r. Use the mean difference. Or $d=(C_1-C_2)/2C_r$. Correction for the decrement of the decremeter must be made. See Experiments 86 and 87. Compute the number of oscillations per spark.

Experiment 86. Measurement of the decrement of a decremeter. Using C.W.

In the formula for the decremeter, d, is the sum of the decrement of the sending station and of the decremeter. Or $d=d_1+d_2$. The decrement of the decremeter can be measured by means of a C.W. circuit. Since the C.W. circuit is undamped the decrement of the circuit is assumed to be zero and the measured decrement is that of the decremeter. Bring the decremeter near to the C.W. circuit and proceed as before. If the wave length of the C.W. circuit can be changed the decrement at various wave lengths can be measured and a curve plotted. From this curve the decrement of the decremeter can be taken and used as corrections in the future. If the meter reads in amperes the current must be reduced to .7 of the first value.

Experiment 87. To measure the decrement of a decremeter using damped waves.

Since $d=RT/2L$ doubling the resistance in the decremeter circuit will double the decrement of the decremeter. Measure as in Experiment 85 but the result $d_1+d_2=d$. Place the resistance in the decremeter circuit until the current at resonance is halved, then measure the decrement again.

This result is $d_1+2d_2=D$, then, $d_2=D-d$.

The exact value of this resistance need not be known. An ordinary resistance box can be used. The resistance should be non-inductive. In practice the introduction of the resistance will change the setting of the resonance point a little. Keep adjusting to resonance as the resistance is changed.

This assumes that the aerial circuit is not damped very much and that the coupling is not very close. Introducing resistance into the decremeter circuit halves the current in the decremeter but has no effect on the current in the aerial. In a one to one transformer with close coupling with resistance load, assuming 100% efficiency, introducing a given amount of resistance either in the primary or in the secondary will halve the currents. If the coupling is loose introducing resistance in the primary will change the value of both primary and secondary currents. But resistance introduced into the secondary circuit will affect the secondary alone.

This method is much more simple than the one usually given. These results check with those obtained by the C.W. method.

See Circular 74, Bureau of Standards, p. 94; Physical Review, Vol. 19, p. 274, 1922; Ind. Acad. Sci. Proc., p. 223, 1922.

THE TELEPHONE AS A CURRENT MEASURING INSTRUMENT

Ordinary milliammeters and galvanometers for high frequency current are not very sensitive. The maximum range of a hot wire galvanometer is usually 100 milliamperes, and can not be relied on much below 20 milliamperes. The telephone will detect current of the order of 10^{-6} ampere. The telephone is often used to obtain a general idea of the value of the current. The minimum current that a telephone can detect can be measured as follows.

Experiment 88. To estimate the value of an A.C. current with a telephone.

Connect a 60 Cycle or 500 Cycle frequency source of A.C. current through a hot wire milliammeter and a resistance as in the Figure 99. Around the resistance R_1 connect a circuit containing a high resistance and the telephone. The resistance R_2 must be high compared to that of the telephone and to the resistance R_1. Place a resistance in multiple with the telephone. From the resistance R_1 and the current in the meter calculate the *Pd* around R_1. From this *Pd* and the resistance R_2 and the phone resistance calculate the current through the resistance R_2. Adjust the shunt resistance S, around the phone until the sound in the phone is just audible. Then from the theory of shunt circuits $I_p = IS/(S+P)$. Where I_p is the current through the phone; I is the current through R_2; I_p is the least current that can be detected by the phone; S and P are the resistances of the shunt and phone. If R_2 is great compared to the resistance of the phone, I can be considered to be independent of the value of S, or constant.

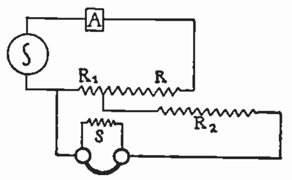


Fig. 99

In terms of the current through the ammeter, $I_p = i(R_1/R_2)S/(S+P)$. Where i, is the current through the meter.

Caution: do not use ordinary resistance boxes for R or R_1 unless the current through them is very low.

Experiment 89. To compare the sensitiveness of phones.

Measure the resistance of the phones. Place the phones in series in a high frequency circuit (100 to 1000 cycles), Figure 100a, the resistance of which is very high; *i.e.*, the current is constant. The plate circuit of a vacuum tube will answer. With a resistance box shunt around the phone until the sound is just audible. Then the current through the phone is

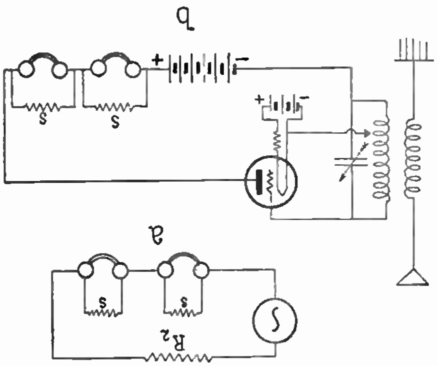


Fig. 100

$$I_p = IS/S + P$$

Where I_p is phone current I is the current of the circuit S is the resistance of the shunt. P is the resistance of the phone. Repeat with the second phone. Then the sensitiveness is proportional to the reciprocal of I_p.

This assumes that I is constant at all times or that the total resistance of the circuit is not changed appreciably by shunting the phone.

If both phones are shunted at the same time and both shunts adjusted until the sound is just audible in both phones at the same time, the current I need not be constant. Note that an adjustment of shunt No. 2 will change the current in Phone No. 1, unless the resistance, R_2, of the circuit is very great. The true adjustment is obtained only after a series of approximations.

A good source of alternating current for the comparison of phones is to tune to one of the Atlantic coast stations using an Alexanderson alternator, such as New Brunswick, N.J., a self heterodyne circuit being used, Figure 100b. The sensitivity of a phone varies to some extent with the frequency. The frequency of the A.C. in this case can be varied at will. Phones can be compared at low and high pitches. A tuning fork can be used to get the approximate frequency.

Experiment 90. To measure the audibility of signals.

The telephone is shunted until the signals are just audible. Then, $I = I_p(S+P)/S$. I_p is the least current which is audible and is assumed to be known and constant. The relative audibility of signals can be determined by taking the ratio of the currents.

Stanley, Vol. 1, p. 428; Sig. Corp. Radio, p. 448.

RADIO TELEPHONE TRANSMITTER

The radio telephone transmitter consists of a generator of high frequency alternating current and a means of modulating this current. The modulator varies the intensity of the alternating current at any desired rate. In the telephone the intensity of the current is varied in unison with the vibration frequency of the voice. Another way of saying the same thing is to say that the amplitude of the alternating current is changed in unison with the voice. This when looked upon as composition of waves is a high frequency wave of constant amplitude combined with a relatively low frequency wave of varying amplitude and frequency. Thus the wave consists of a constant frequency carrier wave and two side bands which have the summation and difference frequencies.

The generator of high frequency is generally a large tube known as a power tube connected to one of the various oscillating circuits. These may be single coil, as the Hartley circuit, or a double coil feed back circuit.

The modulator is a device which changes the intensity of the current in the aerial.

There are three methods of modulation used: absorption modulation, grid modulation, and plate modulation.

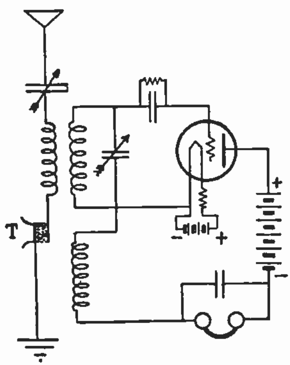


Fig. 101

Experiment 91. Absorption Modulation.

A simple absorption method consists of placing an ordinary telephone transmitter in the aerial of an oscillating circuit. Any receiving circuit that will oscillate will answer, Figure 101. This method using an oscillating receiving tube can be made to work a distance of a few blocks. The diagram shows the ordinary three coil regenerative receiver with the telephone transmitter or microphone in the aerial circuit. Couple the circuit so that the tube oscillates vigorously.

Experiment 92. Plate modulation.

The usual method used in plate modulation is known at the Heising system. This consists of an oscillating circuis of high frequency which may be considered to give a wave form of constant amplitude. Upon this an irregular wave, the frequency and amplitude of which is in unison to the voice, is superimposed.

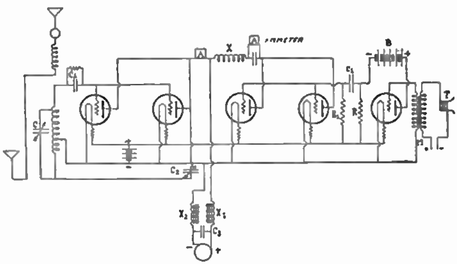


Fig. 102

The circuit consists of one or more tubes as oscillators and as a usual thing the same number of tubes as modulators. The diagram, Figure 102, shown is a Hartley Connection. An antenna with counterpoise is shown. Two oscillator tubes and two modulator tubes and one amplifying tube are used. The amplifying tube is usually a smaller tube than the others. C_1 are grid condensers which may be made of glass plates. Instead of the grid condensers and the grid leak resistances C battery of the proper voltage to place the operating point at the middle of the I_p, V_g curve may be used. X is a coil of 260 turns of No. 30 wire wound on a tube $2\frac{1}{4}$ inches diameter, inductance, 2.2 mil henry. X_1 and X_2 are choke coils of about 1 henry inductance.

These choke coils tend to keep the total plate current constant. Since the current used in the modulating tubes varies in unison with the voice frequency the potential on the plates of the oscillating tubes will vary in unison with the voice frequency and cause the intensity of the high frequency current to vary in unison with the voice frequency.

M is a telephone coil, T is a microphone. B is a B battery. The specifications are for small power tubes. Set up and adjust as in Experiment No. 95.

Lauer & Brown, p. 239, Radio Corp. of America Catalog,

Experiment 93. Grid modulation.

This consists of a circuit in which the voice changes the potential of the grid of an oscillating tube in unison with the voice frequency.

The diagram, Figure 103, given is that of a "Resistance" Telephone circuit in which the modulated current is connected to the oscillator by means of resistances instead of coils. The circuit is the Colpitts circuit. R_1 is a resistance coil approximately equal to the resistance of the microphone. R_2 is a grid leak resistance of 50 to 100 thousand ohms made of india ink on card board. Or of lamp black in a glass tube of about five milliameters diameter and ten to fifteen centimeters long. Brass plugs or screws are inserted into the ends for connections. The oscillating tubes are 5 watt power tubes. An amplifying tube is used to amplify the speech frequency before it is impressed upon the grid leak. A *B* battery of about 22½ volts is used for the plate of the amplifying tube.

The plate potential is a D.C. generator of 350 volts. Choke coils of about 1 henry are placed in the

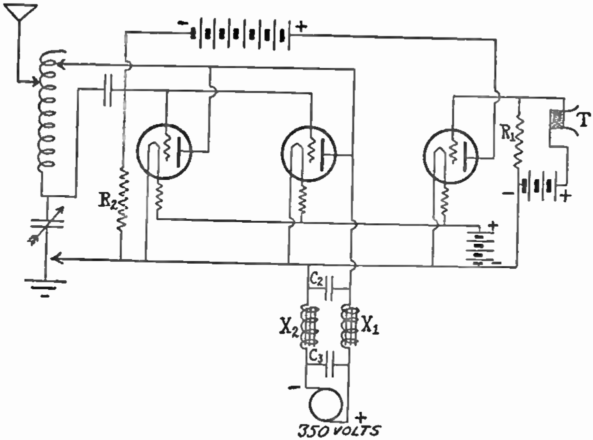


Fig. 103

generator circuit to keep the high frequency current out of the generator. C_2 is a glass plate by-pass condenser .0005 mf. to pass the high frequency current around the generator. C_3 is a condenser of 1 mf. capacity. This together with the choke coils should eliminate the hum due to the commutation of the generator. Set up and adjust following the general direction of Experiment No. 95.

Experiment 94. Construction of a portable demonstration radio phone transmitter.

A small illustrative radio transmitter can be constructed using the small radiotron amplifying tubes, 201A. Use 45 or 62.5 volts for the plate potential. One tube is used as the oscillator and the other is used as the modulator, Heising modulation, Figure 104.

The telephone coil can be connected to the grid of the modulating tube. A square coil aerial consisting of 7 turns of wire wound on a cross made of two 4 ft. laths can be used. Connect a wire to the middle of this

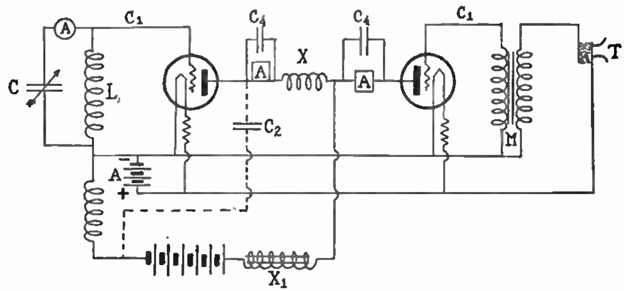


Fig. 104

coil. The oscillating circuit will consist of half of the coil and a variable condenser. The end point of the coil is connected to the grid of the oscillating tube and the middle point to the negative filament. The other half of the coil is placed in the plate circuit and serves as the feed back coil. The primary of an audio amplifying transformer can be used as the inductance X_1 in series with the B battery. M is a telephone transformer coil, or one can be made of an old Thordarson audio coil which has a good secondary. Remove the primary and replace with a coil wound of No. 24 or 30 wire.

This apparatus can be set up on a small table with castors on the legs so as to be moved about. This set can be picked up on an ordinary receiver. Begin with the transmitter near the receiver and when tuned the distance may be made greater. By rotating the transmitter around the directive effect of a coil transmitter will be noted. The distance between transmitter and receiver can be made more than 1000 feet.

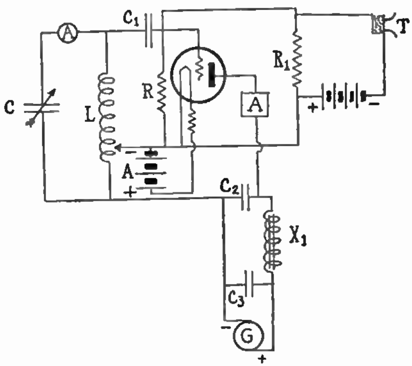


Fig. 105

With this set using 67 volts on the plate of two 201 tubes, one oscillator and one modulator, a distance of over 1100 feet has been covered. The voice was very distinct. This was accomplished in the daytime with a great amount of local disturbance. A large induction coil and static machines were running in rooms adjoining the receiving room. A three stage amplifier was used but owing to the local disturbance the reception was much better using one stage of amplification.

The input was 3 milliampere at 67 volts making about .2 watt. If the inverse distance law applies this is equal to 500 miles with 500 watts. This was transmitted through heavy timber in the daytime from a small coil aerial. An amplifying tube of the same size can be used to amplify the voice current onto the modulating tube. A set using grid modulation can be constructed in the same manner, Figure 105.

Experiment 95. Adjustment of a radio telephone transmitter.

Any radio phone transmitter will serve. Small power tubes will serve as well as the large tubes to illustrate the function of the various parts. If the five watt tubes are not at hand small amplifying tubes such as radiotron 201A tubes can be used as described in Experiment No. 94, and illustrated in Figure 104. If these small tubes are used the current in the radio circuit may be too small to affect the hot wire milliammeter, 50 milliammeters can be obtained with 201A tube. D.C. milliammeters can be placed in the plate circuits of the modulating and oscillating tubes. With the small tubes X_1 may be the primary or the secondary coil of an ordinary audio frequency transformer. The capacity, C, is an ordinary variable condenser. If power tubes are used a transmitting condenser should be used.

The D.C. milliammeters can be voltmeters, Weston 280 or others. If placed between C_2 and the plate of the tube a by-pass condenser C_4 should be placed around the meter to by-pass the radio frequency current. If C_2 is placed as indicated by the dotted connection, C_4 is unnecessary.

The tubes should be normal tubes of their class. In order to determine this the plate current grid voltage characteristic curve of all tubes should be taken with normal filament current and plate potential. A tube may be a freak and cause the conclusions to be erroneous. With amplifier tube 201A the plate potential should be 45 to 60 volts with the grid zero. With 5 watt tubes, 350 volts on the plate the grid should be from 15 to 20 volts negative. The condensers may be made of glass plates. C_3, Figures 103, 105 should be a good condenser of large capacity, microfarads. The 2 microfarad telephone condensers can be used but there is danger of short circuiting. Place a fuse in series. For inductances and choke coils the high side of ordinary transformers may be used. For exact values consult catalog of the Radio Corporation of America or the catalog No. 14, of the Manhattan Electrical Company.

Arrange an ordinary receiving circuit and tune it to the transmitter in the same manner as when receiving a distant transmitter. Either the transmitter or receiver should be portable. If a high potential generator is used place the receiver on a portable table using a coil aerial.

Start the oscillator and tune the receiver and note the presence or abscence of the generator hum. Move the portable piece far enough away so that the voice of the operator at the transmitter can not be heard except through the telephone. Place the stationary set in a closed room if possible. Note the plate potential, the grid potential, and the readings of the ammeters and the quality of the voice as heard over the phone. Change the potential of the grid of the oscillator by inserting a C battery at C_1, and record the readings of the various instruments and the quality of the voice. The small dry cells taken from flash light batteries or B batteries are convenient for C batteries in the grid circuit. When placed in series changes of $1\frac{1}{2}$ volt steps can be made.

Change the potential of the grid of the modulating tube by inserting a C battery at C_1' and record the readings. The change made on one tube may change the adjustment of the other tube. Compare the readings of the plate current with the plate current grid potential curve of the tube. Note the position of the optimum readings on the curve. Use various telephone transformers at M. Try various microphones or transmitters at T. The quality of the best radio phone transmitting station is no better than the microphone T. Change C_3 and X_1 and note generator hum. Use small and large condensers for the by-pass condenser C_2 and note results.

Compare the loudness and tone of the carrier wave squeal when the receiver tube is oscillating to the intensity of the speech when the receiver is not oscillating as X_1 is changed. Remove the by-pass condensers from the milliammeters and note the results. Increase the distance between the receiver and transmitter as much as possible. The same thing may be done by rotating a coil aerial about a vertical axis. A certain position should be found such that the transmitter can not be heard. Endeavor to get the modulation such that the position where the voice dies out is near the position where the carrier wave squeal dies out.

The efficiency of the oscillating tube should be as great as possible. The intensity of the voice should be loud with no distortion at all audible frequencies. Place an amplifying tube in the microphone circuit so that the voice frequency is amplified before being impressed on the modulator. Use resistance coupling and then an audio transformer coupling.

Record the readings of all the meters both when speaking and when not speaking and note the values of the capacities and inductances if known. If not known record the number or marks of the various pieces. When the best adjustment is obtained measure the capacities and inductances.

Instead of batteries in the grid circuits at C_1 and C_1' grid condensers and grid resistances may be used. These will be more tedious to adjust and more uncertain in value. After the final adjustment compare the characteristic curve taken with the given plate voltage.

These adjustments can be made with grid modulation using one tube. See Figure 103, R_1 is an ordinary cheap resistance box. R is a grid leak made of card board and india ink. These must be adjusted by trial. See Experiments 61 and 93 for grid leaks.

110 volt D.C. may be used on the plate if that current is available. See Experiment No. 98.

Theory suggests that the plate current of the modulator tube should be equal to the plate current of the oscillating tube. Excellent modulation has been obtained by using an excessive negative potential on the modulator tube.

See Ballentine, p. 153.

Experiment 96. Constant frequency telephone circuit, crystal control.

The constant frequency circuit is one in which the wave length does not depend upon the aerial circuit and consequently the wave length does not change when the aerial is swayed by the wind or when other conductors

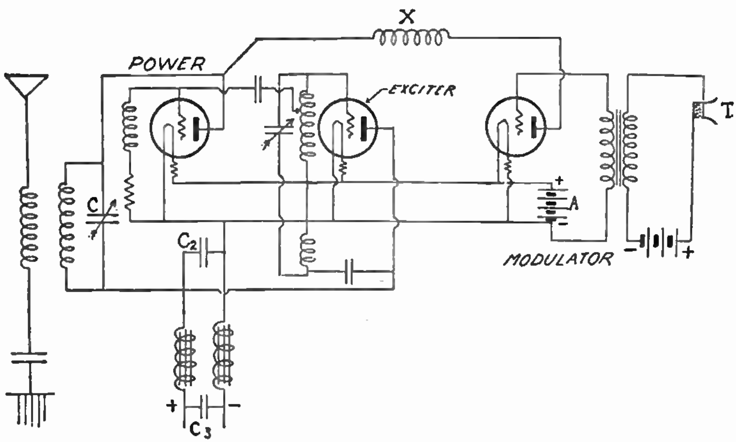


Fig. 106

such as elevators near the aerial are moved. The exciter is usually a small tube the frequency of which depends upon the constants of the simple circuit such as the Hartley circuit, Figure 106. The power tube is simply a power amplifier feeding energy into the aerial circuit. The modulator tube is connected to the power tube in the usual manner.

Although the wave length of the transmitter is independent of the aerial circuit the output of the station does depend on the exact tuning of the aerial to the exciter. If the aerial swings in the wind the output of the station will change with the swinging.

Adjust a constant frequency transmitter using the general procedure as in Experiment 95.

Small tubes and coil aerials can be used in the experiment instead of aerial and power tubes.

Ballentine, p. 124.

CRYSTAL CONTROL

A type of constant frequency circuit is one in which a quartz plate or crystal is made to oscillate either at its fundamental frequency or at an overtone of the fundamental. For details on cutting the quartz and mountings see Inst. Radio Engineers, p. 448, August, 1926; QST p. 15, July 1926 and p. 26, Sept. 1926.

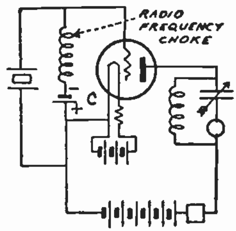


Fig. 107

The crystal can be connected to a tube as in Figure 107.

As the tuning condenser in the plate circuit is varied the meters will indicate oscillation when the circuit is in unison with any of the various overtones of the crystal. A wave meter will indicate that the frequency of oscillation is constant and is independent of any slight variation of the tuned circuit. If the circuit is detuned too much the tube ceases to oscillate.

If the tube circuit of Figure 107 is substituted for the exciter in the circuit of Figure 106 the power tube will be held at a constant frequency and be independent to any small variations of the circuit.

Figure 108 is a diagram of a crystal controlled short wave telegraph transmitter for the 80 or 40 meter band.

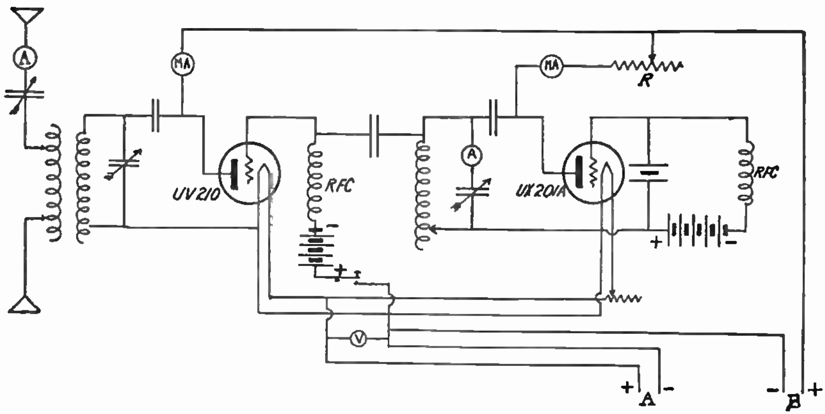


Fig. 108

Radio Amateur's Hand-book, p. 160.

Experiment 97. Transmitter without carrier wave.

Complete Modulation. It is possible to arrange a circuit so that it does not radiate except when modulated. There is no carrier wave except when the microphone is in use. Figure 109 is a diagram of the connections. The two tubes can be thought of as high frequency amplifiers of the radio current from the oscillator or tube generator. The potential of the two grids will be the same and the plate currents of the two tubes will be in opposite phase with respect to the transformers T_1 and T_2 and the current in the aerial will be zero. When the microphone is actuated the audio frequency potential of the grids will be in opposite phase. This causes the radio frequency current from one tube to increase and the other to decrease. In this manner there will be a current in the aerial the

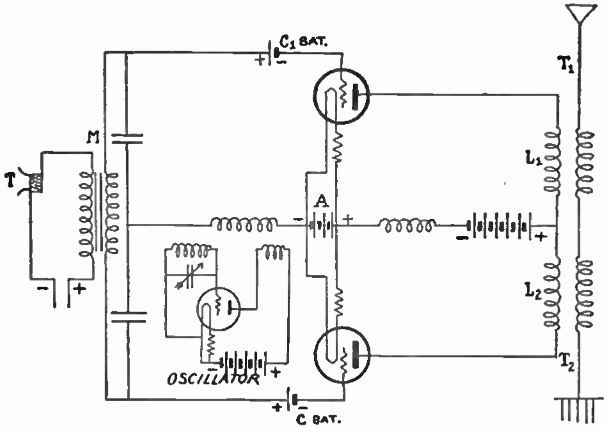


Fig. 109

intensity of the current will vary with the voice frequency. Sometimes this is spoken of as transmitting without carrier wave, using the side bands only.

Construct a complete modulated set of small tubes using a coil aerial. The construction can be made following the diagram Figure 109 using the general principles of the portable transmitter, Experiment 94.

Instead of the aerial in Figure 109 use a tuned coil of five to seven turns of wire on a square frame four feet diagonal. For L_1 and L_2 use coils of two turns each mounted on the same frame, one on each side of the loop. The phase of the current in the two must be such as to neutralize the current in the loop except when speaking in the microphone. If the three coils are mounted on three frames the coupling can be adjusted.

Make adjustments following Experiment 95 as a general outline.

Van Der Bijl, p. 324.

Experiment 98. The use of 110 volt lighting circuits for filament and plate potential in generating circuits.

The 110 volt D.C. lighting circuits can be used for plate potential when Radiotron tubes 201A and 202 are used. Most amplifying tubes, 201A will stand 110 volts on the plate. However, a 150 volt voltmeter in the plate circuit is a safe precaution. Most 5 watt power tubes, 202, will oscillate with as low a plate potential as 110 volts.

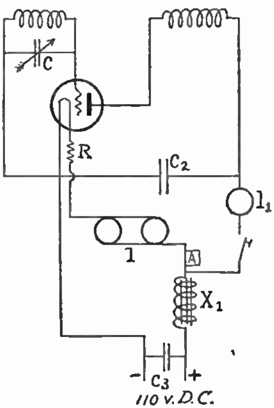


Fig. 110

The filament of the tubes can be heated from the D.C. mains if the proper amount of resistance is placed in series with the filament.

Figure 110 is a circuit showing the connections. The filament current from the positive terminal of the switch passes through an ammeter and a resistance, *l*, composed of a few incandescent lamps, the usual filament rheostat, *R*, the filament of the tube; and to the negative terminal of the switch. A choke coil, X_1, can be inserted but as a usual thing this is not necessary unless the circuit is being used as a telephone transmitter or more than one circuit is attached to the same D.C. circuit. Note that X_1 in this circuit carries the filament current. The ordinary choke coils will get hot. If two or more circuits are on the same source there is danger of high ferquency current circulating between the two sets. This choke coils should

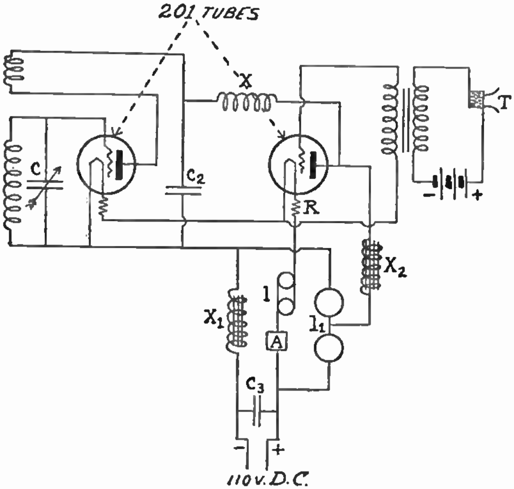


Fig. 111

have low resistance and should not heat under the constant filament current of one or two amperes. An ordinary 60 cycle transformer will serve for choke coil.

As a safety precaution a 10 watt lamp is placed in the plate circuit at l_1. D.C. voltmeter placed in same position will serve for safety as well as for a milliammeter. For the radiotron tube 201 which takes 1 ampere, two 60 watt lamps placed in parallel will give about the right amount of current. For 201A tube a single 25 watt lamp will serve.

The tube should be removed and a wire short circuit should be placed around the tube and the lamps adjusted until the current is the required amount, with the full resistance of the rheostat, R, in the circuit. For the five watt power tube the current is 2.35 amperes and larger or more lamps should be used. (4, 60 watt lamps.) For a 112 tube a 50 watt lamp can be used.

Never place the tube in the socket until the current is adjusted to the proper value. If from 50 to 60 volts is wanted on the plate, two 10 watt tubes can be placed in series as in Figure 111, and the plate connection made to the middle point. This is the safer connection if 201 tubes are used.

Figure 111 is a telephone circuit as described under the telephone transmitter. Unless great precaution is taken to eliminate the generator hum this will not be very satisfactory as a transmitter. C_3 is a 2 microfarad paper condenser. An audio transformer can be used as the inductance in the plate circuit at X_2.

In this circuit two tubes are used and the filaments are placed in series. If the coil, L, is a coil aerial, a key can be placed in the plate circuit and the set used for C.W. telegraph transmission.

These circuits can be used for radio resistance measurements, and for the experiments on resonance curves, or any other purpose where the generator hum is not detrimental. It is almost impossible to make the Hartley circuit oscillate under these conditions. Separate "feed back" coils are necessary.

110 volt A.C. circuits can be used if the tubes will oscillate using the same connections. The maximum potential on the plate will be about 155 volts. Be sure the tube does not "flare over" with this potential. If the set does not oscillate well increase the number of turns in the feed back coil. One 201A tube should give 50 to 100 milliamperes in a coil of good construction.

ENERGY OF THE OSCILLATIONS

When a tube begins to oscillate there is as a general thing a change of the plate current as shown by a D.C. milliammeter. If the grid potential is near the foot of the curve, at *a*, Figure 112, and the tube oscillates vigorously the upper half of the oscillations will be greater than the lower half and there will be a rectified component that will be in the positive direction, the plate current as shown by a D.C. meter will rise from *a′a′* to *b′b′*. If the grid potential is near the upper or saturated part of the curve at *C*, say, there will be rectification in the negative direction and the D.C. ammeter will show less current dropping from *c′c′* to *b′b′*.

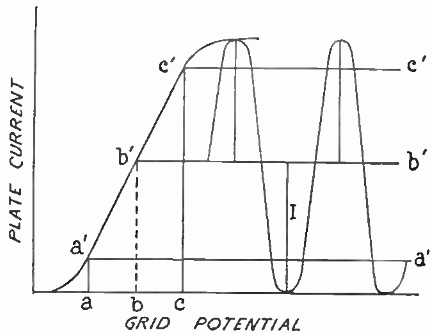


Fig. 112

If the grid potential is held at the middle point of the characteristic curve, the maximum amplitude of the A.C. component will be equal to I, the D.C. current in the plate circuit. Then since the energy used is I^2R and since the virtual I in alternating current is the maximum $I/\sqrt{2}$ then for the A.C. component, $I^2_{virt}R = I^2_{max}R/2$. Before the tube began to oscillate the energy was $I^2_{max}R$.

Since the D.C. ammeter shows the same current when oscillating as when not oscillating and since the total energy of the B battery is the same in each case and the A.C. component is one half of the total, the efficiency is 50%. This is the maximum efficiency of the tube as source of A.C. current when the wave form approximates to a sine curve. The heat developed in the tube will be greater when not oscillating than that produced when oscillating.

MEASUREMENT OF POWER IN RADIO CIRCUITS

Since all radio circuits are in resonance, i.e., circuits in which the current is in phase with the electromotive force, the measurement of power should seem to be a simple procedure. However, such is not the case.

The chief trouble is the fact that there is no satisfactory radio voltmeter. The electromotive force is usually in a coil or aerial and it is impossible to separate the electromotive force from the inductance and capacity effects. We can measure the value of the radio current with a hot wire ammeter and we can measure the resistance of the circuit and it is usual to express the power in terms of I^2R, where I is the current and R is a term which is the sum of the true resistance and a fictitious resistance called radiation resistance.

To illustrate, if we did not have a voltmeter and wished to measure the power delivered to a motor we might measure the current and insert a known resistance and read the current again and calculate the resistance in the same manner as we could do if instead of a motor the circuit consisted of a number of incandescent lamps using the same power. The resistance measured will be the sum of the true resistance and a resistance which might be called the running resistance of the motor.

Then the power used is I^2R. Which means that the power used in the motor is the same as that used in a circuit whose resistance is R.

In damped wave, spark stations it is usual to rate the power of the station by the power delivered to the A.C. (60 cycle) transformer.

In C.W. stations using tube generators the power is that delivered to the plate of the tube by the *B* battery or generator. Western Electric telephone stations are rated by the output of the tube (antenna rating). The power in the antenna circuit is I^2R where I is the antenna current and R, is the resistance as measured by inserting resistance in the aerial or by the impedance method.

Experiment 99. To measure the input and the output and the efficiency of a tube generator or of a transmitting station.

Set up a tube generator using the Hartley circuit, or any other circuit. Place an ammeter in the filament circuit, a milliammeter in the plate circuit, and a radio ammeter in the radio circuit. Be sure the plate current does not flow through the radio ammeter. Measure the voltage of the *B* battery or generator.

Adjust the connections until the radio ammeter reads a maximum. Measure the resistance of the radio circuit, Experiment 80.

From the various readings calculate the plate input, V_pI_p, the output, I^2R, and the efficiency.

The measurements may be taken with a regular transmitting station. 110 volt D.C. potential may be used with 5 watt tubes 110 volt A.C. may be used also.

Measure the output, input, and efficiency in both cases.

Experiment 100. Measurement of the percent of modulation.

The percent of modulation is defined as the ratio of the change of amplitudes of the wave due to modulation to the amplitude of the wave when not modulated, expressed in per cent.

Figure 113 represents from *A*, to *B*, the carrier wave, the amplitude of which is *c*. From *B* to *C* the diagram

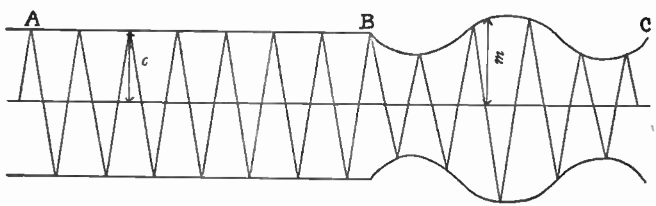


Fig. 113

represents a wave modulated with a sine wave potential. The maximum amplitude of the modulated wave is *m*. The percent of modulation is $100/(m-c)/c$.

If $m=2c$ then there is 100% or complete modulation.

The modulation can be determined by measuring the amplitude of the carrier wave and again measuring the maximum amplitude when the wave is modulated. A peak voltmeter can be used, Experiment 110.

The transmitting station can be received on a single tube or a radio frequency amplifier of two or three tubes. When the transmitter is quiet not running the grid potential of the detector tube may be brought to the required potential to make the plate current zero. Care must be taken to see that the potential is not more negative than this point. The point of zero plate current on the mutual, grid characteristic, Experiment 44 is to be found. A convenient potentiometer is shown in Figure 58. The *C* battery potential is read on the volt meter. When the carrier wave with no modulation is picked up the *C* battery is adjusted again for no plate current. This *C* battery potential minus the first potential gives the amplitude corresponding to c. The transmitter is now modulated, preferably by a constant harmonic E.M.F. and the *C* battery again adjusted for zero current. This reading minus the first gives m. For good results the transmitter must be modulated with a constant A.C. potential.

The percent modulation of a broadcasting station can be measured. In this case the modulation is not constant and readings will give maximum modulation.

Measure the modulation of a small local transmitter. Measure several commercial C.W. stations and broadcasting stations.

Experiment 101. To calibrate a wave meter by means of Lecher wires.

Some years ago it was shown by Lecher and others that it was possible to produce stationary electric waves on wires and that the velocity of these waves was very approximately the same as electro-magnetic waves in free space. In the early days the oscillatory discharge of a condenser through an inductance was used to produce the waves. During the last few years the three electrode tube has been used to produce the disturbance.

The oscillator, Figure 114, consists of a single turn of No. 12 copper wire four inches in diameter connected to the grid and plate terminal of an ordinary porcelain vacuum tube socket. The middle of this loop or turn of wire is cut and a .002 mica fixed condenser inserted. Across the grid and plate terminals a special variable condenser is fastened. This condenser is made from a Cardwell condenser by removing the stator plates and substituting two plates of sheet copper. Terminals are soldered to these sheets making two variable condensers in series, the rotor being the middle of the two. The rotor is connected to the negative filament, making a Colpitts circuit. The plate current is fed to the plate through a choke coil made of 150 turns of fine wire wound in one layer on a glass tube one-fourth inch in diameter. A grid leak resistance is connected from the grid to the filament. Such an oscillator

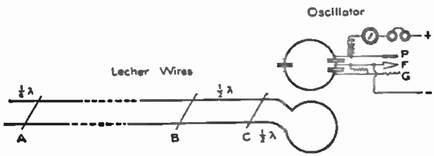


Fig. 114. Diagram of Lecher wires, and oscillator.

will oscillate at frequencies corresponding to 3.5 meters to 5.5 meters. By reducing the capacity and the diameter of the loop the wave length can be reduced to less than 1.5 meters. A five watt tube may be used, or an ordinary 201A amplifying tube can be used with about 100 volts *B* battery.

The Lecher wires consist of two parallel wires fifty to one hundred feet long, strung on insulators in a hall or between two posts or trees in the open. These wires should be from ten to twenty centimeters apart and about seven feet high. At one end the wires should extend about three feet beyond the insulators. These two ends are fastened together to form a loop which can be placed near the oscillator. When using a 201A tube in the oscillator a milliammeter or voltmeter used as a milliammeter is inserted in the plate circuit to indicate when the wires are in resonance with the oscillator. A head set may be substituted, using the resonance click method. When the wires and oscillator are in resonance there will be a sudden kick of the meter as the frequency of the oscillator is changed by rotating the variable condenser. If the wires are long there will be five or six such points of resonance on the dial. If the loop of the wires is too close the wires may absorb so much energy that the oscillator ceases to oscillate. Loosen the coupling so that the kick occurs at the same point on the dial when the capacity is decreasing as when the capacity is increasing.

Set the oscillator in resonance with the Lecher wires using the longest wave possible. Have an assistant connect the two Lecher wires with a short sliding wire at the far end. This will throw the Lecher wires out of resonance. Manipulate the slider until a point of resonance, A, is found. This point will be approximately one-fourth wave from the end. Then place the slider across the Lecher wires near the oscillator and find the point, C, which is one-half wave from the loop end. Then find the point, B, which is one-half wave from C. The distance $A-C$ is a whole number of half waves. $A-C/B-C$ should be near a whole number, n, say. Then $A-C/\mathrm{n}$ gives a better value for the length of a half wave. It will be seen that the entire length of the wires will be $\mathrm{n}+\frac{3}{2}$ half waves. Then $(\mathrm{n}+\frac{3}{2})\frac{1}{2}\lambda=$ a constant, L, which is the length of the Lecher wires.

Find the next point of resonance and find A, B, C and L. Proceeding as above for all points of resonance, the various values of L give a check on the accuracy of the method.

Since the frequency of the oscillator is found to vary with the filament current is is better to calibrate the wave meter while taking these readings.

Wave Meter

A very simple and efficient wave meter for short waves can be made by bending a piece of No. 12 bare copper wire into a circle about four inches in diameter and fastening to a wooden board. The ends of this circular wire should be about one inch apart. By means of a short screw at the center of the circle fasten a wire so as to slide over the circular wire. Between the screw and one end of the circular wire insert a small fixed glass plate condenser. The capacity of this condenser should be about .00003 microfarads. Using photographic plate glass, the area of the two plates of sheet metal is about one square inch. The exact area must be found by trial. A dial or scale should be provided to measure the angular position of the slider.

Fig. 115

The meter can be calibrated by setting the oscillator to a definite wave as measured on the Lecher wires and then removing the coupling loop and placing the wave meter in its place and by sliding the radial wire until resonance is indicated by the voltmeter in the plate circuit. With the Lecher wires of reasonable length, some five or six points can be thus obtained. When the angle or position of the radial wire is plotted against wave length it is found that a line is obtained which is nearly straight.

To compare a long wavemeter with a short wavemeter

A tube oscillator which is made to oscillate vigorously, and thus be rich in overtones is brought near the short wave oscillator. Numerous over tones will be heard in a telephone which is in the long wave oscillator. Set the two oscillators to exact resonance when the short wave meter is set for its longest wave. Then $W = nw$, where W, is the long wave as read by the long wave meter, w, is the short wave as read by the short wave meter, and n, is a whole number to be determined. Change the short wave oscillator to a shorter wave very slowly and count the over tones passed. Then $W = (n+m)w_2$ where w_2, is the second wave read with the short wave meter.

From the above, $W = mw_1w_2/(w_1 - w_2)$ and $n = mw_2/(w_1 - w_2)$. n, must be a whole number and the value obtained should be very close to a whole number.

Use n as the nearest whole number and check the value of W.

Fleming, p. 265; Stanley, Vol. 2, p. 343; J.O.S.A., Vol. 11, p. 641, Dec., 1925; Q. S. T., p. 19, April, 1925; Phil. Mag. Vol. 42, p. 265, Aug. 1921.

Experiment 102. Standing waves in space.

If waves, on water or on a rope are reflected so that there are two sets of waves moving in opposite directions there will be stationary waves set up. Nodes being the place where there is no disturbance and antinodes being at the place of greatest disturbance.

If an electric wave is reflected from a reflector there will be nodes and antinodes formed in space. These antinodes can be detected by a convenient detecting device, lamp or milliammeter if the power is sufficient. In a rope which has one end tied the frequency or length of the rope must be changed until the length of the rope is an odd number of quarter wave lengths. In the same manner the distance from transmitter and reflector must be adjusted.

The oscillator can be a short wave tube oscillator as described in Experiment 101 on Lecher wires. This is coupled to a vertical aerial with counterpoise, or if there is not a verticle space the straight aerial and counterpoise can be placed horizontal. Figure 116. This can be made of two brass rods slipped into equal lengths of close fitting brass tubing. The length of these rods and tubes will depend upon the wave length. If the pieces are from one half to three fourths of a meter long the aerial can be adjusted to be in the neighborhood of two meters from end to end. These are placed end to end and joined together at the middle with a loop of wire about four inches in diameter. Make the two ends of equal length and couple the loop loosely with the oscillator. With a milliammeter in the plate circuit the adjustment for resonance can be made.

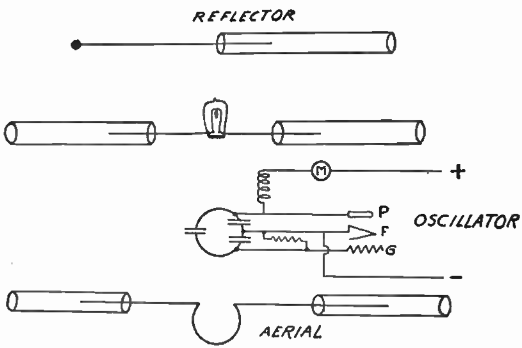


Fig. 116

Adjust to resonance and couple to the oscillator until a large amount of energy is absorbed by the aerial system.

The reflector can be a second rod and tube whose total length is about the same as the first or a little longer. This can be adjusted by bringing it a foot or so from the first and changing length until the plate meter shows resonance. Place this parallel to the oscillator aerial in a horizontal position at a distance of 8 or 10 meters measured on a line perpendicular to the aerial. The exact distance depends upon the wave length.

A third aerial system constructed much like the first can be connected with a small lamp or other indicating device at the middle point. The positions of the reflector and the detector are moved until the detector shows a maximum current. This will be a fourth wave from the reflector when best results are obtained.

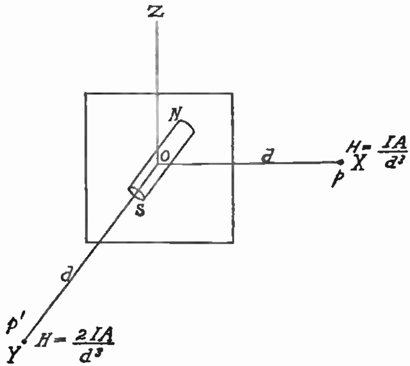


Fig. 117

When properly adjusted the antinodes will be found a half wave apart.

FIELD INTENSITY MEASUREMENTS

Experiment 103. To measure the induction close to the oscillator.

The field close to an oscillator is mostly all induction and at a distance $\lambda/2\pi$, the induction and radiation are numerically equal and since they are in quadrature the measured result will be 1.41 times the value of either.

Since from a coil the radiation varies inversely as the first power of the distance and the induction varies inversely as the cube of the distance, at distances of $\lambda/20$ or less all the field is practically due to induction.

Since the induction field of a coil is the same as that from a short magnet or magnetic shell, Figure 117, the intensity

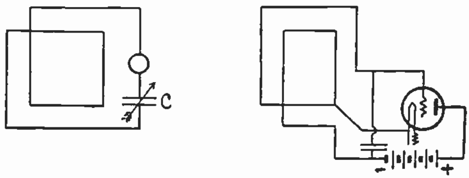


Fig. 118

of the field in the plane of the coil is $H=IA/d^3$ and perpendicular to this direction the intensity is $H=2IA/d^3$; where I is the current in the oscillator and A is the area of the coil, i.e. $A=n$ times the areas of one turn when there are n turns.

The E.M.F. induced in a coil at any position is ωHa, where $\omega=2\pi n$, n being the frequency, H the field perpendicular to the plane of the coil, and a is the area of the pick up coil.

Then E.M.F. $e=2\pi nIAa/d^3$ at a distance d from the oscillator and in the plane of the oscillator. The current $i=e/R$ where R is the radio resistance of the receiving coil. Current and resistance must be expressed in absolute units and all lengths in centimeters.

The oscillator can consist of a coil of 5 to 7 turns wound on a frame 4 feet in diameter. Connect to a five watt tube using the Hartley circuit, Figure 118. The wave length will be 300 to 500 meters.

The receiver will consist of a similar coil with a variable condenser and a radio milliammeter in series.

If the resistance of the receiver is kept low, readable current can be obtained when the distance is 2 to 7 meters or more. Take readings at various distances in the plane of the oscillating coil and perpendicular to the plane of the coil. It will be found that maximum readings are obtained when the two coils are parallel.

Measure the resistance of the receiving coil, using the resistance variation method and a radio frequency resistance box.

Compute the value of received current and compare with the experimental results.

Starling, p. 3 and p. 225; Dellinger, Bureau of Standard Scientific Papers No. 354, p. 452.

Experiment 104. To measure the radiation from a coil.

The field due to alternating current consists of two parts, induction and radiation. For 60 cycle A.C. it is necessary to make the distance hundreds of miles before the radiation field is comparable to the induction. Close to the circuit the induction is so enormous compared to the radiation that radiation is never noticed.

Since the intensity of induction and radiation are numerically equal at a distance of $\lambda/2\pi_1$, the field from radio antennas is usually all radiation at the position of the receiver.

The theory of radiation is too long to give here but it can be shown that from an aerial the induction varies inversely as the square of the distance while radiation varies inversely as the distance. From a coil the induction varies inversely as the cube of the distance and the radiation varies inversely as the distance.

From a coil aerial the radiation is, $H=4\pi^2 INA/(10\lambda^2 d)$. A short wave generator will be advantageous since the distance, d, can be small and since the value of H varies inversely as the square of wave length, and also because the re-received current is proportional to n, the frequency. The oscillator can be a one turn coil connected to a high potential condenser using a Colpitts circuit and a power tube. With such a circuit and a coil whose diameter is

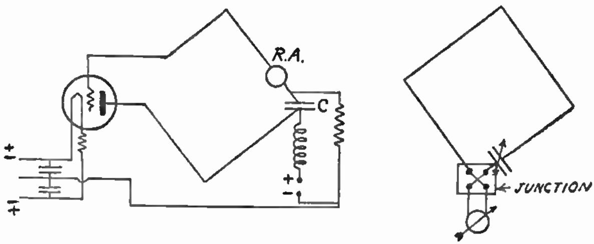


Fig. 119

2 or 3 feet, a wave length of less than 20 meters can be obtained. The receiver is a single turn of wire with a small variable condenser and sensitive low resistance thermo junction for ammeter.

Figure 119 gives the diagram of connections for oscillator and receiver.

Since the E.M.F. induced in a coil by a field, H, is $E=Ha\omega$ where a, is the coil area and $\omega=2\pi n$. And since the current, $i=E/R$. Dellinger's formula for i can be derived. This formula is, $i=7450h_s l_s h_r l_r N_s N_r/(R\lambda^3 d)$

where h, l, and N are height, length and number of turns respectively and the subscripts, s, and r, refer to sending and receiving coils.

The E.M.F. e, induced in a vertical wire by a magnetic field moving with a velocity, v, is $e = hHv$ where h is the height of the wire. If the same wire is in an electrostatic field, E, the E.M.F. is $e = Eh$.

In electro magnetic waves we have two components, the electric, E, and the magnetic, H, which are at right angles to each other.

From the above we get that $e = hHv = Eh$ or $E = Hv$, where $v = 3 \times 10^{10}$. In the electro magnetic system of units we find that this is also the relation between E and H. The energy is both electrostatic and electro magnetic and are equal and are always associated together. So that E and H are really two aspects of the same thing and if we know H, we know E. Radiation is usually given in terms of E.

$E = 3 \times 10^{10} H$ absolute units per centimeter. If we divide by 10^8 we have volts per centimeter. If we multiply by 100 we have volts per meter. If we multiply by 10^6 we have microvolts per meter. Or $E = 3 \times 10^{10} H$ microvolts per meter. Thus field strength expressed in absolute units is numerically, the same as when expressed in microvolts per meter. Radiation fields are usually expressed in microvolts per meter, written $\mu V/m$.

In order to neglect the induction measurements must be made at a distance greater than one half a wave length.

Measure the radiation at distances greater than $\lambda/2$ and check with theory. The resistance of the receiver must be measured with a resistance box which is accurate at high frequency. In a direction perpendicular to the coil the radiation is zero. Verify experimentally.

Note the effect of trees and buildings. It is interesting to set the oscillator so a tree is in the plane of the coil. Measure the intensity at various points about the tree. Plot a curve showing the intensity about the tree.

Dellinger, Bureau of Standards Scientific Papers 394, p. 463; Moullin, p. 217.

Experiment 105. To measure the radiation from a distant sending station.

In measuring the radiation of a distant station a receiver is used which is very much like a superheterodyne receiver. The diagram Figure 120 shows the connections. For

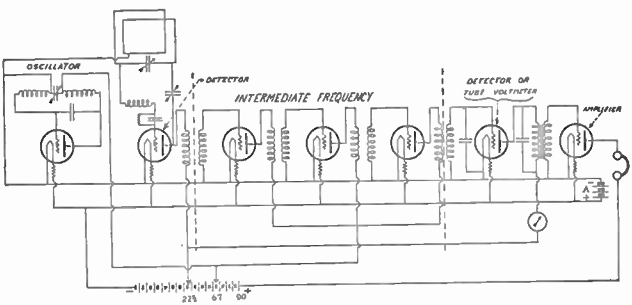


Fig. 120

exact work the set should be screened so as to eliminate inter tube action. See references. A tube voltmeter is used to measure the potential on the intermediate frequency detector. This is not very hard to do but to calibrate the voltmeter in terms of microvolts per meter is a more difficult matter. Since the calibration depends upon all the tubes, coils, etc. remaining exactly constant it is impossible to calibrate it once for all.

The usual method is to apply a variable but known small potential to the receiving coil until the tube voltmeter reading has the same value as it did when receiving the station. This is seen to be a substitution method. From this potential which is the same as that across the receiving condenser the value of E or H is calculated.

This potential must be a radio frequency potential with the same frequency as the receiving station. This requires an attenuator or potentiometer made of radio frequency resistances, which is difficult to construct.

A more simple method is to create an equal field at the same frequency and thus duplicate the readings. The field can be produced by a coil connected to a tube in an oscillating circuit.

From the current in the coil, dimentions of the coil, and the distance, d, from the receiver the field can be calculated. However there are many disturbing factors which render this method very uncertain. Reflections from objects such as walls and furniture make this method give nothing but a general idea of the magnitude.

With a small coil coupled to a screened oscillator the distance need not be so great and reflections do not play so great a part.

An attempt to make the measurements will be instructive if the only result is the discovery of the difficulties. Calculations should be made before hand to get an approximate size of coil to produce a given field when the current is a readable amount. The field intensity for good reception of broadcast programs, free from all interference such as violent static and tube noises must be about 10000 $\mu V/m$. Fair reception is often had when the field intensity is very much less than this.

From the average broadcast station the field is less than 1000 $\mu V/m$ at 100 miles. The average night intensity, 800 miles from a 5000 watt station during the winter months has been found to be 5. $\mu V/m$. Varying from 16 $\mu V/m$ to 0.1 $\mu V/m$.

Institute of Radio Engineers, Vol. 14, p. 333, June 1926; Inst. Radio Engineers, Vol. 14, p. 508, Aug. 1926; Inst. Radio Engineers, Vol. 15, p. 768, Sept. 1927.

Experiment 106. To reactivate a tube.

If a modern thoriated filament tube has had too much plate potential on the plate or the filament has been too hot while in use or if old age has overtaken the tube it can usually be rejuvinated.

The tube without plate or grid potential, grid and plate open or free, is first "flashed" for a short time and then "aged" for a longer time.

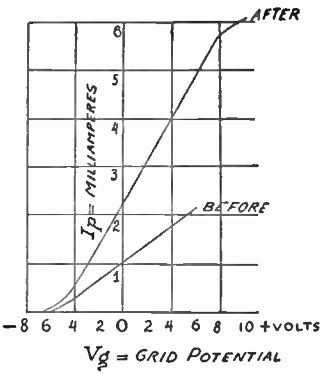


Fig. 121

The following general instructions will apply to all such tubes. The tube is flashed for thirty seconds to one minute with a potential on the filament three times the rated filament potential. For a 201A tube this is three times five volts.

Then the tube is aged for two to ten minutes by having the filament connected to a potential 50% higher than the rated potential. For a 201A tube this is $7\frac{1}{2}$ volts.

A storage battery can be used or any other convenient potential. A toy transformer such as are used to run toy trains is convenient. This has a switch on the secondary giving voltage steps of $2\frac{1}{2}$ volts up to about 25 volts.

Figure 121 shows a mutual characteristic curve of a 201A tube taken before and after reactivation.

Radio Amateur's Hand-book, p. 151.

Experiment 107. Method of estimating the A.C. current in the plate circuit of a power tube.

Assume the curve in Figure 122 is the characteristic curve of the tube. Assume the grid potential is V_g, three volts negative, say, and that the plate current is I_p, two milliamperes, perhaps. Assume the A.C. potential, Max. Pot., is e_1. Then the alternating current in the plate circuit is represented by the sine curve, the amplitude of which is I_1. This will be a sine curve and the average value of the current is still I_1, and the D.C. ammeter reading is still two milliamperes.

Let the grid potential be doubled to e_2. The A.C. current is represented by I_2, which is nearly a sine curve, the bottom tips being slightly deformed by the fact that the foot of the characteristic curve is bent. The average current is almost the same as before. The D.C. meter will indicate a little more than two milliamperes.

Suppose the grid A.C. potential is made e_3, which is three times e_1. Then the A.C. current is represented by I_3. The upper part of the deformed sine curve extends from 2 mil-amps to 5 mil-amps and the lower extends down from 2 to near zero. The average value of this curve which extends from zero up to 5 will be near $2\frac{1}{2}$ milliamperes. The upper amplitude of this curve is 3 milliamperes. The lower half should be 3 milliamperes. Then if the steady D.C. current is increased to 3 milliamperes by decreasing the negative potential of the *C* battery to 2 volts, the change of the D.C. meter will be slight when the E.M.F., e_3, is applied to the grid.

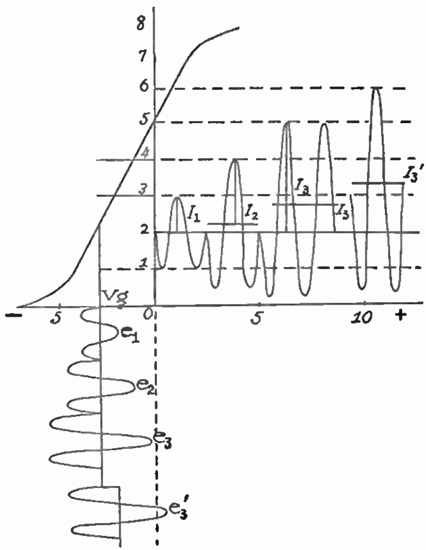


Fig. 122

The amplitude of the sine curve is 3 milliamperes and the virtual A.C. current is $3/\sqrt{2}$. If the steady current is increased to $3\frac{1}{2}$ milliamperes the D.C. ammeter will not change but the excursions in either direction is three.

If the C battery is made zero the plate current will be five and the ammeter will not change due to the fact that there is an A.C. current of $3/\sqrt{2}$ milliamperes in the plate circuit, unless the characteristic curve bends near 7 or 8 milliamperes.

To determine the A.C. current the milliammeter is read. Then the A.C. potential, ϵ, is applied at intervals, and the reading of the D.C. meter noted. By means of a C battery potentiometer the plate current is decreased until there is a change of reading when the potential, e, is applied. The reading of the D.C. instrument at the point where this change is just large enough to be detected may be taken as the amplitude of the A.C. current. The A.C. current is the D.C. meter reading divided by the radical 2.

The power is proportional to the square of this value, or $I^2{}_p/2$.

To measure power arrange a convenient C battery potentiometer. Arrange to apply a known small A.C. potential.

Measure power with change of e and with change of B battery.

Practical Application.—In amplifiers we wish power but do not wish to waste B battery. A C battery may be used to reduce the plate current. This should not be reduced beyond the point where a D.C. milliammeter reading is constant when the amplifier is in use.

Any fluctuation of the milliammeter indicates that the A.C. curve is being deformed. This of course means that we have distortion and poor reproduction of musical tones.

To estimate the A.C. current in a plate circuit from the action of a D.C. milliammeter.—Suppose the steady reading of the milliammeter is 2 millamperes. Suppose that at times when loud tones come in the milliammeter increases to 4 milliamperes.

The average value of this deformed curve is 4. The upper excursion is at least up to 8 milliamperes. This is six above the steady value. Therefore the steady value should be near 6 milliamperes so that the excursions can extend up from 6 to 12 and down from 6 to zero.

The characteristic curve of this tube should be a straight line up to 12 or there will be distortion due to the bend. If the load causes the current to move to the point where the curve is not straight the tube is over loaded and a larger tube should be used.

If there is distortion due to the upper bend the milliammeter will fluctuate to lower values than the steady value of the current when loud signals are being amplified. This will be true unless the steady value happens to be in the middle point of the curve. Then we have distortion on both halves of the sine curve.

Grid Current Distortion.—In a transformer coupled amplifier the resistance of the secondary coil of the transformer is very high. The current may be made almost zero if the potential of the grid is negative. The grid current is zero and the only current is the small capacity current, $CE\omega$, where the capacity, C, is the tube capacity. If the potential extends much past the zero then we have grid current and then an IR drop in potential.

Since this current is zero during part of the cycle and is not proportional to the E.M.F. of the A.C. current, there will be distortion due to this erratic IR drop. In our curve, Figure 122, there will be a slight grid current when the plate current reaches 6 milliamperes. If the A.C. current is much more than $3/\sqrt{2}$ it will be well to increase the B battery and thus move the characteristic curve to the left and use correspondingly more negative C battery.

Experiment 108. Measurement of power in power amplifiers.

Assume $I_p = B(V_p + aV_g) = PV_p + GV_g$ where $E = (V_p + aV_g)$. Power in any circuit $= EI$.

If the power is expended on a resistance, Power $= I^2R = E^2/R = W$.

$$W = \frac{(V_p + aV_g)^2}{R}$$

This is the power from the B battery when the current is constant. In power amplifiers the power is due to the A.C. current caused by the fluctuation of V_g.

$$\frac{dW}{dV_g} = 2a\frac{(V_p + aV_g)}{R}$$

Suppose we have a resistance load. A loud speaker can be in series with R and still be an approximate resistance load.

Connect the grid terminals to a 60 cycle A.C. source so that the potential can be varied from 01. volt or less to one or two volts.

The D.C. plate current will flow through the choke coil and the D.C. milliammeter will give the D.C. current. If the choke is large enough a hot wire meter in series with the D.C. meter will read the same as the D.C. meter.

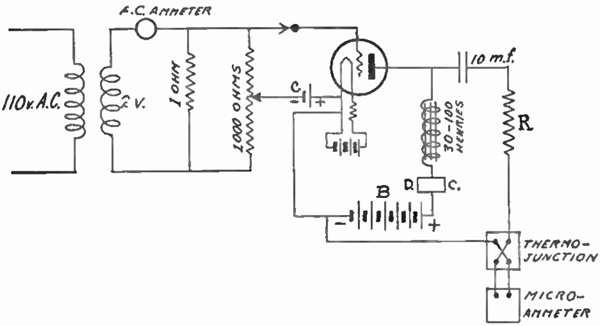


Fig. 123. Measurement of Power in Power Circuit.

A condenser and hot wire meter is placed in series with the load which may be a resistance or loud speaker. (We have assumed a resistance load.) The output will be I^2R. The square of the hot wire meter readings will be proportional to the power. A "current squared" meter reading will be proportional to the output. This should be proportional to e, and to V_p.

Connect up and check the D.C. ammeter to see that the A.C. current is all going through the condenser.

Increase e and V_p until readable results are obtained.

Increase e and read the power, keeping V_p constant.

Repeat, using larger and larger B battery.

Note the D.C. ammeter at the same time. If the D.C. ammeter is not constant there is distortion.

Change the *C* battery until there is no distortion. The D.C. ammeter should read as low as possible but not low enough to create distortion.

Compare the results with the plate current grid potential curve.

The *C* battery should be adjusted so that the grid current is zero.

Distortion is due to two things,—to rectification and to the *IR* drop of grid current.

Plot I^2 against e, V_p being constant.

Plot I^2 against V_p, e being constant.

If a sensitive thermo junction is not available a current transformer can be used as in Figure 124. An improvised transformer can be made from a burned out audio transformer. Usually the primary coil opens and the secondary is still good. Remove the primary coil and wind a second of No. 30 wire.

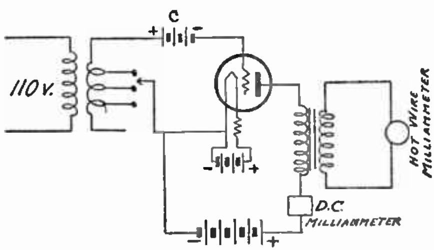


Fig. 124

The ratio of the transformer can be measured by measuring the current through the "secondary" with a delicate junction and at the same time the current in the new coil with a milliammeter.

If the junction can not be calibrated relative values can be used. See Experiment 49.

Experiment 109. To construct a beat note audio oscillator.

A Straight line Frequency Audio Oscillator.

In a laboratory there is need of a source of alternating current of varying frequency. This need was formerly met by using alternating generators in which the speed of the rotor could be changed. Frequencies from a few cycles up to 3000 cycles were obtained in this manner. Since the three-electrode tube has come into general use, audio oscillators having iron cores have been used, Experiment 59. In order to get any considerable range of frequency it is necessary to substitute several coils and condensers from time to time. This is troublesome, and each coil or condenser calls for a new calibration.

If two oscillators which are oscillating at radio frequency are tuned so they are near the same frequency a continuous note is heard in a telephone which is connected to one of the oscillators. This note is due to the alternating currents producing beats, caused by the difference of the frequencies of the oscillators. The frequency of this current can be made anything from near zero to frequencies above the limits of hearing. The intensity of this current is small but this can be amplified to usable values by means of a resistance amplifier.

If one takes an ordinary .001 microfarad semi circular plate variable condenser and a coil which will give a maximum wave length of about 12,000 meters and plots the frequency curve for the combination, one will get a curve which has great curvature for small capacity and becomes almost a straight line for the higher values of the capacity. One can choose two points on the curve such that the difference of the capacity is .00025 microfarads and the difference in the frequency is 5000 cycles. This curve between the two points is not far from a straight line. If one has two such oscillators and sets them so as to oscillate at the particular frequency corresponding to the first point, place a .00025 condenser set at zero in parallel with one of the condensers, and then changes the capacity of the

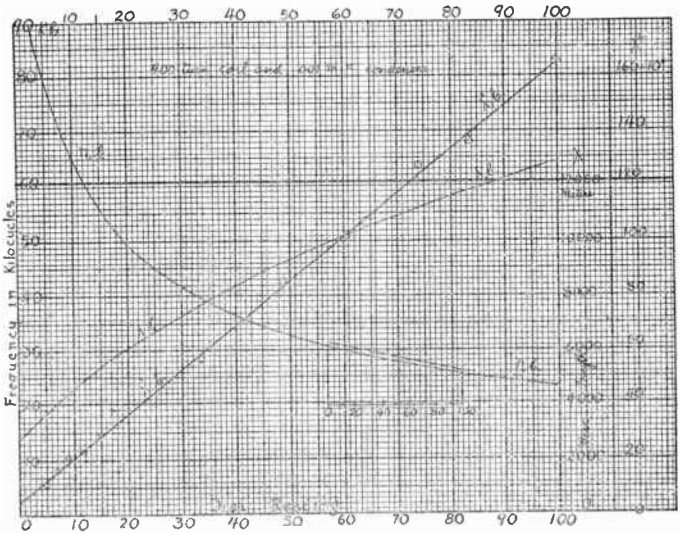


Fig. 125. Calibration curves of the audio oscillator. The curve showing the frequency is approximately a straight line through a change of frequency of 5000 vibrations.

small condenser, he can get any audio frequency he wishes between zero cycles and 5000 cycles per second. The small condenser should be made of semi-circular plates so that the capacity is proportional to the dial setting. With a 0 to 100 division dial each division on the dial corresponds to 50 cycles.

The curves in Figure 125 give the calibration of an oscillator which consisted of a 400 turn honey-comb coil and an .001 microfarad variable air condenser with a 0 to 100 dial. Since the capacity was found to be proportional to the dial readings the abscissas are plotted as dial readings instead of in terms of capacity. The straight line was obtained by plotting the square of the wave length λ^2, against the dial readings. The data for this curve were obtained by comparing the oscillator to an oscillating wave meter whose maximum range was 5000 meters.

The fundamental, first and second overtones was used in getting this line. From this line wave length curve and frequency curves were gotten as in Experiment 35.

The lower end of the curve flattens out and a small portion of it is not far from a straight line. It will be noted that the frequency which corresponds to 57 on the dial differs from the frequency which corresponds to 82 on the dial by exactly five kilocycles or 5000 vibrations. The capacity change between the two points corresponds to 25 divisions on the dial, or one-fourth of the total of the .001 condenser, or .00025 microfarads. In Figure 125 a straight line has been drawn just above the curve connecting these points, in order to show how near the curve approaches a straight line.

If the oscillator condenser is clamped so as to remain fixed at the value corresponding to 57, and a .00025 condenser is placed in parallel and set at zero capacity, and a second oscillator is set so that the beat frequency between the two oscillators is zero then as the small condenser is changed the beat frequency will change from zero to

5000 as the condenser dial readings change from zero to 100.

If more accuracy is needed, the frequency should be read off of the curve between the two points instead of off of the straight line. Using the straight line the average error is about five percent.

The diagram of the connections is shown in Figure 126. The oscillators consist of a honey-comb coil of 400 turns,

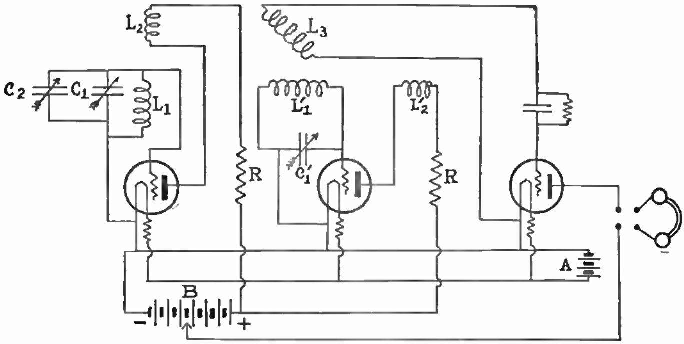


Fig. 126. Diagram of the connections of the audio oscillator.

with a tickler coil of 150 turns, in the plate circuit, $L_1L_1^1$, $L_2L_2^1$ and a .001 m.f. variable air condenser, C_1 and C_1^1. Resistances of 20,000 ohms are inserted, one each in the plate circuit of the tubes which were 201A amplifier tubes. The *B* battery was 45 volts. The purpose of the resistances is to suppress harmonics in the oscillator.

The coils of the two oscillators are placed so that one set of coils is perpendicular to the other set of coils. The pick-up coil, L_3, is a 1200 turn honey-comb coil connected to a detector tube. This coil is placed so as to make angles of about 45° with each oscillator. C_2 is the .00025 microfarad condenser placed in parallel with C_1. The intensity of the current as it comes from the detector is great enough for most work where a head set is used. One stage of amplification makes the intensity about right. Two stages make the intensity very loud. The intensity probably changes with the frequency.

The relative intensity of the sound from the loud speaker changes much more than the relative intensity of the sound from a head set in the plate circuit of the detector tube. The indications are that if a good resistance amplifier was used the intensity variation with frequency would not be so great.

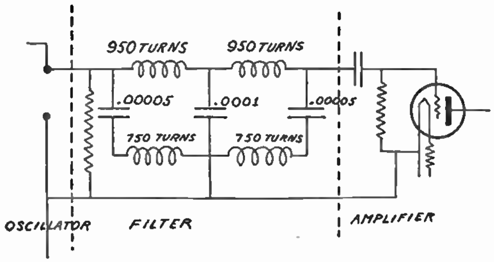


Fig. 127

In many cases the change with frequency is immaterial, since null methods are used.

The oscillator is very simple in construction and is one that can be made in most laboratories, either permanently or "scrambled" together for the occasion.

To insure good tone quality a filter should be placed between the oscillator and the amplifier. Such a filter is shown in Figure 127.

This is constructed of honey-comb coils, 950 turns and 750 turns and .0005 microfarad fixed condensers.

If the oscillator, detector, filter, and amplifier are all placed in separate metallic screening boxes the quality will be improved.

The output of the oscillator or amplifier can be measured by filtering the A.C. current from the D.C. and passing the A.C. current through a sensitive thermo junction in series with a non-inductive resistance of about 50,000. ohms. From the current and resistance the output E.M.F. can be calculated. The variations of the ammeter as the frequency is changed gives the variation of the output. The output should be constant for all frequencies.

Experiment 110. Measurement of potential with a tube.

Peak Voltmeter.—In the peak or slide back, voltmeter a tube is connected as in Figure 128. *C* is a *C* battery, connected to a potentiometer of a few hundred ohms, made of a non inductive resistance. Referring to Figure 129 which is the mutual characteristic curve, I_p, V_g, the action of the peak voltmeter can be explained. Under normal conditions when the grid is connected to the negative filament the plate current can be made zero by applying a negative potential of v_0 volts to the grid. This can be seen to be measured by the D.C. voltmeter, *V*.

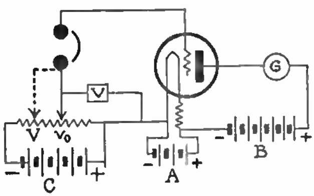


Fig. 128

If an A.C. potential of whose maximum, peak, voltage is v, is superimposed on the grid there will be a current which will be indicated by the ammeter in the plate circuit. If the potential of the grid is made equal to negative V, the current will again be zero. Then $v = V - v_0$.

The ammeter in the plate circuit should be very sensitive, either a micro ammeter or sensitive galvanometer works best. With a sensitive instrument there is some uncertainty of the exact point of setting, so much so that often it is thought best to set to some small deflection, one division say, instead of zero. The potential measured is the peak voltage. The virtual voltage is this value divided by 1.41 provided the wave form is a sine curve.

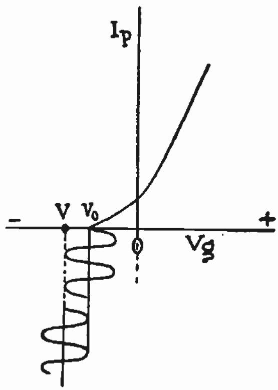


Fig. 129

Tube Voltmeter. The Tube voltmeter is a three electrode tube connected so that there will be a rectified current in the plate circuit. The tube is connected to a known A.C. potential, 60 cycle or more, with a good wave form. A curve is plotted and when the tube voltmeter is connected to another circuit the voltage is assumed to be that read off the curve.

Referring to the diagram of Figure 80 Experiment 67 "Test of an Audio Transformer," a tube voltmeter is shown with the various constants given. This diagram is taken from Nema Radio Hand book. This circuit uses a 201A tube. Some recommend a tube of low impedance such as a UX 171 tube with a large resistance in the plate circuit. The resistance being from 200,000 ohms to 2.5 megohms with a *B* battery from 22½ volts to 250 volts.

Figure 130 shows a circuit for calibrating a tube voltmeter. A low potential transformer, toy transformer, is connected to a 110 A.C. supply. The low side is connected to an accurate 1. ohm resistance with an ammeter and regulating rheostat in series. Care should be taken that none of these resistances are over loaded. A potentiometer made of a good resistance box whose resistance is 1000 ohms or more is connected around the terminals of the 1. ohm coil. By means of a slider or traveling plugs the desired potential can be applied to the grid of the tube. If the current in the ammeter is one ampere and the potentiometer resistance is 1000 ohms the potential per ohm of the potentiometer is 1/1000 of a volt.

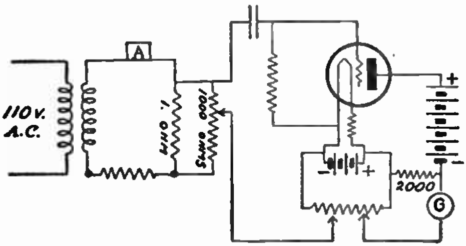


Fig. 130

A second potentiometer with two sliders is shown connected around the *A* battery. One slider regulates the initial potential of the grid and the other regulates the initial current in the galvanometer. The initial current can be made to be zero.

Moullin's high frequency voltmeter has the plate circuit connected to the positive *A* battery terminal. As manufactured it measure potentials up to 1.5 volts.

Figure 131 is a diagram of the Moullin voltmeter circuit.

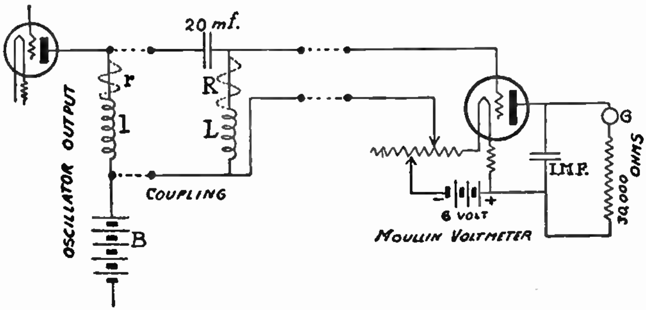
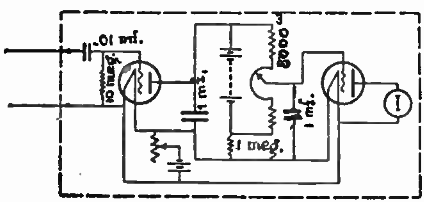


Fig. 131

When using a tube voltmeter to measure the potential around such a device as a loud speaker through which there is a D.C. current a coupling device of a large condenser



V.T. Voltmeter

Fig. 132

and large choke coil or resistance should be used. If the potential is around an inductance the inductance, *L*, should be at least 10 times *l*. *L*, should be 50 or 100 henries. If the potential is measured around a resistance. *r*, instead of an inductance a large resistance, *R*, should be used. This resistance should be about 20 times the resistance, *r*.

Figure 132 shows the diagram of a tube voltmeter in which two tubes are used, one being an amplifier. With this apparatus millivolts can be measured.

Moullin, Radio Frequency Measurements, p. 35; Dickey, Inst. Radio Eng. Vol. 15, p. 687, 1927; Medlam and Oschwald, Experimental Wireless London, Oct. and Nov. 1926; Colby, Journal of Scientific Instruments, Vol. 3, p. 342, 1926.

Experiment 111. Construction and test of a rectifier.

The most simple rectifier perhaps is the aluminum cell rectifier. This consists of two electrodes one of lead and the other of aluminum in a dilute solution of ordinary baking soda. There are many other solutions which will work but baking soda is very convenient. The connections are made as in Figure 133.

The potential on each cell should not be more than 50 volts. Several cells can be put in series for high voltage. The surface of the aluminum should be one square inch for each 40 milliamperes.

Figure 133a is a "full wave" rectifier connected to the ordinary lighting circuit. Figure 133b is a rectifier connected to a special transformer with a middle tap.

In Figure 133b the aluminum cells might be replaced with two electrode vacuum tubes. If the two tubes replace the cells and have their plates connected, one each to the two terminals of the transformer, the current will come out of the filament terminals. (A battery must be used to heat the filaments). The filament terminal will be positive and the mid tap will be negative.

A gas rectifying tube can be used as in Figure 134. In this figure a filter is shown which smoothes the pulsat-

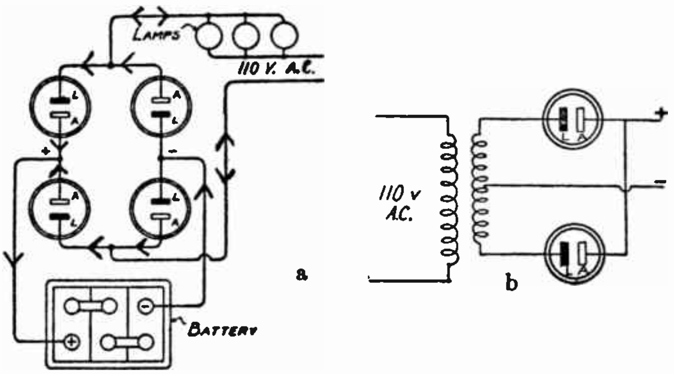


Fig. 133

ing D.C. to a constant current. This combination is known as a *B* battery eliminator.

Connect up a rectifier with a filter and take a D.C. ammeter and an A.C. ammeter and place in series in the output circuit. If the current is properly rectified both should read the same. The ammeters should be tested on a good D.C. circuit such as from a storage battery. Remove the various condenser and choke coils and notice the effect.

A telephone shunted around a resistance can be used. There should be no hum. Test the effect of removing the condensers. The ammeters can be placed in various parts of the filter circuit.

If the current is not rectified the A.C. meter will read more than the D.C. meter. The per cent of rectification

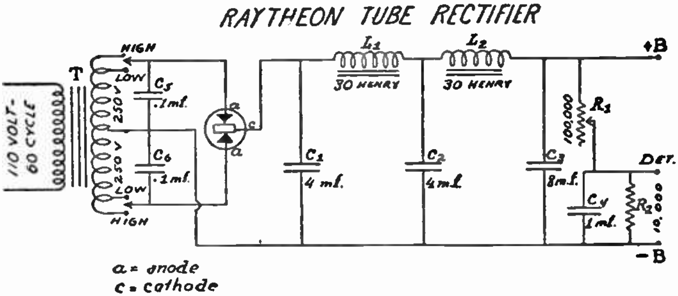


Fig. 134

is the ratio of the D.C. current to the A.C. current.

Radio Amateur's Hand Book, p. 75.

WIRED WIRELESS

In wired wireless the principle of radio transmission is used where wires are used to transmit the signal instead of the ether of space. Since the frequency is above audio frequency any transmission line such as telephone or power line can be used as the medium to transmit the messages. The capacity of ordinary electrical apparatus, such as transformers, is so great that the high frequency current passes without appreciable obstruction.

In ordinary radio the number of receivers is not limited except by distance and other factors which decrease the intensity. The world is on one party line. In wired wireless all listeners must have access to the transmission or telephone system which is used.

In ordinary radio hundreds of transmitting stations can use the same ether at the same time if they distribute the frequencies or wavelengths. In wired wireless a number of

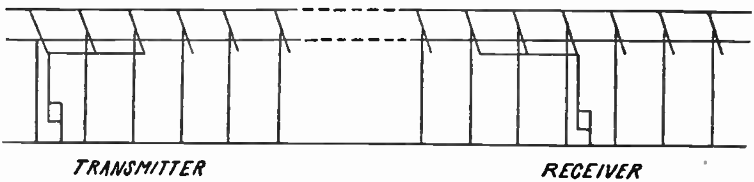


Fig. 135. Diagrammatic Connections Used in Wired Wireless.

transmitters can use the same transmission line. The listener can select the station he wishes to listen to by tuning his receiver.

The transmitter can be any radio telephone transmitter using an antenna aerial placed parallel to the transmission line. The transmission line absorbs the energy of the transmitter and carries it to the various receivers which may be connected to aerials which parallel some wire of the same transmission system.

Experiment 112. Wired wireless transmitter and receiver.

Connect a small radio telephone transmitter such as that described in experiment 94 using a coil aerial. Make a coil of a few turns of wire and connect one end of the coil to a large condenser, microfarad, and connect the coil and condenser to a plug screw into a lamp socket of the lighting circuit. Place this coil near the coil aerial. In an adjoining room or building connect a receiver to a short aerial which is placed near the lighting circuit or connect by means of the ordinary apparatus which is used when the lamp socket is used as an aerial. This apparatus is simply a condenser whose capacity is about .001 mf.

Tune to the transmitter in the ordinary manner.

There will be objectionable noises due to the 60 cycle hum or other causes. Filter circuits can be arranged to remove these noises.

Experiment 113. Types of receivers.

It is impossible to enumerate all the different types of receiving circuits. All receiving circuits can be classed in some half dozen types. All the various wave meter, oscillating, and sending circuits can be used as receivers with a detector.

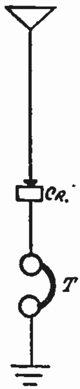


Fig. 136

The most simple receiver is the crystal detector receiver. The most simple one of this type is a crystal and a telephone placed in an aerial circuit, Figure 136. To use this circuit the intensity of the signals must be very strong.

Place a variable inductance or a variable condenser around the telephone and crystal and we have a means of tuning the circuit. With a double slide tuner, Figure 137, we have a means of tuning both the aerial circuit and the crystal circuit. The maximum response is obtained when the aerial circuit, the aerial and the portion of the coil included between the ground and aerial tap, as well as the portion of the coil between the upper portion and the second tap, is tuned to the signal.

An oat meal box with 70 turns of wire, 40 turns from aerial connection and then 15 taps with 2 turns between taps make a good receiver of this type.

The loose coupler circuit, Figure 138 is the best crystal circuit. The aerial is tuned by the sliding tap and the secondary is tuned by means of the variable condenser. If the coupling is loose and the resistance of the secondary circuit is small this circuit is selective. Unless a great deal of care is used in the construction of a good low resistance aerial the range with crystal detectors is not very great. 25 to 50 miles is good.

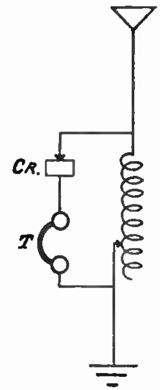


Fig. 137

If an electron tube is substituted for the crystal detector in the above circuits the range is greatly increased. With a tube in the above circuits we have plain detector circuits, not regenerative.

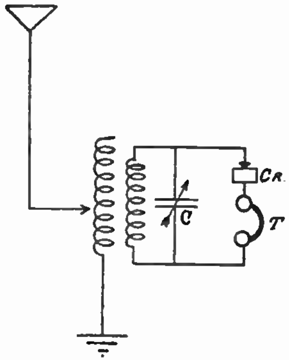


Fig. 138

Fig. 139 is a regenerative circuit which has become very popular. It is very easy to tune. It has the disadvantage that the grid of the tube is connected to the aerial circuit and any local disturbance such as induction hum from transformers will be communicated directly to the tube. The resistance of the aerial will cause the wave to be "broad" and the selectivity of the circuit will be poor. One redeeming feature is the tuned plate circuit. This is tuned by means of the variometer in the plate circuit.

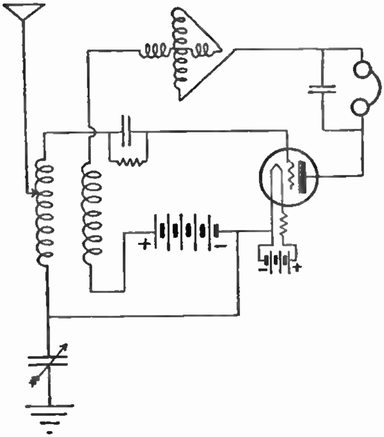


Fig. 319

Figure 140 is another two coil regenerative circuit. The loose coupler of Figure 138 can be used in this manner. This circuit is fairly selective but is likely to be noisy. Two coil circuits are a nuisance to the community. When the tube oscillates the aerial becomes a transmitting station. Since the aerial is conductively coupled to the circuit there is no way of reducing the energy radiated by loosening the coupling.

The three coil regenerative circuits are the most selective and most free from local disturbance. Figure 141 is a three coil circuit which is usually given as the typical regenerative circuit. The three coils should be mounted so that the coupling between coils can be changed. The aerial circuit is tuned either with a condenser or by means of taps

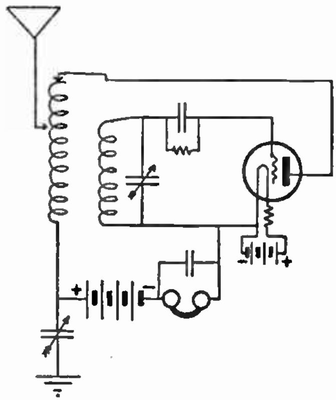


Fig. 140

on the coil. The secondary circuit is tuned by means of a variable condenser. The construction of coils for the reception of 200 to 600 meters is described in the following.

RECEIVING COIL

Procure 100 feet of number 24 cotton covered copper wire. Wind this wire on a rolled oats box or any paper tube whose diameter is about four inches. Make three coils of 25 turns of wire in each coil. Wind the coils one layer deep. Leave a space of about one-half inch between each coil. Each coil will have two terminals—six terminals in all. Number the terminals 1, 2, · · · , 6, numbering from left to right. Connect No. 1 to the ground, No. 2 to the aerial. Connect No. 3 to the grid terminal of the tube, No 4. to the negative filament of the tube. Connect one of the variable condensers to terminals No. 3 and 4 also. Connect No. 5 to the negative filament of the tube, No. 6 to one terminal of the phone, the other terminal of the phone to the negative terminal of the *B* battery and the positive terminal of the *B* battery to the plate terminal of the tube. The by-pass condenser should be connected around the phone terminals and the grid condenser placed in series

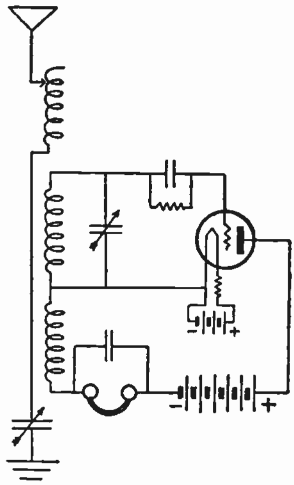


Fig. 141

with the grid circuit. The second variable condenser is placed in series or in parallel with the coil connected to the aerial. This makes a good regenerative circuit. All high power phone stations in a radius of 1000 miles can be heard with this outfit, on good nights.

This coil may be made into a loose coupler by cutting the coils apart and fastening the coil to wooden blocks. Fasten the middle coil rigidly to a wooden support and by

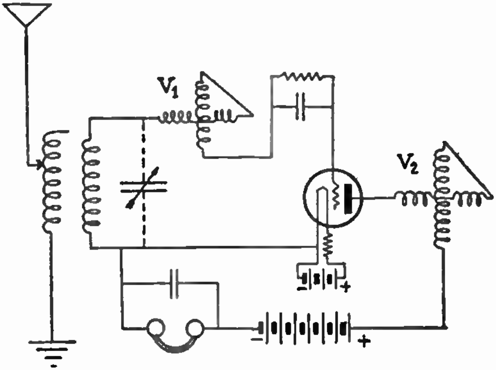


Fig. 142

means of hinges fasten the other two on each side of the first so that they will swing like the leaves of a book from a position parallel to the middle coil to a position at right angles to the middle coil. Mount so that when the coils are closed they occupy the same relative position that they did before they were cut apart. Six binding posts, one for each terminal, will add to the convenience of this coil. The wave length range of this receiver using a 43 plate condenser is from 200 to 600 meters.

Figure 142 is a variometer circuit. The primary and secondary coils are usually a vario-coupler. The aerial circuit is tuned by means of taps on the primary coil. The secondary circuit is tuned with a variometer in the grid circuit. The plate circuit is tuned by means of a second variometer. The regenerative action is from the plate variometer to the coils in the secondary circuit. The grid and plate variometers are usually placed about 18 inches apart with the vario-coupler between them.

Instead of the grid variometer a variable condenser across the secondary coil can be used to tune the secondary.

The two coil set of Figure 139 usually can be changed into the set of Figure 142. The condenser can be taken out of the primary circuit and placed in the secondary circuit. The primary is tuned by means of the taps on the primary coil. The connections to the tube can be changed to that of Figure 142 with one variometer.

ILLUSTRATIVE EXPERIMENTS

Experiment 114. Oscillatory discharge of a Leyden Jar.

One of the earliest experiments upon which radio depends is the discovery of the fact that when a condenser, Leyden jar, discharges through an inductance the discharge is oscillatory. The usual method of showing this is by means of the rotating mirror. This method is objectionable because the mirror is usually not in the right position at the time the discharge takes place.

A method which I have described in The Physical Review, Vol. 35, 405, 1912, is as follows. Connect a Leyden jar in series with a rather large inductance, the secondary coil of an induction coil, Figure 143. Make a spark gap of two metal rods mounted in wooden supports one above the other but not quite parallel. Make the distance between the closest ends about one centimeter.

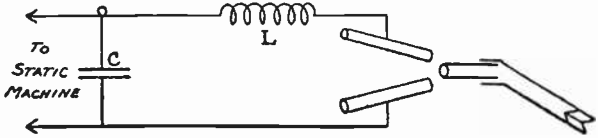


Fig. 143

By means of a small tube direct a stream of air against the small end of the gap. The discharge will take place at the closest point and the air stream will drive the ionized air along the gap so that the successive oscillations will follow the air blast and thus be spread out along the gap.

The jar should be charged by a static machine so that one discharge will take place in five or ten seconds. In this experiment every discharge can be seen to be spread out by all the observers. The inductance can be short-circuited to show the effect of the inductance.

Experiment 115. The singing arc.

The singing arc is an experiment which audibly shows the principle of the arc sending station.

Take an ordinary arc lamp on a 110 volt D.C. circuit, Figure 144. Place hard carbons in the lamp. Cored carbons will not hiss. In multiple with the arc place a condenser and inductance in series. The condenser can be paper condensers in multiple so as to have from five to ten microfarads capacity. The inductance is made of a cylinder of wood four or five inches in diameter wound with No. 6 or 9 bare copper wire. The turns being ¼ inch apart. The oscillations set up in the circuit will cause a shrill note to be given from the arc. The pitch of this can be varied by means of the inductance or capacity. When the

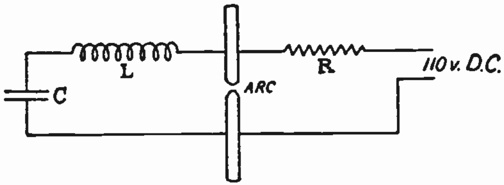


Fig. 144

note is very high if a "long wave meter" which is connected to a tube so as to oscillate is brought near the singing arc the wave length can be measured. It can be shown that the arc has a definite wave length but that the wave is not a pure sine wave. It is sine wave with a large number of irregular ripples superimposed upon it.

If the pitch of the arc is put in unison with a Dalton whistle or a high pitch tuning fork and the wave length is measured we have a method of checking the wave meter against a known audible frequency.

Experiment 116. Seibt's experiment.

Seibt's experiment is a good visible illustration of the effect of tuning. Two coils wound on glass tubes about two feet long and three inches in diameter are wound with one layer of insulated wire.

One is wound with No. 30 wire and the other with No. 26. These coils usually terminate with brass terminals with a ball at the top and a support at the lower end. These coils are connected to the circuit at the lower end. The circuit consists of a Leyden jar or two for the condenser and a variable inductance made of heavy bare wire wound on a wooden cylinder. If this coil is mounted so as to rotate about the axis of the cylinder and the sliding contact is a wheel on a brass rod the inductance can be varied by rotating the cylinder. A spark gap is inserted in series with the circuit. The coils are connected to one side of the gap and the other side is connected to the ground, Figure 145. The Leyden jars are connected to an induction coil or high potential transformer. As the inductance is varied the wave length is varied and when the wave length of the circuit is the natural wave length of one of the coils, if the oscillation is strong enough, the upper end of the coil rises to such a potential that sparks break out into the open air. As the wave length is varied the second will flare out when its natural wave length is struck.

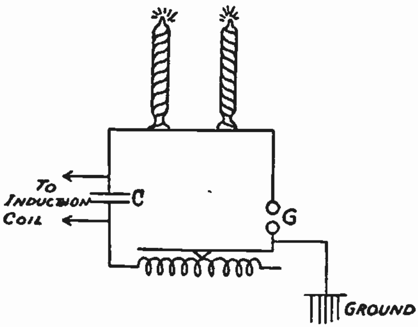


Fig. 145

The wave length can be measured by means of a wave meter with a lamp or milliammeter in series or by closing the gap and placing a buzzer around the condenser of the circuit and by means of a telephone and crystal in the wave meter.

A large tube generator might be used if a means of showing the high potential is fixed to the top of each coil. A brush of light paper or foil.

Experiment 117. The Tesla coil.

The principle of the Tesla coil is that of the oscillating transformer used in all spark transmitters. The circuit consists of condenser, Leyden jars, the primary of the Tesla coil, which consists of five to ten turns of heavy

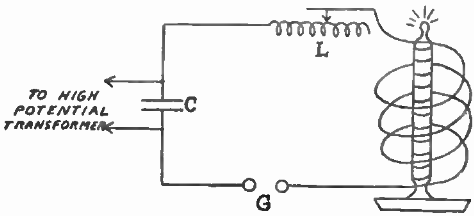


Fig. 146

wire wound about 10 inches diameter, a spark gap and a variable inductance, Figure 146.

This is energized by an induction coil or high potential transformer. The secondary coil consists of a coil of fine wire on a glass tube, see Seibt's experiment, set in the middle of the primary coil. As the variable inductance is changed the secondary coil "spits fire" when in tune with the circuit. In this experiment the small coil is inductively coupled to the circuit while in Seibt's experiment it is conductively coupled.

A tube generator might be used if a potential indicator is fastened to the top of the primary. The wave length can be measured as in Seibt's experiment.

LABORATORY APPARATUS.*

Condensers. For radio condensers use 43 and 23 semicircular plate variable condensers mounted in separate cases with binding posts. For fixed condensers use those made of tin foil and photographic plates. Directions for making are given in Experiment 20. With ordinary photographic plates a condenser of four or five sheets of tin foil will have a capacity of about .001 microfarads. Two sheets of tinfoil and three glass plates make good grid condensers. After one or two have been constructed and measured one can judge the number of sheets to use to make a condenser of any particular capacity.

Where a glass plate condenser is used by students it is hard to keep the terminals connected to tin foil. Thin sheet copper with the terminal wires soldered to the sheets are more substantial. The glass plates can be bound together with electricians adhesive tape.

Buzzers. Any buzzer such as Century buzzer will serve. The buzzer listed in electrical catalogs as Lungen buzzers have been found to be very satisfactory. Their frequency is not very high but the noise from the buzzer seems to be rather easy to muffle.

* The General Radio Co., Cambridge, Mass. makes a specialty of high grade precision apparatus for laboratory use.

The buzzer, dry cell and a break key should be mounted together. The buzzer should be placed in a wooden cubical box, inside dimensions 5 inches. The box is filled with hair deadening felt.

Induction coils. In capacity and inductance measurements use the small induction coil found in all telephones.

Telephones. Use good telephones, resistance 2000 ohms or more.

Coils. Coils such as slide tuning coils can be used. However with the ordinary slide tuning coil there is danger of the slider touching two or more turns of wire at once. In this case the turn or turns are short circuited and choke out the oscillation. Again the exact position of the slide is doubtful and there is difficulty when reproducing the exact conditions at a later time.

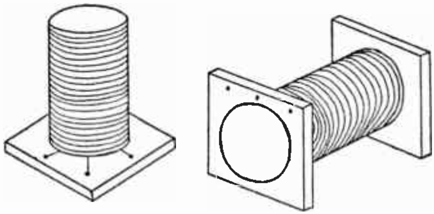


Fig. 147

Coils made in sets have proven very satisfactory. These coils are made on tubes of such diameter that one will slide into the other, both coils having the same number of turns of wire. All coils are wound single layer. Three terminals are brought to binding posts on each coil. The two ends and the middle point. In this way the coils can be used with a tube to make regenerative circuits such as Hartley circuit or the usual "feed back" circuit.

Figure 147 gives a general idea of the set. The tubes are paper tubes procured from a local carpet store. Linoleum, when shipped is rolled on these tubes. Sets are made with 20, 40, 80, 160, etc. turns.

The following table will serve to give one a general idea of the wave length range of coils when used with an

Diameter.	No. turns.	No. wire	Wave length	
3¾ inch.	10	20	100 to	225 meters.
3¾	20	20	150	360
3¼	40	20	175	500
3¾	40	20	200	650
3¼	80	20	300	1170
3¾	80	20	400	1400
4	25	20	200	600
5	20	20	175	550
5	35	20	300	850
3½	260	30	1000	3500
6	100	18	600	2000
6	200	18	1000	3200
6	130	20	800	2500
6	260	20	1300	4200
5	190	22	1100	3700
5	380	22	1700	5500
6	350	22	2000	6000
Square coil				
50×50 centimeters	7	20	150	450
Square, 4 ft.				
diagonal	3½	22	225	700
diagonal	7	22	300	1000
Square 2×2 meters	4		150	720
Square 2×2 meters	6		230	1000
Square 2×2 meters	10		350	1700
Rectangular,				
18×40 feet	1		200	730
18×40 feet	2		300	1100
18×40 feet	3		400	1580

ordinary .001 mf. 43 plate variable condenser. This data is approximate only.

For the extreme long waves honey comb coils are convenient.

(If the student has a receiver or other apparatus it adds to the interest to allow him to measure and calibrate his own apparatus. Usually it is possible to make connections to condensers and coils by means of twisted wires. The circuit must be open however. Paper placed under the tap contact on the inductance usually will do this.)

WAVE METERS

Any of the above coils and a 43 plate condenser will make a good wave meter. Connect the coil and condenser with short heavy wire. Do not use twisted wire or lamp cord. The connections should be made so that the coil and the condenser will always occupy the same relative position. The capacity and the inductance can be measured and the wave lengths calculated. Experiments 18, 23 and 28.

It is easier to get good results using a coil whose maximum wave length is 4000 to 6000 meters than a short wave coil.

The measurements and calculations may be made with the large coil and a second short wavemeter made and compared using overtones, Experiment 35 or it may be compared directly with the Bureau of Standards, Experiment 36.

The standard wavemeter which we used in the preliminary tests with the Bureau of Standards was a 43 plate condenser and a seven turn square coil 50 cm. $\times$50 cm. The error of 50% of the readings was less than ½%. The average error was .85%.

The calibration was made from capacity and inductance measurements.

MILLIAMMETERS

If a milliammeter is not at hand voltmeter can be used in many cases since the resistance of 200 ohms to 1700 ohms is small compared to the resistance of a tube. For student work it is much safer to use a voltmeter as a milliammeter than it is to use a regular milliammeter as the resistance of the voltmeter prevents excessive currents in case of short circuits. Weston Voltmeter Model 280 requires 15 milliamperes for full scale deflection. Model 1 Weston requires about 10 milliamperes for full scale deflection. When these voltmeters are placed in a circuit, where there is a radio frequency component in the current, by-pass condensers must be placed around the instrument to take care of the high frequency current.

RADIO FREQUENCY METERS

The smallest range of a radio frequency ammeter is about 100 milliamperes for full scale deflection. These should be used in wave meter circuits. Hot wire or thermo junction ammeters can be had from instrument makers in any range from 100 milliamperes to hundreds of amperes. Special thermo junctions can be had which when connected to a micro-ammeter will measure as low as one milliampere.

A LOW-POWER ELECTRON TUBE GENERATING SET FOR LABORATORY USE, FREQUENCY RANGE 100 TO 3000 KILOCYCLES PER SECOND

By H. J. Walls, Junior Electrical Engineer.
Bureau of Standards
(Copied by permission)

The electron tube generating set herein described utilizes a 5-watt power tube having tungsten or oxide-coated filament. The set is capable of supplying about 250 milliamperes of radio frequency current to a low resistance tuned circuit at any frequency within its range. On the higher frequencies considerably more current will be obtained.

Owing to the large band of frequencies covered by this generating set it is necessary to use two tuning inductors. A small one called "*A*" is used when it is desirable to obtain frequencies from 3000 to 630 kilocycles (100 to 475 meters), and a large one called "*B*" is used when a frequency of from 1000 to 100 kilocycles (300 to 3000 meters) is desired. Connections are made with the inductor by means of clips which grasp the taps extending from the inductor. These clips provide a rapid and convenient means for varying the inductance in the circuit.

The small coil "*A*" consists of 24 turns of No. 18 B & S guage double-cotton covered copper wire wound on a tube $3\frac{7}{16}$ inches in diameter and about $2\frac{1}{2}$ inches long. The space occupied by the windings is about $1\frac{3}{8}$ inches. Taps are brought out from the sixth, twelfth and eighteenth turns and are staggered somewhat so there will be little danger of the clips touching when they are placed on the adjacent taps. The taps are made by twisting a 2-inch loop of wire a few times. After the winding is completed the insulation is removed from the wire which forms the loop and it is then completely twisted together and soldered.

The large coil "*B*" consists of 200 turns of No. 22 B & S guage double cotton covered copper wire wound on a tube 5¾ inches in diameter and about 9 inches long. The windings occupy about 7¾ inches of the length of the tube. Taps and are brought out from the 30th, 45th, 60th, 75th, 90th, 100th, 110th, 125th, 140th, 155th, and 170th turns. These taps are also staggered for reason mentioned above.

Small changes in dimensions given above may be made without great change in wave length range. It would be desirable to place the completed coils in a warm oven for a few hours and then give them a coat of good insulating varnish (not shellac) to exclude moisture.

The coupling coil consists of two or three turns of wire, about No. 16 or 18 B & S guage double cotton covered about 4 inches in diameter. It is arranged so that the wavemeter may be readily coupled to it for measuring the frequency of the circuit. This coil may be dispensed with if it is convenient to couple the wavemeter directly with the tuning inductor.

Condenser C_1 is a variable air condenser which has a maximum capacity of 0.001 microfarads or more. This condenser together with the variable inductor is used in tuning the circuit for different frequencies. Condenser C_2

is a paper condenser having a capacity of 1 microfarad. It is used to by-pass the radio-frequency currents around the high voltage supply.

This apparatus should be securely fastened to a small board perhaps about 12 by 20 inches. Necessary binding

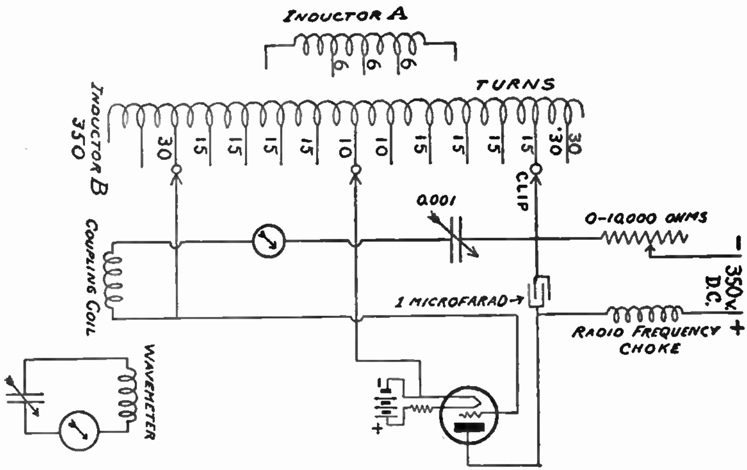


Fig. 148

posts or clips should be supplied and the apparatus wired up with wire not smaller than No. 18 B & S guage incased in varnished cambric tubing. All joints should be securely soldered. Lamp cord with the clips securely soldered to one end is very convenient in making connection to the inductors.

If the generating set is to be used for precise work such as wavemeter standardization by means of signals of known frequency it is desirable to completely surround it by fine mesh screening which is grounded. It would also be well to ground the circuit at some low-potential point, as for example the negative side of the filament.

The plate current may be supplied by a small generator or by small block batteries. This generator set has been operated satisfactorily on voltages as low as 80 volts. A higher voltage is preferable however.

CONSTRUCTION OF AN ELECTROSCOPE OR ELECTROSTATIC VOLTMETER

Instead of an electro static volt meter an electroscope can be used in Experiment 60.

This electroscope is patterned after the electroscopes used in the measurement of radio-active substances such as radium. A radio-activity electroscope can be used if one is at hand. The case of the electroscope is a can $2\frac{3}{4} \times 3\frac{1}{4} \times 5$ inches with a lid made of sheet tin by a tinner. Openings or windows 1×2 inches are cut in the side of the can. The lower edge of these windows are $1\frac{1}{4}$ inches from the bottom. The edges are $\frac{1}{2}$ and $\frac{3}{4}$ inch from the sides. These are placed in the broad sides. On the outside of the can rectangular tubes are soldered about the windows. These tubes are $1\frac{3}{4}$ inches long and of such dimensions as to leave $\frac{1}{4}$ inch spare between the edge of the window and the inside of the tube. The elevation and plan of the electroscope is shown in Figures 149. In one of the narrow sides a hole with a collar about $\frac{3}{4}$ inch in diameter is placed. The center of this opening is $1\frac{1}{2}$ inch from the top.

In the short cylinder a rod which has one end bent up at right angles to the rod is insulated by pouring melted sulphur into the cylinder while the rod is supported in proper position by a cork which extends a short distance into the cylinder. After a few hours the cork can be removed leaving the sulphur plug. In melting the sulphur, care must be used not to get the sulphur too hot or to burn it. The melted sulphur must be clear amber liquid. If the sulphur takes the waxy condition it should be discarded.

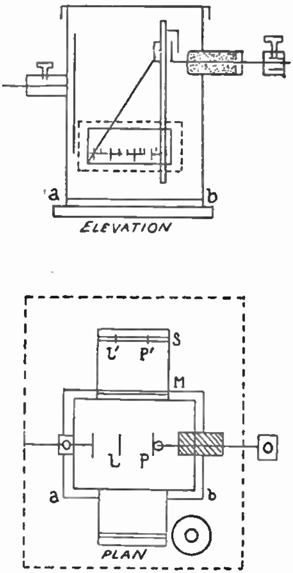


Fig. 149

The leaf is attached to a narrow plate which is supported on the bent end of the rod by means of a short length of small tube which is soldered to the back side of the plate and which fits snugly over the bent end of the rod. The leaf which is a narrow strip of gold or aluminum foil should be attached to the plate with gum from a postage stamp so as to be straight and to swing freely, bending at a point near the plate.

Opposite to the insulated plate is a second plate of metal so placed that its position can be altered and thus change the sensitiveness of the electroscope.

To read the deflection a scale, *S*, is shown in the plan is mounted on the back window. A strip of cross section paper, stuck to the glass with paraffin while hot, will answer. The paraffin serves two purposes; it sticks the paper to the glass and renders the scale translucent. Half way between the scale and the leaf system a mirror, *M*, is mounted. This mirror may be a narrow strip of an ordinary mirror. Through the front window one sees in the mirror images of the plate, *P*, and the foil, *L*, at *P′*, and *L′*. These images are in the same plane as the scale, *S*, which can be viewed by looking over the mirror, *M*. The position of *L′* can be read on the scale, *S*, and after the position has changed, its position can be noted again. By comparing the two positions with the calibration curve of the electroscope the change of potential dV_p can be obtained.

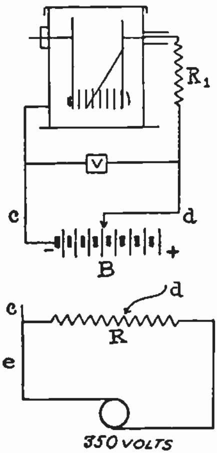


Fig. 150

Calibration of Leaf. The instrument can be calibrated by connecting to known potentials and noting the deflection of the leaf. A *B* battery with taps is convenient, Figure 150. Readings should be taken every five volts from 0 up through the maximum deflection. A curve, Figure 151 can be plotted using X = deflections, Y = volts. Since it may be necessary to change the sensibility of the electroscope by means of the movable plate in order to obtain convenient deflections it is well to calibrate the electroscope after using it in the experiment. Care must be taken to calibrate it with the movable plate and all other parts in the same relative position as they were in the experiment. A small camera level attached to the base

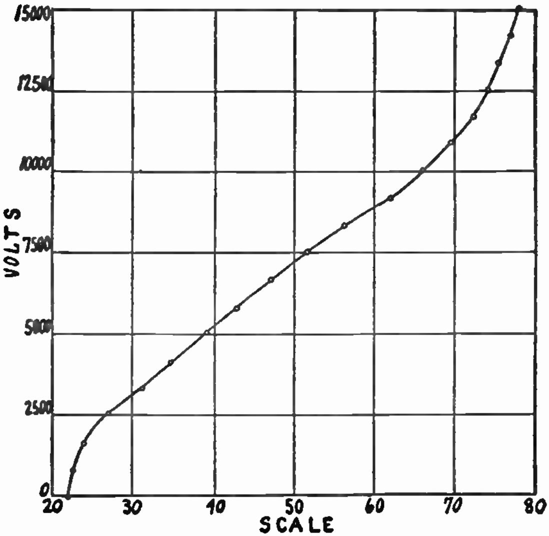


Fig. 151

of the instrument makes it convenient to set the electroscope in the same position every time.

There is danger when using the electroscope that the potential may be great enough to deflect the leaf until it touches the movable plate and short circuit the battery.

This will fuse the leaf and a new one must be placed. A resistance such as a grid leak resistance may be placed in series with the leaf and thus protect the leaf from heavy current, if D.C. is used for calibration. The narrower the leaf is cut the more sensitive the instrument will be. Aluminum leaf cut 1 millimeter wide will be extremely sensitive. Five volts per millimeter deflection is good. Cut the leaf between paper with a sharp safety razor blade. The paper and foil is held on a sheet of glass by means of a straight edged ruler.

Instead of a D.C. generator a transformer can be used for calibration if one has an A.C. voltmeter. For extremely high potentials, 10 to 30 kilovolts, a high potential transformer can be used. The potential of the transformer can be approximately determined by the voltage ratio of the transformer when the transformer is not loaded. This is done by placing a small A.C. potential, 4 or 5 volts on the primary and measuring the potential of the secondary coil by means of a calibrated electrostatic voltmeter. The maximum range of this voltmeter being about 500 volts. From the known potentials the ratio can be determined. Having the voltage ratio the potential of the transformer can be computed when the primary voltage is varied from 30 to 110 volts. The voltage of the secondary in both cases is the open circuit voltage since the current taken by the electrostatic voltmeter is of the order of 10 microamperes or less. When using D.C. a grid leak resistance can be placed in series with the electrostatic voltmeter for safety. When using A.C. the grid leak can not be used.

The following are the maximum potential ranges of the above instrument; with an aluminum foil leaf 1 millimeter wide, 75 to 300 volts; with a gold foil leaf 1 centimeter wide, 100 to 500 volts; with a leaf made of sheet aluminum .05 millimeter thick and 9 millimeters wide 500 to 3000 volts. This last is the upper limit of an instrument of the above dimensions since the distances between parts are small and sparking began at about 3500 volts. For 30,000 volts the distance between parts should not be less than about 2 inches. For this potential the case should be about 6×9×15 inches with other parts in proportion. The leaf should be made of heavier sheet metal and suspended so as to hinge over a small wire. The sheet will not bend as does the foil. The leaf of .05 millimeter foil is hinged by hanging over a small wire. The insulation in the larger instrument is a disc of hard rubber or "Bakelite" at least 4 inches in diameter fastened in a hole in the side of the case. All sharp corners and points should be rounded off.

Figure 151 is a calibration curve of an instrument made according to the above directions. The case of this instrument is a five gallon oil can. With a heavier "leaf" higher potential can be measured.

The power used in such an instrument is approximately zero, since it is essentially a condenser whose capacity is very small. The capacity of the smaller instrument is from 5 to 10 centimeters. The larger instrument should not be more.

J. A. Swindler, Phys. Rev. Vol. 18, p. 1140, 1926.

CODE PRACTICE TABLES

The following arrangement of tables and apparatus was found to work well at Indiana University in the U.S. Army School for Radio Operators. The tables were about $3\frac{1}{2}$ feet wide, wide enough to accomodate students at each side, and running the full length of the room. In the middle of the table

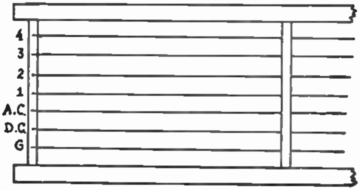


Fig. 152

was a light frame supporting a wire fence. The fence consisted of seven strands of No. 12 galvanized iron wire. The lower wire was marked *G* for ground connection. The second was marked D.C. and was connected to a six volt storage battery and used with regular Morse telegraph sounders by the telegraphers. The other terminal of the battery was connected to *G*. The third wire was marked A.C. and a buzzer circuit was connected to this wire and to *G*. The other wires were numbered.

The keys were mounted on boards and were provided with two wires which were soldered to clips which easily made connections to the iron wires. Each student had a head set which were provided with clip terminals. If a student wished to listen to his own sending he connected the key and phone in series with the clips and connected to ground and to A.C. The student or instructor could send to any particular student or to all at once by connecting the key to A.C. and to circuit No. 1, say, and the listeners connecting their phones across No. 1 and to ground. By using the other wires the students at the tables could be divided into four sets at one time.

The fence made a convenient division of the table as well as a switch board with very little obstruction to light or air.

For A.C. current source an ordinary buzzer was connected through the 100 volt coil of a transformer and the table was connected to a 25 volt coil of the transformer. A, 1 microfarad condenser was placed around the buzzer.

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