OPPORTUNITY

DIODE TUBES
Lesson 2150A

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DIODE TUBES

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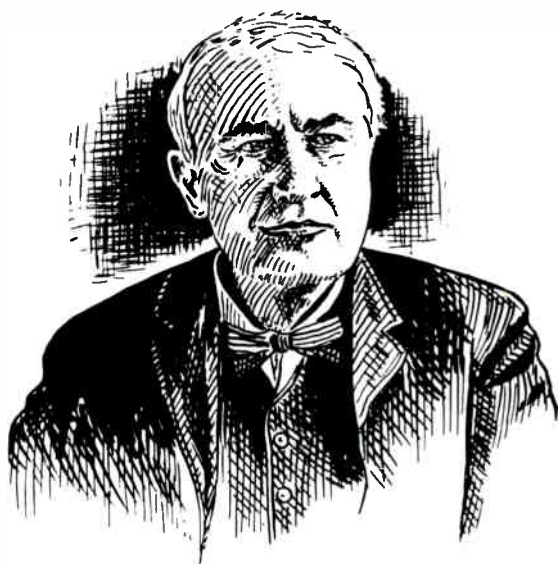
Thomas Alva Edison. Among his hundreds of inventions there were many that contributed to the progress of electronics. His discovery that current passes from a hot to a cold electrode in a vacuum led to the invention of the diode vacuum tube.

DIODE TUBES

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No man is free who is not master of himself.
                -- Epictetus

DIODE TUBES

Electronics is the branch of electrical science which deals with devices that control electrons. The most common devices used for this purpose are electron tubes and semiconductors. Electron tubes were by far the more common of the two until recent years, when new developments in semiconductor devices made the semiconductors practical for many applications. Electron tubes are still widely used in most types of electronic equipment.

An ELECTRON TUBE is a device in which electrons leave the surface of a conductor, pass across a space, and are collected by a second conductor. The conductors are called ELECTRODES. Various tubes contain two or more electrodes. These electrodes are usually enclosed in an envelope made of glass or metal.

Two general classes of electron tubes are the vacuum tubes and the gas-filled or gaseous tubes. You have no doubt seen vacuum tubes in television or radio receivers. They are called vacuum tubes because all the air is removed from inside the envelope. It is this type of tube that is described in this lesson.

THE DIODE

One type of electron tube is the diode. The term DIODE means a tube or semiconductor device having two electrodes. In the vacuum tube diode, one of the electrodes is called the CATHODE and the other is called the PLATE. In the normal operation of this tube, electrons can leave the cathode and move across the separating space to the plate, but they cannot travel in the opposite direction.

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1. What does the term diode mean?

2. In the diode tube, electrons can pass in only one direction be-
tween the two electrodes.   True or False?

*   *   *

Diode Action

Because of the limitation in the direction of electron move-
ment between the cathode and plate, a diode presents low
resistance to current in one direction only. This action may
be illustrated as in Figure 1. Here, diode D_1 is represented
as a closed switch having terminals P and K.   Battery B_1
applies its voltage across D_1 such that terminal P is made
positive with respect to terminal K. As a result of this ap-
plied voltage, a current of electrons is produced in the di-
rection indicated by the arrows.   In this simple circuit,
current I is limited only by the low resistance offered by the
switch D_1.   If we turn the battery around, as in Figure 2,
its voltage makes terminal P negative with respect to ter-
minal K. With applied voltage of this polarity, D_1 does not
conduct, and is represented here as an open switch. There-
fore, circuit current I equals zero, as indicated in the fig-
ure.

*   *   *

3. A diode presents low resistance to current in (a) one direction
only, (b) both directions, (c) neither direction.

*   *   *

Symbol

The circuit connections of every electronic system, such as
aircraft guidance systems, communication systems, and
electronic measuring instruments are shown by means of
schematic diagrams.   Figure 3 shows the symbol used to
represent one type of electron tube diode in schematic dia-
grams.   The circle represents the envelope.   The plate,
labeled P, is drawn in the form of an inverted T. The cath-

ode, labeled K, is drawn in the form of an inverted L. As used here, the cathode portion of the symbol represents either of two general types of cathodes, both of which are described in detail later. In Figures 1 and 2, the P terminal of the switch represents the plate of diode D_1, while the K terminal represents the cathode. The diode conducts when the plate is positive with respect to the cathode as in Figure 1, and is nonconductive when the plate is negative as in Figure 2.

Bias

A voltage is called a BIAS when it is applied across the electrodes of a device. In Figure 4, voltage E_1 is a bias. It is the voltage that battery B_1 applies across the plate and cathode of diode V_1. In this circuit, E_1 makes the plate of the diode positive with respect to the cathode, producing current I. On the other hand, in Figure 5, bias voltage E_1 makes the plate of V_1 negative with respect to the cathode. As explained, the diode is then nonconductive and does not permit current in the circuit.

*   *   *

4. What do we call a voltage applied across the electrodes of a device such as a diode?

*   *   *

NOTICE THAT WE EMPLOY THE LETTER E TO DESIGNATE VOLTAGE AND THE LETTER V TO DESIGNATE A TUBE IN THIS LESSON. THIS IS STANDARD PRACTICE IN DESCRIPTIONS OF ELECTRON TUBE CIR- CUIT OPERATION, BUT IS DIFFERENT THAN THE SYMBOLS USED WITH TRAN- SISTORS AND SOME OTHER DEVICES.

Gating and Rectification

GATING is the circuit action which produces an output when

a certain specific input or set of inputs is applied. In its simplest form gating produces a dc current from an ac current. RECTIFICATION is a type of gating in which the output is generally used to power other circuits or stages. Practically every electronic system uses diodes that either gate or rectify.

Generally, we use the term RECTIFIER when speaking of diodes that normally conduct relatively large currents and whose only purpose is that of rectification. Large industrial equipment uses numerous rectifiers. Often devices are required either for gating or to rectify small signal currents of a few milliamperes or less. Usually these units are simply called diodes.

* * *

5. Diodes perform what two basic actions in electronic circuits?

* * *

The gating action is illustrated in Figures 6 and 7. Diode V_1 acts as a gate which "opens" and "closes" as required to provide a desired output from its circuit. Input voltage E_{IN} is applied to V_1 and R_1 in series. Resistor R_1 and the resistance of V_1 form a voltage divider. Part of the applied voltage E_{IN} is across each of these resistances. The part across V_1 is indicated as E_{V_1}, and the part across R_1 as E_{R_1}. Voltage E_{R_1} is the output of this circuit.

In Figure 6, input voltage E_{IN} makes the upper input terminal positive with respect to the lower terminal, as indicated. Therefore, voltages E_{V_1} and E_{R_1} have the indicated polarities. Since E_{V_1} makes the plate of diode V_1 positive with respect to the cathode, V_1 conducts current or is conductive. The resistance of the conductive diode is very much less than the resistance of R_1. As a result, the voltage division is such that E_{V_1} is very small, and E_{R_1} is nearly equal to E_{IN}. Thus, in this gate circuit, a positive input voltage produces a positive output voltage, E_{R_1}, which

is nearly equal to the input voltage.

With respect to ground ($\perp$), the cathode of V_1 is positive by the amount of the voltage across R_1. However, the small voltage E_{V_1} makes the plate of the diode more positive than the cathode. Even though it is very small, voltage E_{V_1} across the diode causes V_1 to conduct, since conduction of the tube requires only that the plate be positive with respect to the cathode.

*   *   *

6. The output of the gate circuit of Figure 6 is (a) E_{V_1}, (b) E_{R_1}, (c) E_{IN}.

7. In the gate circuit of Figure 6, the plate of V_1 is made positive with respect to the cathode by (a) E_{R_1}, (b) E_{V_1}, (c) the output voltage.

*   *   *

In Figure 7, input voltage E_{IN} makes the upper input terminal negative with respect to the lower terminal. Therefore, the polarities of the voltages across V_1 and R_1 are the opposite of those in Figure 6. As indicated in Figure 7, E_{V_1} makes the plate of V_1 negative with respect to the cathode. Since this voltage is opposite that which causes normal conduction, the diode does not conduct.

The insulating materials in which the electrodes of V_1 are mounted permit a minute leakage current. However, this current is so small that it can be considered equal to zero. Therefore, V_1 has practically infinite resistance under these conditions. For practical purposes, we can simply consider that all of E_{IN} is across the infinitely high resistance of V_1, and none is across R_1. Thus, as indicated in the figure, E_{V_1} is equal to E_{IN}, and E_{R_1} is equal to zero. Since E_{R_1} is the output of the circuit, the output is zero when a negative input voltage is applied.

*   *   *

8. In the gate circuit of Figure 7, output voltage E_{R_1} is zero be-
    cause the input voltage causes the resistance of the diode to be
    (a) equal to that of R_1, (b) very low, (c) very high.

*   *   *

In the diode gate circuit example of Figures 6 and 7, a posi-
tive input voltage is permitted to appear across the output
terminals.   If diode V_1 is reversed so its cathode connects
to the upper input terminal,
the gate circuit allows nega-
tive input voltages to appear
across the output terminals,
but blocks positive input volt-
ages.   Thus, depending upon
its arrangement, a gate cir-
cuit may be open for voltages
of a desired polarity and
closed for voltages of the op-
posite polarity.

Figures 8 and 9 illustrate the
rectifying action of the diode.
The circuit of Figure 8 causes
an alternating voltage to pro-
duce a direct current.   Here
E_{IN} is an alternating voltage
applied to V_1 and R_L in series. R_L represents any load de-
vice to which we desire to supply direct current.   The load
could be a motor, a relay, an x-ray tube, or some other dc
device. The variations of E_{IN} are represented by the upper
curve in Figure 9.   Positive alternations of E_{IN} make the
plate of V_1 positive with respect to the cathode. As a result,
V_1 conducts a current I consisting of electron flow in the
direction indicated by the arrows in Figure 8. Since V_1 has
very low resistance when it is conducting, the magnitude of
I is determined almost entirely by E_{IN} and R_L.

The 6AL5 is a dual diode tube of the miniature
type commonly used in radio and TV circuits.
Courtesy GE Receiving Tube Department

The lower curve in Figure 9 shows that current I rises along with the positive alternations of E_{IN}. When E_{IN} reaches its maximum value, I is at its peak also. Then, E_{IN} falls to zero, causing I to fall to zero.

The negative alternations of E_{IN} make the plate of V_1 negative with respect to the cathode. V_1 is then nonconductive, and circuit current is zero. Hence, the lower curve in Figure 9 shows current I to be zero during the negative alternations of E_{IN}.

During the conductive intervals of V_1, the current is carried by load R_L as indicated in Figure 8. Therefore, the lower curve of Figure 9 represents the current supplied to the load. As shown, this rectified current consists of a series of pulses, all in one direction. A current of this kind is called pulsating dc.

                *   *   *

9. The rectifier circuit of Figure 8 supplies dc to the load when the input to the circuit is alternating voltage because the diode can conduct in one direction only. True or False?

                *   *   *

VACUUM TUBE DIODE OPERATION

When a vacuum tube diode is conducting, the action taking place within the tube is that of electrons leaving the cathode and moving across the empty space to the plate. This electron flow is called SPACE CURRENT. The action by which electrons leave the cathode is called electron emission.

Electron Emission

ELECTRON EMISSION is any process by which electrons leave the surface of a material. Several methods are available for producing emission from solid materials. That

used most commonly in electron tubes consists of heating a metal object called the emitter or cathode.   The two words emitter and cathode are employed interchangeably to refer to the electrode that serves as the source of electrons.

The free electrons in a metal move about continuously, colliding with each other and with the atoms and molecules of the metal.   When the metal is heated,   the electrons move faster. When the electrons are moving fast enough some of them are able to pass right through the surface of the metal to the outside.

This type of emission is called **THERMIONIC EMISSION** from the   Greek   word   "thermo" meaning heat.   The emitter must be heated to a very high temperature to produce enough emission for practical applications.   Also,   the emission is most effective in vacuum. If it occured in air, the dense concentration of air molecules would not let the emitted electrons get very far from the emitter.   Also,   most metals

A glass, actal base diode commonly used as a half-wave rectifier in high voltage supplies. Courtesy GE Receiving Tube Department

would burn up in air at the high temperatures to which they must be raised to emit useful quantities of electrons.

*   *   *

10. To produce sufficient thermionic emission for practical purposes such as the control of an industrial process, the emitter is heated to (a) a little above room temperature, (b) a very high temperature, (c) a temperature just above its melting point.

*   *   *

As the electrons leave the emitter, they form a cloud near the emitter. This cloud of electrons is called a **SPACE CHARGE.** Since the space charge is made up of electrons, it has a negative potential. This fact prevents it from building up indefinitely. The negative space charge repels electrons back into the emitter. A condition of balance is reached in which the number of electrons repelled back to the emitter just equals the number being emitted. The extent of the space charge depends upon the material and temperature of the emitter.

Emitters

There are two basic types of emitters or cathodes, called the directly heated type and the indirectly heated type. The directly heated emitter is a wire **FILAMENT** which carries the current that produces the heat. One construction employed for this type of emitter is shown in Figure 10A. Here, the filament is held in the shape of an inverted V by three supports. The supports connected to the ends of the filament are conductors. They complete an electric circuit from the filament through the base of the tube to an external source of current. Emission takes place from the surface of the filament. Because of its properties, this type of emitter is commonly referred to as the filament when speaking of a tube in which it is employed. The filament wire varies in size from a fine wire in the small receiving type tube to a wire of considerable thickness in the large tubes used in transmitting equipment.

The indirectly heated emitter consists of a metal cylinder which emits electrons from its outer surface when it is heated. A wire heating element called the **HEATER** supplies the heat by radiation to the emitter. In this arrangement, the emitter is commonly referred to as the cathode. Figures 10B and 10C show two constructions used. As shown, the heater is located inside the cathode, but insulated from it electrically. The only purpose of these heaters is to supply heat to the cathode.

*   *   *

11. Radio communication equipment uses many tubes of the in-
     directly heated emitter type.   What is the source of heat in
     the indirectly heated emitter?

*   *   *

As shown in Figure 10, in the indirectly heated emitter,
conductive supports connect the two ends of the heater through
the base of the tube, thus providing for connections to an
external source of current.   A third conductive support
permits connecting the cathode to an external circuit.   The
broad definition of "cathode" is the electrode that supplies
electrons.   In this sense, the filament of Figure 10A is a
cathode, the same as the cylinders of Figures 10B and 10C.
Often, the word cathode is employed in this general sense
when there is no reason to be concerned with the particular
type of emitter.

Filament and Heater Current Supplies

We have mentioned that the emitter in the diode is heated to
cause it to give off electrons by thermionic emission.   The
heat is provided by passing a current through the filament
in a directly heated tube, and through the heater in an in-
directly heated tube. This heating current is obtained from
an external source provided expressly for the purpose.   The
current can be either ac or dc.   A common source of ac
filament or heater current is a transformer that steps the
117 V line voltage down to the low voltage required by the
filament or heater of the tube.   Typical filament and heater
voltages required are 1.4, 3.15, 6.3, and 12.6 volts.   A
dry-cell battery is a common source of dc for this purpose.
For example, television and console radio receivers employ
the transformer method, while portable receivers use bat-
teries as filament and heater supplies.

Figure 11A shows a battery supplying the heating current to
the filament of a directly-heated diode.   In this circuit,

filament current I_f consists of electron flow from the nega-
tive terminal of battery B_1, through the filament, and to
the positive terminal of B_1.   The magnitude of this current
depends only upon the battery voltage and the resistance of
the filament.   It is not affected by the number of electrons
emitted by the filament. That is, the filament current does
not supply electrons for emission. It merely heats the fila-
ment so electrons that are near the surface can fly off into
the space around the filament.   Therefore, at any instant,
there are as many electrons returning from the filament to
the battery as are flowing from the battery to the filament.

In Figure 11B, battery B_2 applies a voltage that makes the
plate of V_1 positive with respect to the filament. This volt-
age produces **PLATE CURRENT** I_b which, outside the tube,
has the form of electron flow from the plate to the positive
terminal of B_2, and from the negative terminal of B_2 to the
filament.   Plate current I_b and filament current I_f have
practically no effect upon each other, even though both are
carried by at least part of the filament.

Figure 12 shows the heater of an indirectly heated diode
supplied heating current by battery B_1. B_2 produces plate
current I_b.   The heat generated in the heater by I_h passes
to the cathode.   As explained, the heater and cathode are
very close to each other so the heat is transferred easily
from the heater to the cathode.   However, they are insulated
electrically, so that there is no electrical connection be-
tween the circuits that carry heater current I_h and plate
current I_b. Thus, heater current I_h is completely independ-
ent of plate current I_b.

Electron Collection

As mentioned, after leaving the cathode, the electrons form
a space charge which surrounds the cathode.   The plate
collects the electrons by drawing them to it out of the space
charge.   The collection action takes place when a voltage
makes the plate positive with respect to the cathode, as in
Figure 4.   As the electrons pulled from the space charge

reach the plate, they enter it and are then conducted through the external circuit to the voltage source.

Plates

The plate is built so that it surrounds the emitter and can collect as many electrons as possible.   There are many plate shapes used, varying with tube types.   A few of the most common are shown in Figure 13.

Saturation

In the electron tube, the space charge acts as a reservoir of electrons from which the plate takes electrons at a rate that depends upon the plate voltage.   Figure 14 illustrates the action.   An electric field of the indicated direction causes electrons to leave the space charge and move to the plate. The more positive the plate, the stronger the field and the larger the plate current.

There is a weak field between the space charge and cathode also, as indicated.   Its direction is such that it causes a few of the electrons to return from the space charge to the cathode.   Thus, THE SPACE CHARGE LIMITS THE PLATE CURRENT IN A DIODE TUBE.   This is the normal oper- ating condition of the diode in most applications.

*   *   *

12. The electric field between the space charge and plate has direction such as to cause electrons to flow to the plate when an applied voltage makes the plate (a) positive with respect to the cathode, (b) the same potential as the cathode, (c) nega- tive with respect to the cathode.

13. The electric field between the cathode and space charge urges electrons toward which electrode?

14. When a diode is employed as a detector and operated under the conditions of Figure 14, the plate receives electrons from the space charge rather than directly from the cathode. True or False?

*   *   *

If the plate voltage is increased, more and more electrons leave the space charge and flow to the plate. Finally, at a high plate voltage, the plate takes all the electrons that are emitted by the cathode, and there is no space charge. A single electric field extends from the cathode to the plate, as indicated in Figure 15. A further increase of plate voltage causes little increase in the plate current because the plate is already taking every electron emitted by the cathode. This condition is known as SATURATION. The plate current at this point is called saturation current.

The 5Y3-GT is a dual diode employed as a full-wave rectifier in medium power circuits. Courtesy GE Receiving Tube Department

Normally, operation at saturation is employed only in applications such as gating or where the diode must conduct large but brief pulses of current. Only diodes specially designed for this operation are used. The heavy saturation current would destroy a diode not designed for these applications.

*   *   *

15. When a diode in a gating circuit is in saturation, the plate is taking (a) all the electrons emitted, (b) electrons from the space charge only, (c) no electrons from the cathode.

*   *   *

CHARACTERISTICS AND RATINGS

The general nature of tube operation as well as specific

information about the applications of tubes can be learned
most easily by examining their characteristics and ratings.
Characteristics are measurable properties that depend upon
things such as the material of which a device is made and
the size and shape of the device. Ratings are limiting values
assigned to a device by its manufacturer. Tube ratings are
maximum allowable operating voltages and current which
cannot be exceeded without danger of damaging the tube or
shortening its life.

The various manufacturers publish data sheets that give the
characteristics and ratings of the different tube types. From
these sheets it is easy to determine which tube to use for a
particular job. You can also see whether a tube is operating
the way it should in a given circuit. Data sheets usually
show some of the more important relationships by means of
graphs or curves.

Characteristic Curves

A characteristic curve is a graph that shows the way in
which one variable quantity affects another variable quantity.
For example, one variable quantity may be the voltage ap-
plied between the plate and cathode of a diode tube, while the
other quantity may be the tube's plate current. A graph
that shows how the plate current depends upon the applied
voltage is a type of characteristic curve commonly included
on the manufacturer's data sheets.

The voltage applied between the plate and cathode of a diode,
as in Figure 14, is called PLATE VOLTAGE. This voltage
is measured with the cathode as the reference point. Thus,
if the plate voltage makes the plate positive with respect to
the cathode, the plate voltage is said to be so many volts
positive. If it makes the plate negative with respect to the
cathode, it is said to be so many volts negative.

The relationship between the plate voltage and plate current
of a diode is commonly shown by a curve like that of Fig-
ure 16. Here, positive plate voltage is given along the scale

at the bottom.   The scale at the left is marked off in terms
of plate current. The graph is called a plate characteristic
curve.   By means of this curve, you can find the plate cur-
rent produced in a diode of the type represented by the curve
for any given plate voltage within the range of the graph.

For example, with a plate voltage of 20 volts applied to the
tube, the curve shows that a plate current of approximately
80 ma is produced.   As the plate voltage is increased, it
causes the plate current to increase.   Hence, the curve
rises continually and smoothly as we move to the right on
the graph.   Finally, at the plate voltage of 100 volts, the
diode conducts a plate current of 1000 ma, or 1 ampere.
This curve assumes that the plate voltage makes the plate
more positive than the cathode by the specified amount.

                    *   *   *

16.   Referring to Figure 16, what is the approximate plate current
        when a plate voltage of positive 60 volts is applied to the diode ?

17.   Suppose you want to use the diode represented by the curve of
        Figure 16 as a rectifier.   What value of plate voltage would
        you apply to produce a plate current of 700 ma?

                    *   *   *

With any given plate voltage applied to a diode, the plate
current increases with the temperature of the emitter. For
this reason, a curve like that of Figure 16 can show the
plate voltage-plate current relationships at a single emitter
temperature, and this temperature only.   Therefore, the
curve is useful only if we specify the emitter temperature
or an operating condition that determines the temperature.
Tube manufacturers commonly specify the normal operating
voltage applied to the filaments of directly heated emitters
or to the heaters of indirectly heated emitters.   In Fig-
ure 16, the voltage is given as E_f = 5 volts. An increase in
filament or heater voltage increases the current in the fila-
ment or heater. In turn, this increases the temperature of

the emitter, producing greater emission.   With more elec-
trons in the space charge,   more can be pulled to the plate
at a given plate voltage.

     *   *   *

18. For the diode tube it represents, the curve of Figure 16 indi-
  cates the plate voltage and current relationship, regardless
  of the temperature of the emitter.   True or False?

     *   *   *

When a manufacturer publishes a curve like that of Fig-
ure 16, the curve does not represent the characteristics of
an individual diode sample. Instead, it represents the aver-
age characteristics of a large number of diodes of the same
type.   Usually, the curve is labeled "average plate charac-
teristics. " Few diodes of a given type have characteristics
that exactly match those of the published curves. However,
when you are going to use a tube of this type as a rectifier,
for example, you can assume that the characteristics of any
diode of this type are reasonably near those indicated by
the curve.

Classes of Diodes

Diodes can be classified in various ways such as the appli-
cations for which they were designed, the kind of emitter
employed (directly heated or indirectly heated), and the
number of diode units included in one envelope. One classi-
fication in terms of tube operation is made on the basis of
the relative magnitude of the plate currents.

In general, diode tubes designed to conduct plate current up
to about 50 milliamperes are considered low-current tubes.
The high-current tubes are capable of carrying plate cur-
rents ranging from several hundred milliamperes to several
amperes.

Typical Characteristics

Figure 17 shows the plate characteristic curve of a typical low-current diode tube. Unlike the example of Figure 16, Figure 17 includes plate voltage values over a range of only 10 volts. Thus, the plate current increases from zero to a maximum value of 60 ma as the plate voltage is increased from zero to 10 volts. Diodes of this general class are designed for use in circuits where a small applied voltage is available and the plate current needed is not large. A common application is that of an FM detector in radio and television receiver circuits.

The plate characteristic curve of another low-current diode is given in Figure 18. Notice that the highest plate voltage included on this graph produces a plate current of only a little over 16 milliamperes. Tubes of the type illustrated by this curve are used as rectifiers where it is desired to produce a high dc voltage across the load, but very little direct current is needed. For example, the plate current in this diode is only 12 ma when the plate voltage is about 320 volts, while in the diode of Figure 17, a 12 ma plate current is produced by a plate voltage of only 3 volts. A common application of diodes with characteristics like those illustrated by Figure 18 is that of a rectifier for supplying high voltage to the picture tube in a television receiver.

One diode of the high-current type has the plate characteristics shown in Figure 19. This tube is used where it is necessary for the diode to conduct relatively large plate

Relatively high current is conducted by this diode tube in high voltage circuits.

Courtesy GE Receiving Tube Department

current with only a small voltage applied to the plate. Whereas the low-current diode of Figure 18 conducts a plate current of only about 1 ma with 50 volts applied to its plate, the tube of Figure 19 produces a current a thousand times as large with the same plate voltage applied to it. Diodes like that represented by the curve of Figure 19 are employed often where the plate current has the form of pulses at rates of several thousand per second. These diodes are used also in gating applications.

Figures 20 and 21 give the plate voltage-current curves of two other typical diodes in the high-current class. Diodes like that with the curve of Figure 20 are employed as rectifiers where the load currents are large insofar as commercial equipment such as television receivers is concerned. On the other hand, the curve of Figure 21 is that of a diode used in industrial equipment. This tube is employed as a rectifier also, but the plate currents indicated are considered relatively small from the standpoint of most industrial needs.

The plate characteristics of another industrial type diode are shown in Figure 22. Notice that the plate current values run up into the thousands of milliamperes, while the plate voltages range up to nearly 3000 volts. Since a thousand milliamperes equals one ampere, the current scale could be marked off in amperes. Thus, 4000 ma equals 4 amp, 8000 ma equals 8 amp, and so on. Tubes of this type are employed as rectifiers where very large currents are needed at high voltages. Common uses of this kind are found in radar equipment, for example.

Industrial type vacuum diodes like those represented by the curves of Figures 21 and 22 are generally known as kenotrons. In these tubes, the plate is commonly called the anode. However, in their basic operation, all vacuum diodes are the same, though they differ in size, structure, and type of emitter, depending upon the application for which they are designed.

*   *   *

19. Suppose you need a diode that produces a large plate current
     with a plate voltage of only 50 volts applied. Checking the
     curves of Figures 17 through 22, you find that, at a plate
     voltage of 50 volts, the largest plate current is produced by
     the diode represented by the curve of Figure (a) 18, (b) 22,
     (c) 19.

*   *   *

Plate Resistance

As explained earlier, plate current is produced in a diode
when an applied plate voltage makes the plate positive. For
a given applied voltage, the magnitude of the plate current
depends upon the limiting effect of the space charge in the
tube.   Since the diode does not permit an infinitely large
current to flow, it offers a certain amount of opposition to
plate current. If the applied plate voltage is increased, the
plate current increases.   You can compare this action to
the increase produced in the current in a resistor when you
increase the voltage across the resistor.   An opposition to
plate current exists in all electron tubes. It is called PLATE
RESISTANCE.

*   *   *

20. What is plate resistance?

*   *   *

The plate resistance of a tube is of two kinds: dc plate re-
sistance and ac plate resistance. Both are calculated by
means of Ohm's Law. The DC PLATE RESISTANCE is the
opposition to plate current offered by the tube when an UN-
CHANGING positive voltage is applied to the plate. It is
equal to the plate voltage divided by the plate current, and
is represented by the symbol r_b. The curve in Figure 17
shows that a plate voltage of 6 volts produces a plate cur-

rent of 30 ma in the diode represented. Using $r_b = E/I$, we can substitute 6 volts for E and .03 ampere for I to obtain:

$$r_b = \frac{6}{.03} = 200 \text{ ohms}$$

Thus, this diode has a dc plate resistance of 200 ohms when a plate voltage of 6 volts is applied to it.

For any given diode, the plate resistance is not the same at all plate voltages. For example, using Figure 17 again, a plate voltage of 3 volts applied to this diode produces a plate current of 12 ma. In this case:

$$r_b = \frac{3}{.012} = 250 \text{ ohms}$$

Here, with the lower plate voltage, the plate resistance is greater. As another example, if we apply 9 volts to the plate of this diode, a current of 52 ma is produced. With this higher voltage applied, the plate resistance is only:

$$r_b = \frac{9}{.052} = 173 \text{ ohms}$$

Thus, unlike the resistance of a resistor, the plate resistance varies with the applied voltage. When the voltage decreases, r_b increases, and when the voltage increases, r_b decreases. This nonlinear relation can be seen as the curvature of the plate characteristic curve. If the plate resistance were the same at all plate voltages, this curve would be perfectly straight.

The AC PLATE RESISTANCE is the opposition of a tube to a CHANGE IN PLATE CURRENT. It is the result of dividing a small change of plate voltage by the corresponding small change of plate current. Maintaining the plate voltage positive, we can vary it alternately above and below some given value, causing like variations in the plate current. The resistance offered by the tube to these variations of plate current is considered the ac plate resistance of the tube.

The ac plate resistance is an important characteristic and is closely related to operating conditions. It is represented by the symbol r_p. The subscript p is used to distinguish this ac resistance from the dc resistance r_b. In general, when the term plate resistance is used without qualification, the ac plate resistance is the one that is meant.

As an example of the calculation of r_p, suppose we vary the plate voltage of the diode of Figure 17 between the values of 5.8 and 6.2 volts. This is a total change of 6.2 − 5.8, or 0.4 volt. When the plate voltage is 5.8 volts, the plate
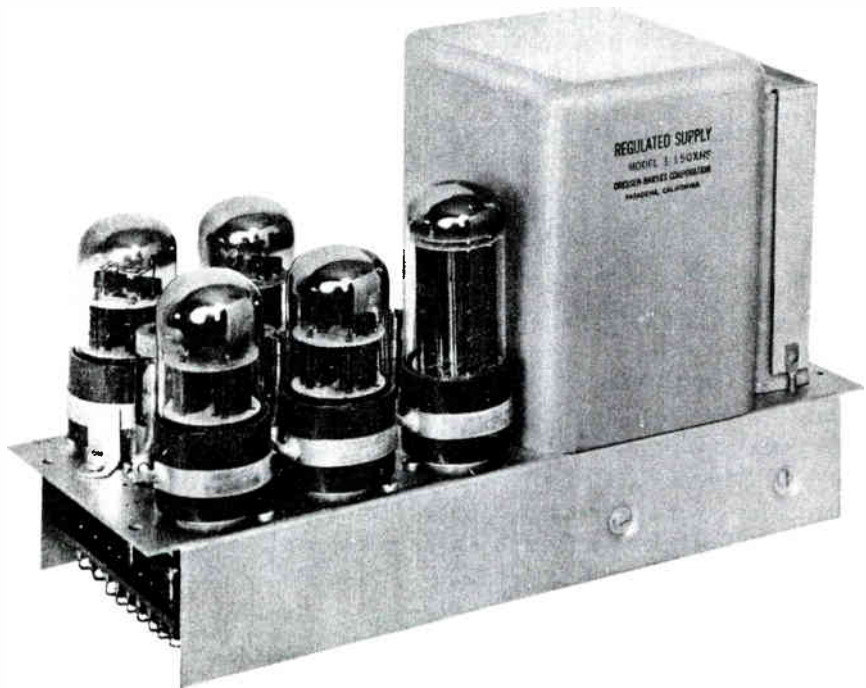
Diodes ore commonly used os rectifiers in power supplies such os the one shown obove.
Courtesy Dressen-Barnes Corp.

current is approximately 28 ma, and when the voltage is 6.2 volts, the current is 31 ma. Therefore, the total change of plate current is equal to 31 − 28, or 3 ma. Dividing the

change of plate voltage by the change of plate current we have:

$$r_p = \frac{0.4}{.003} = 133 \text{ ohms}$$

Notice that this value is considerably less than the dc plate resistance of 200 ohms at the plate voltage of 6 volts. Calculations of r_p at other points along the curve would show that, due to the curvature of the curve, the ac plate resistance varies in the same way as the dc plate resistance, being higher at the lower plate voltages and lower at the higher plate voltages.

*   *   *

21. What is the ac plate resistance of the television receiver high-voltage diode represented by Figure 18 when its plate voltage is varied between the values of 240 volts and 280 volts?

*   *   *

Manufacturer's Ratings

As mentioned, manufacturers assign ratings for those tube characteristics which must be kept within certain limits to insure satisfactory performance. Such ratings help electronic equipment designers use the capabilities of each tube to best advantage.

The electron tube industry employs three kinds of ratings. One, called Absolute Maximum, is generally used for industrial and transmitting tube types. These ratings are limiting values that should not be exceeded with any tube of the specified type under any conditions of operation. The other two kinds of ratings are used for receiving type tubes. The first, the Design Center ratings, are limiting values which should not be exceeded with a tube of the specified type under normal operating conditions. These ratings allow for normal variations in tube characteristics and operating conditions. They are used for tubes developed

before 1957.   The other system, the Design Maximum
ratings, is a set of limiting values which should not be ex-
ceeded with a tube of the specified type under any conditions
of operation. Adopted in 1957, these ratings allow for nor-
mal variations in tube characteristics, but not in operating
conditions.

Ratings assigned to diode tubes include the maximum peak
inverse plate voltage, maximum peak plate current, maxi-
mum dc output current, plate dissipation, and maximum
peak heater-cathode voltage. A voltage applied across the
plate and cathode of a diode that makes the plate negative
with respect to the cathode is called inverse plate voltage.
Since the inverse voltage produces no space current in the
tube, it must be withstood by the high resistance of the
materials that electrically insulate the plate from the cath-
ode. If the inverse voltage is high enough, it can cause the
electrical breakdown of this insulation.   The MAXIMUM
PEAK INVERSE PLATE VOLTAGE   is the highest instan-
taneous inverse voltage that the tube can withstand without
danger of breakdown.

                    *   *   *

22. Inverse plate voltage makes the plate of a tube (a) negative
      with respect to the cathode, (b) positive with respect to the
      cathode.

                    *   *   *

The MAXIMUM PEAK PLATE CURRENT is the highest
instantaneous plate current that a tube can carry safely at
intervals in the direction of normal current flow. The MAXI-
MUM DC OUTPUT CURRENT, sometimes called dc plate
current, is the highest average plate current which can be
handled continuously by a rectifier diode. This rating is
based upon the power which the plate is capable of dissipating
in the form of heat. This power is called the PLATE DIS-
SIPATION. The heat is generated in the plate by electrons
arriving at and striking the plate. Plate dissipation is given

in watts.

The **MAXIMUM PEAK HEATER-CATHODE VOLTAGE** is the highest instantaneous voltage that a tube can stand safely between its heater and cathode. This rating is used in applications where excessive voltage might be introduced between the heater and the cathode.

DIODE TUBE CONSTRUCTION

Figure 23A shows a cutaway view of a diode tube. The heater in the center is surrounded by the cathode, which in turn is surrounded by the plate. The electrodes are held in place and prevented from touching by insulated supports not shown in this part of the figure. Metal pins that extend through the bottom or base connect the electrodes and heater to external circuits. Figure 23B shows a tube of this type enclosed in its glass envelope. Here, the lower circular insulated support is visible. The combination of numbers and letters on the envelope indicates the tube type.

Figure 23C is a bottom view of the tube, showing the arrangement of the base pins. The pins are numbered in the clockwise direction, beginning with the first pin clockwise from the gap. The gap makes it almost impossible to place the tube into a socket in the wrong position. IMPORTANT: TUBE PINS ARE ALWAYS NUMBERED CLOCKWISE LOOKING AT THE BOTTOM OF A TUBE OR SOCKET.

*   *   *

23. With reference to the bottom view of a tube, the base pins are numbered in the (a) clockwise direction, (b) counterclockwise direction.

*   *   *

To show which base pin connects to which part inside the tube, some schematic diagrams show pin numbers with the tube symbols. An example is given in Figure 23D. This

symbol indicates that pin 5 connects to the plate of this particular tube, pin 7 connects to the cathode, and pins 3, 6 and 4 to the heater. Pins 1 and 2 do not connect to any of the tube elements. They are included in the base so the tube will be inserted properly in its socket, and to provide additional support for the tube. The connection between pin 6 and the heater permits using the heater as a voltage divider in applications where this use is desirable.

Another diode construction is shown in the cutaway view of Figure 24A. This tube employs a filament type emitter. As shown, the filament is held inside the plate by a pair of conductive support rods. In turn, the rods are supported by a glass holder known as a header. Passing through the header, each conductor connects to a base pin. The plate of this tube does not connect to a base pin. Instead, it connects to a cylindrical metal cap at the top of the tube. The reason for this arrangement is that this tube is a type to which high voltages are applied between plate and filament. The insulation of the entire glass envelope is between the plate cap and the filament base pins to prevent high-voltage breakdown of the tube.

The type 1X2 diode rectifies pulses in high voltage supply circuits.
Courtesy GE Receiving Tube Department

Figure 24B shows the bottom view of this tube. As shown, the base contains eight pins that are evenly spaced. To assure proper insertion into the socket, an aligning plug with a key projects from the center of the base. The socket for a tube of this kind has a center hole with a keyway into which the plug and key fit. Hence, the aligning plug makes it impossible for the tube to be placed into its socket in-

correctly.

Tubes that have bases of this kind are called octal tubes.
The pin numbering is clockwise, as before, beginning with
the first pin clockwise from the key. Figure 24C shows
what is called the basing diagram for this diode. Here, the
small circles that represent the base pins are numbered in
the same order as in Figure 24B. As shown, the filament
connects to pins 2 and 7, and these are the only base pins
used for external connections in this particular tube. The
top cap to which the plate connects is represented by a small
rectangle at the top of the diagram.

                    *   *   *

24. In the tube of Figure 23, the cathode connects to base pin
     number (a) 5, (b) 6, (c) 7.

25. The plate of the diode of Figure 24 connects to (a) base pin 4,
     (b) the top cap, (c) base pin 5.

26. The heater of the diode of Figure 23 connects to base pins
     number (a) 2 and 7, (b) 3, 4 and 5, (c) 3, 4 and 6.

                    *   *   *

Figure 25 shows a third diode construction in a cutaway
view. Here, the disk-shaped cathode is supported by a
metal cylinder, inside of which the heater is located. The
metal plate is supported by a tubular-shaped ceramic in-
sulator. A hole in the middle of this insulator permits the
plate to project downward close to the cathode. The external
plate circuit connects directly to the large upper portion of
the plate. A metal ring in contact with the cathode support
cylinder provides for the external circuit connection to the
cathode. A second tubular ceramic insulator separates the
cathode ring from the metal heater buttons which are the
means of connecting to the heater. All the metal parts in
this tube are made of titanium and all the insulation is ce-
ramic. This permits the tube to be operated at higher tem-
peratures than tubes that use glass envelopes and other

insulating materials.

SUMMARY

Electron tubes are devices that control the flow of electrons. An electron tube that has two electrodes is called a diode. The electrodes are called the plate and the cathode, respectively. When heated, the cathode emits electrons which form a cloud called a space charge around the cathode. An applied voltage that makes the plate positive with respect to the cathode causes the plate to attract electrons from the space charge. Thus, electrons travel via the space charge from the cathode to the plate. This flow of electrons takes place in one direction only. That is, no electron flow occurs normally from the plate to the cathode.

The property of the diode to conduct in one direction only is employed in gating and rectification applications. The cathodes used in the various types of diodes are of two kinds. The directly heated cathode is a filament which carries its own heating current. The cathode-heater type consists of a tubular emitter inside of which a heating element is located. Manufacturers publish the characteristics and ratings of their various tube types as an aid to the equipment designer. Important among these are the plate characteristic curves which show how plate current varies with plate voltage.

IMPORTANT DEFINITIONS

BIAS - [BIGH uhs] - A voltage applied across the electrodes
of a device.

CATHODE - [KATH ohd] - In an electron tube, the electrode
from which electrons enter the space between the
electrodes. Also called an EMITTER.

DIODE - [DIGH ohd] - A two-electrode device that controls
electron flow, either an electron tube or a semicon-
ductor device.

ELECTRODE - [i LEK trohd] - A solid conductor terminal.
A metallic element in an electron tube.

ELECTRON EMISSION - [i MISH 'n] - Any process by which
electrons leave the surface of a material.

EMITTER - See CATHODE and FILAMENT.

FILAMENT - A cathode or emitter consisting of a wire that
carries a current which provides the temperature re-
quired for thermionic emission.

GATING - Action of producing an output only when certain
inputs are applied.

HEATER - A wire heating element that supplies the cathode
with the heat needed to produce thermionic emission.

MAXIMUM DC OUTPUT CURRENT - The highest average
plate current which can be handled continuously by a
rectifier diode.

MAXIMUM PEAK HEATER-CATHODE VOLTAGE - The
highest instantaneous voltage that a tube can stand
safely between its heater and cathode.

IMPORTANT DEFINITIONS (Continued)

MAXIMUM PEAK INVERSE PLATE VOLTAGE - The highest instantaneous inverse voltage that a tube can withstand without danger of breakdown.

MAXIMUM PEAK PLATE CURRENT - The highest instantaneous plate current that a tube can carry safely at intervals in the direction of normal current flow.

PLATE - In an electron tube, the electrode to which the main stream of the emitted electrons flows.

PLATE CURRENT - The electron flow from the space charge to the plate inside the tube, and from the plate through the external circuit to the cathode.

PLATE DISSIPATION - [dis i PAY sh' n] - The power that the plate of a tube is capable of dissipating in the form of heat.

PLATE RESISTANCE - The opposition a tube offers to plate current.

PLATE VOLTAGE - The voltage between the plate and cathode of a tube.

RECTIFICATION - [rek ti fi KAY sh' n] - Converting ac into dc.

RECTIFIER - Any device capable of performing rectification.

SATURATION - [sat cher AY sh' n] - The condition in which the plate of a tube is taking all the electrons emitted by the cathode so that there is no space charge.

IMPORTANT DEFINITIONS (Continued)

SPACE CHARGE - A cloud of electrons in the space be-
tween the electrodes of a tube.

SPACE CURRENT - The flow of electrons through the space
from the cathode to the plate.

THERMIONIC EMISSION - [ther mi AH nik] - Electron
emission caused by heating a metal to a high tempera-
ture.

STUDENT NOTES

PRACTICE EXERCISE SOLUTIONS

1. Diode means a two-electrode tube or semiconductor device.

2. True -- Keep this in mind because it is one of the important principles of tube operation.

3. (a) one direction only. -- Electrons cannot flow in the direction urged by battery B_1 in Figure 2 because the diode is then an open circuit.

4. bias

5. gating and rectification

6. (b) E_{R_1}. -- In this gate circuit example, the output terminals are connected to the ends of R_1. Therefore, the output is the voltage across R_1.

7. (b) E_{V_1}. -- Only E_{V_1} is across the diode. E_{R_1} and the output voltage are the same voltage, and this voltage is not across the diode.

8. (c) very high. -- Because of the high resistance of V_1, almost all of the input voltage is across the diode and none is across R_1.

9. True -- If V_1 conducted in both directions, the current in R_L would be ac.

10. (b) a very high temperature. -- The temperature required is much higher than room temperature. However, a temperature above the emitter's melting point would ruin the emitter.

11. The heater supplies the heat in the indirectly heated type of emitter. In the directly heated type, the filament serves as both heater and emitter.

12. (a) positive with respect to the cathode.

13. the cathode

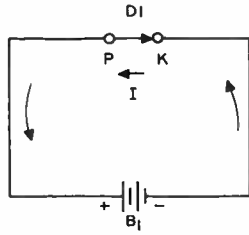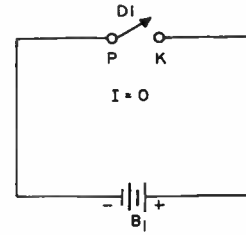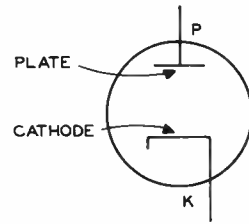14. True -- The space charge is the source of electrons for the plate.

FIGURE 1
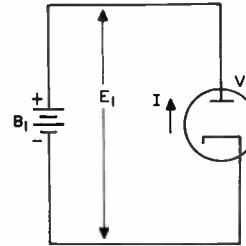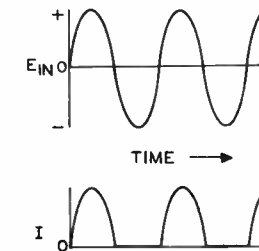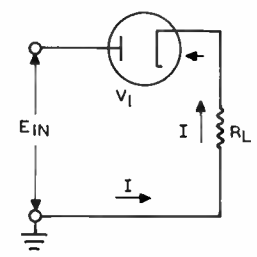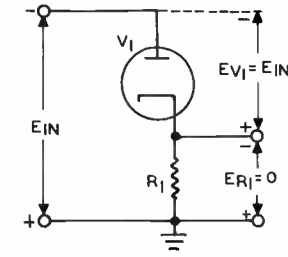

FIGURE 2

FIGURE 3

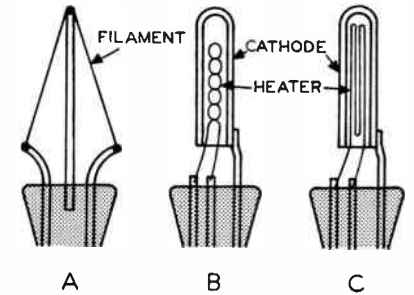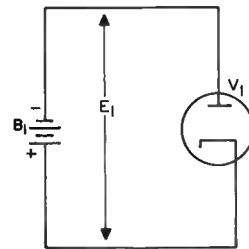FIGURE 4

FIGURE 5

FIGURE 6

FIGURE 7

FIGURE 8

FIGURE 9

FIGURE 10

FIGURE 11

FIGURE 12

2150

A   B

C   D

FIGURE 13

SPACE CHARGE
FIELD   FIELD
CATHODE   PLATE
B₁

FIGURE 14

CATHODE   PLATE

FIELD
B₁

FIGURE 15

$E_f = 5v$

PLATE CURRENT IN MA

PLATE VOLTAGE IN VOLTS
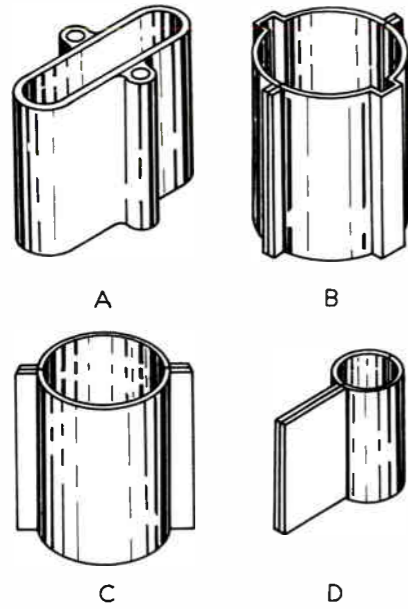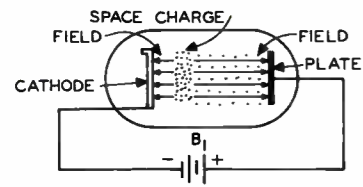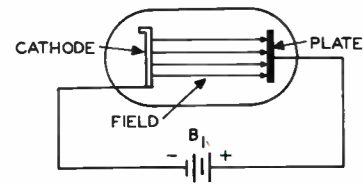
FIGURE 16

PRACTICE EXERCISE SOLUTIONS (Continued)

15. (a) all the electrons emitted. -- No space charge exists when the tube is in saturation, and electrons flow directly from the cathode to the plate.

16. 450 ma -- Locate 60 volts on the plate voltage scale at the bottom, move up the vertical line to the curve, and then across to the left to the plate voltage scale.

17. 80 volts -- Locate 700 ma on the plate current scale, move to the right along the horizontal line to the curve, and then down the vertical line to the plate voltage scale.

18. False -- At any given plate voltage, a change in emitter temperature changes the plate current.

19. (c) 19. -- This curve indicates a plate current of 1000 ma at 50 volts, whereas the plate currents of the diodes represented by Figures 18 and 22 are much lower at this plate voltage.

20. Plate resistance is the opposition presented by a tube to plate current.

21. 20,000 ohms -- The voltage change is equal to 280 - 240, or 40 volts. At 240 volts, the plate current is 8 ma, and at 280 volts it is approximately 10 ma. Therefore, the current change is equal to about 10 - 8, or 2 ma. The ac plate resistance is:

$$r_p = \frac{40}{.002} = 20,000 \text{ ohms}$$

22. (a) negative with respect to the cathode. -- The term "inverse" indicates that the voltage is opposite that which produces cathode-to-plate electron flow.
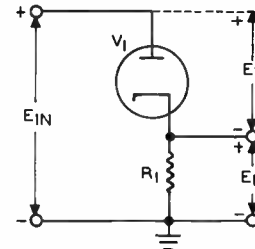
23. (a) clockwise direction.

24. (c) 7.

25. (b) the top cap.

26. (c) 3, 4 and 6.

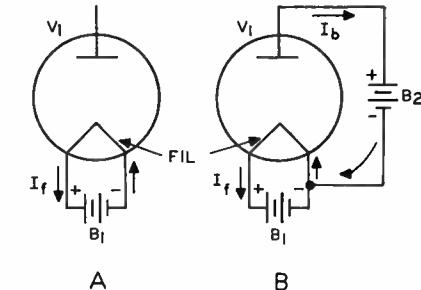FIGURE 17
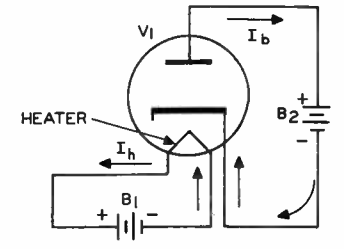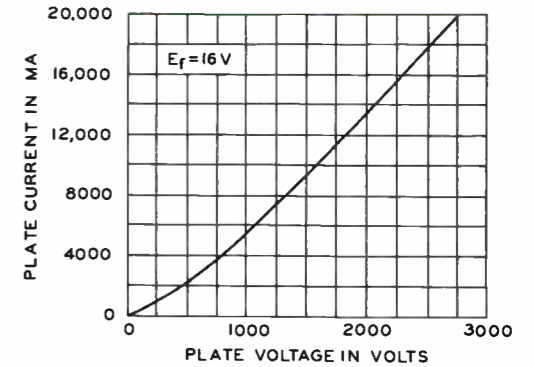

FIGURE 22

FIGURE 18

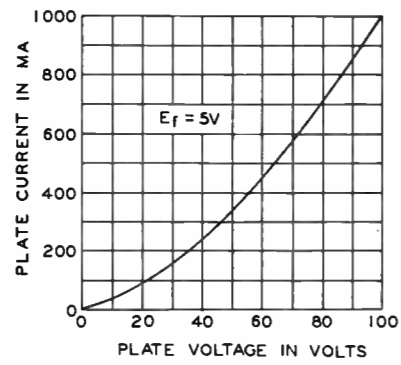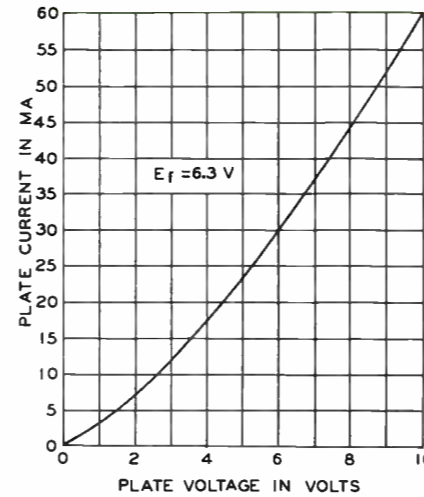FIGURE 19

FIGURE 20

FIGURE 21

FIGURE 23

2150

2150

PLATE CAP
PLATE
FILAMENT
GLASS ENVELOPE
MICA SPACER
GLASS HEADER
BASE
BASE PINS

KEY

A   B   C

FIGURE 24

PLATE
CATHODE
HEATER
CERAMIC INSULATOR
SUPPORT CYLINDER
CATHODE RING
CERAMIC INSULATOR
HEATER BUTTONS

FIGURE 25

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question, as illustrated in the example below.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

LESSON CODE

2150A

Example: An earthworm has

A
B
C
D

(A) two legs. (B) four legs. (C) six legs. (D) no legs.

1. A diode tube presents low resistance to current when the

A
B
C
D

(A) plate is positive with respect to the cathode. (B) cathode is positive with respect to the plate. (C) cathode and plate have the same potential. (D) plate is negative with respect to the cathode.

2. Rectification is the action in which a diode

A
B
C
D

(A) generates an alternating voltage. (B) conducts from plate to cathode. (C) converts ac to dc. (D) converts dc to ac.

3. In the circuit of Figure 8, current I is produced in R_L

A
B
C
D

(A) during the entire cycle (both alternations) of E_{IN}. (B) when E_{IN} makes the plate of V_1 negative. (C) whenever V_1 is not conducting. (D) when E_{IN} makes the plate of V_1 positive.

4. Emission of electrons resulting from heating a material to a high temperature is called

A
B
C
D

(A) field emission. (B) emission current. (C) thermionic emission. (D) space current.

5. In the filament type of emitter, the emitter heat is obtained from the

A
B
C
D

(A) heater element. (B) current carried by the filament. (C) plate current. (D) space current.

6. The indirectly heated emitter obtains its heat from the

A
B
C
D

(A) cathode. (B) plate. (C) space charge. (D) heater.

7. In a diode tube, the space charge limits the

A
B
C
D

(A) heater current. (B) plate supply voltage. (C) cathode temperature. (D) plate current.

8. A plate characteristic curve shows the relationship between the plate current and the

A
B
C
D

(A) heater current. (B) emitter temperature. (C) filament voltage. (D) plate voltage.

9. The curves of Figures 16 through 22 show that plate current

A
B
C
D

(A) increases with plate voltage. (B) decreases as plate voltage increases. (C) increases as filament voltage decreases. (D) increases as plate voltage decreases.

10. The opposition offered by a tube to a CHANGE in plate current is called

A
B
C
D

(A) inverse voltage. (B) plate dissipation. (C) dc plate resistance. (D) ac plate resistance.

VACUUM TUBE OPERATION

Lesson 2153

DeVRY INSTITUTE OF TECHNOLOGY

CHICAGO   PHOENIX   TORONTO

VACUUM TUBE OPERATION

Revised 1968

OPPORTUNITY

10

High powered tubes must be ruggedly built, and usually are water cooled or forced–air cooled to prevent overheating due to the large plate or anode currents they carry.

VACUUM TUBE OPERATION

CONTENTS

****

Great things are made of little things.
                                        --Browning

VACUUM TUBE OPERATION

Vacuum tubes have found use in almost every branch of electronics. These tubes are used in circuits that generate ac voltages at frequencies ranging from low to ultra high, circuits that amplify or increase the magnitude of voltages and currents, and circuits that rectify electric energy. Your television or radio receiver, for example, contains tubes that perform all of these functions.

Vacuum tubes are used very often for amplification. The information or signal to be handled by an electronic circuit is usually applied in the form of a voltage to the input of the tube. The tube circuit also includes a second source of electric power. The tube uses this power to produce an enlarged copy of the input signal. This is the manner in which the tube amplifies. It does not produce power itself, it merely controls power. The term amplify is not limited to only those circuits called amplifiers. Amplifying action is part of the operation of almost all vacuum tube circuits.

THE TRIODE ELECTRON TUBE

A tube that contains three active electrodes is called a TRIODE. In its most common form, the triode consists of a cathode and a plate between which the third electrode is located. This third electrode is called the GRID. It was given this name because of its grid-like structure in some types of tubes. Figure 1 shows one of the several grid structures used. Here, the grid is a single, continuous wire which is wound so it forms a series of oval loops around a pair of vertical support rods.

*   *   *

1.   What is a triode tube?

*   *   *

Figure 2 shows the arrangement of the three electrodes in a typical triode. In this drawing, the plate is cut away to show the grid and filament.   As the tube is of the directly-heated type, the filament is the emitter. As shown, the filament is inside the grid, so that the grid is in the path of the electrons moving from the space charge around the filament to the plate.   The grid wire is very fine, and the turns are spaced far apart.   Therefore, the grid does not physically block an appreciable number of the electrons passing through it.

The electrodes in an indirectly-heated triode are shown in the cutaway view of Figure 3.   Here, the cathode is shown to be surrounded by the grid, which is in turn surrounded by the plate.   As before, electrons moving from the cathode or space charge must pass between the wires of the grid on their way to the plate. This tube is of the nine-pin miniature type, while that of Figure 2 is of the eight-pin or octal type.

Figure 4 shows the arrangement of electrodes in a ceramic triode.   Here, the cathode is a flat disk supported above the heater by a metal cylinder.   This cylinder provides a con-ductive connection between the cathode and the metal cathode ring.   The ring is the means of connecting the cathode to an external circuit.   The grid is a circular grill mounted di-rectly above the cathode.   It is connected by the grid ring to an external circuit.   The plate or anode is a large disk at the top of the tube, and a projection at its center extends downward toward the grid.   Finally, the heater connects to the external circuit by means of a pair of metal buttons. The remainder of the tube consists of three circular ceramic insulators which hold the electrodes in position and prevent them from touching each other.

*   *   *

2.   In typical commercial electron tubes like those illustrated in Figures 2, 3 and 4, (a) the grid is between the cathode and plate, (b) the plate is between the grid and cathode, (c) the cathode is between the plate and grid.

*   *   *

Figure 5 shows a triode made almost entirely of metal. A strong ceramic base wafer serves as a platform which supports the electrodes. Each electrode is solidly supported by a cone-shaped metal flange. The tube employs an indirectly-heated cathode. The heater leads extend down through the open, lower end of the cathode and the base wafer. The smallest of the three support flanges holds the cathode over the heater. The next larger flange fits over the cathode flange without touching it, and supports the grid. The largest flange fits over the grid flange and supports the plate. All three flanges are supported by leads which are held in place by the base wafer.

Some of the leads pass down through the wafer to connect the electrodes to external circuits. The electrodes are positioned with the grid between the cathode and plate as in the tube of Figure 3. The metal tube envelope of Figure 5 has two extensions downward from the base called the indexing lugs. These lugs protect the leads during insertion into the tube socket and permit rapid insertion. A tube having this construction is called a NUVISTOR. Tubes of this type are extremely rugged, though very small in size.

Whatever the physical construction of the vacuum tube triode, the grid has the same purpose. This purpose is to control the flow of electrons from the space charge to the plate. Since the grid is between the cathode and the plate, if we make it negative with respect to the cathode, it repels some of the electrons back toward the cathode, so that fewer get to the plate. Hence, the current from the emitter to the plate in a triode depends upon grid potential as well as emitter temperature and plate voltage.

*   *   *

3. In a triode tube, the flow of electrons from the space charge to the plate (a) is prevented by the grid, (b) can be controlled by the grid, (c) is independent of the grid.

*   *   *

THE TRIODE CIRCUIT

The symbols used for triode vacuum tubes are shown in Figure 6. That of Figure 6A is for tubes with directly-heated emitters, or filament type tubes. Figure 6B is the symbol for tubes with indirectly-heated emitters, or cathode-heater type tubes. Except for the grid, the symbols are the same as those used for diodes. The grid is drawn between the plate and the filament or cathode to represent its physical location in the tube.

Figure 7 shows the basic circuit of the filament type triode. Here, battery B_1 supplies heater current to the filament of triode V_1. The complete path of this current is from B_1, through the filament, and back to B_1. Battery B_2 has its positive terminal connected to the plate of the tube and its negative terminal connected to the filament. Battery B_2 is called the plate supply, and its volt-

A nuvistor triode commonly used in television ond FM rodio tuners.
Courtesy RCA Electron Tube Division

age E_{bb} is known as the plate supply voltage. E_{bb} makes the plate voltage positive with respect to the filament. Battery B_3 applies voltage E_{cc} between the grid and filament. B_3 is called the grid supply, and E_{cc} is the grid supply voltage. B_3 is connected so that E_{cc} makes the grid of V_1 negative with respect to the filament. The difference of potential between the grid and filament is called **GRID BIAS**. In tube circuits, the potentials of all electrodes are given as or assumed to be positive, negative, or zero with respect to the cathode potential as a reference, unless stated otherwise.

Normally, the grid bias is much smaller than the plate supply voltage E_{bb}. Therefore, with the various voltages applied, electrons leave the space charge around the filament and flow past the grid to the plate. **THIS ELECTRON FLOW IS CALLED PLATE CURRENT, AND IS DESIGNATED BY**

THE SYMBOL I_b. As indicated in the figure, the external plate circuit carries the plate current I_b in the form of electron flow from the plate of V_1 to battery B_2, and from B_2 to the filament of V_1. The electrons arriving at the filament replace those emitted into the space charge. This completes the path of the plate current.

* * *

4. An industrial control system employs a triode vacuum tube for which the basic dc supply circuit is like that of Figure 7. In this circuit, the grid is (a) negative with respect to the plate, (b) positive with respect to the filament, (c) positive with respect to the plate.

* * *

The basic circuit employing an indirectly-heated triode is shown in Figure 8. In this case, battery B_1 supplies current to the heater of the tube. Battery B_2 applies voltage E_{bb} between the plate and cathode, producing plate current I_b. In this circuit, the grid bias is the difference of potential between the grid and the cathode. Grid bias is provided by B_3, which applies voltage E_{cc} between the grid and cathode. Battery B_3 is connected so that E_{cc} makes the grid negative with respect to the cathode. Plate current in the external plate circuit consists of electron flow from the plate of V_1 to B_2, and from B_2 to the cathode of V_1.

Figures 7 and 8 show the basic dc voltage relationships that usually exist between the electrodes of vacuum tubes. Various other components are normally added to the circuit to make use of the current flow.

HOW TUBES CONTROL CURRENT

Because of its location between the cathode and the plate, the grid can control the flow of electrons to the plate. This control of plate current by the grid is the fundamental action of electron tubes, other than diodes. It is the underlying

principle upon which all the applications of the tubes described
in this lesson are based.

When the grid is made negative with respect to the cathode
it prevents some of the electrons from passing through it to
the plate. This is due to an electric field between the grid
and cathode whose direction is such as to cause electrons to
move toward the cathode. This field opposes the action of

the field between the cathode
and plate, which causes elec-
trons to move toward the plate.
The more negative the grid is
made, the stronger the grid-
cathode field, and the smaller
the plate current. If the grid
is made less negative, the grid-
cathode field weakens, and the
plate current increases.

Figure 9 shows a triode circuit
in which the grid is connected
directly to the cathode. Be-
cause of this connection, there
is no difference of potential
between these two electrodes.
That is, grid-cathode voltage
E_c is zero. With the grid at
cathode potential, there is no

A twin triode of the glass octal type.
Courtesy Sylvania

grid-cathode field. The grid does not oppose the flow of
electrons through it. Plate current I_b is large, as indicated
by current meter M_1. Applying a negative bias voltage to
the grid as shown in Figure 10 reduces the plate current, as
indicated by the meter. THE LARGER THE NEGATIVE
BIAS, THE SMALLER THE PLATE CURRENT.

These relations can be shown by means of a curve. Figure
11 shows how the plate current of a certain triode varies
with the grid voltage when the plate voltage is equal to 250
volts. This curve is called the grid voltage – plate current
characteristic of the tube. The particular triode represented

by the curve of Figure 11 is commonly employed as an amplifier tube in broadcast radio receivers.

The plate current in milliamperes is given along the left side of the graph, while the scale at the bottom indicates grid voltage or bias in volts. On the grid voltage scale, zero volts is located near the right end, and the values to the left of zero are negative voltages as indicated. The given grid voltage values represent the grid potential with respect to the cathode.

When the grid voltage is zero, as in Figure 9, the curve of Figure 11 shows that the plate current is equal to 7.5 ma. However, the plate current falls to just above 5 ma when a grid bias of -1 volt is applied. If we increase the negative grid voltage to -2 volts, the plate current decreases to about 3 ma.

As we make the grid more and more negative, plate current continues to decrease. Finally, we reach a negative bias value that reduces the plate current to approximately zero. With the tube represented by Figure 11, this occurs at a grid voltage of -4 volts. This condition is called plate current cutoff. The grid voltage that causes it is called the cutoff bias. Grid voltages more negative than the cutoff bias simply cause the plate current to remain at zero. Plate current exists only when the grid voltage is less negative than the cutoff bias.

*   *   *

5. If you were going to use the tube represented by Figure 11 as an amplifier, what value of grid bias would you employ to produce a plate current of 2 ma?

*   *   *

The plate current values indicated by the curve of Figure 11 for the various grid voltages are true only for a particular plate voltage. When a tube manufacturer publishes a curve

of this kind for a given tube, he specifies the plate-to-emitter voltage used when the curve was plotted. In the example of Figure 11, the plate voltage was kept at 250 volts while the grid voltage was set at a series of values over the range indicated. At each grid voltage, the plate current was recorded. This set of grid voltage – plate current data was then used to draw the curve.

If the same process is carried out at a higher plate voltage, the plate current is greater than indicated in Figure 11 at each grid voltage value in the range. A curve drawn from these data would be higher on the graph than the one shown. Likewise, for a lower plate voltage, the curve would be lower than the one shown because the plate current would be less than indicated for each grid voltage.

*   *   *

6.   The plate current values indicated by a single curve like that of Figure 11 are true for (a) any plate voltage, (b) zero plate voltage only, (c) a given plate voltage only.

*   *   *

In the normal operation of most triode tubes, a grid bias is applied that is somewhere between zero and the cutoff bias. The applied input signal then causes the grid voltage either to become more or less negative than the bias for an interval of time, or to vary continuously around the bias value. This results in corresponding changes in plate current. Very seldom does the input signal in an amplifier circuit cause the grid to become positive with respect to the cathode. In most

This transmitting type triode, used as a power amplifier, has an indirectly heated cathode and a metal and ceramic envelope. When forced-air cooled, its anode can dissipate up to 100 watts.

Courtesy General Electric Co.

applications, a positive grid voltage is considered abnormal

operation of the tube. A positive bias can be provided as shown in Figure 12, where B_3 is connected with its positive terminal to the grid and its negative terminal to the cathode. The curve of Figure 11 shows that plate current increases when the grid becomes positive. When the grid voltage is $+.75$ volt, the plate current becomes 10 ma.

When the grid is positive, both the grid and the plate pull electrons from the space charge. Most of the electrons pass between the grid wires, attracted to the highly positive plate. This causes the increase in plate current. However, some of the electrons are captured by the grid. These flow through the external grid circuit consisting of B_3 in Figure 12, back to the cathode. This flow is called grid current (I_c). Since the grid is taking electrons that should go to the plate, grid current is undesirable in most circuits. Therefore, except in certain applications, the tube is operated so the grid never becomes positive. A negative grid does not attract electrons from the space charge.

*   *   *

7.   In most applications, the grid voltage of a triode usually is kept (a) negative, (b) zero, (c) positive.

*   *   *

The basic operation of the triode vacuum tube makes use of variations of the negative grid voltage to cause desirable changes in the plate current. Because it is much closer to the cathode, the grid has much greater control over plate current than the plate does.

HOW TUBES AMPLIFY VOLTAGE

We have mentioned that vacuum tubes are used mainly for amplification and control. The term amplify means to make larger or increase the amplitude of. The process of amplifying is called AMPLIFICATION. A device that amplifies

is called an amplifier. Usually, an amplifier consists of a circuit containing a number of components including one or more tubes or other control devices.

Figure 13 shows a triode voltage amplifier circuit. Here, the grid circuit contains an alternating voltage source, S, in series with the grid bias battery B_3. Source S produces the alternating input voltage E_{IN}, which is to be amplified. Since E_{IN} reverses its polarity as each alternation begins, it aids E_{cc} during one alternation and opposes it during the next. The total voltage between the grid and cathode is equal to E_{IN} and E_{cc} combined.

When the upper terminal of S is negative, the total grid voltage is the sum of E_{cc} and E_{IN}. During the other alternation, when the upper terminal of S is positive, the grid voltage is equal to the difference between E_{cc} and E_{IN}. Since E_{IN} varies through the alternation, this sum also varies. The peak value of E_{IN} in this figure is less than E_{cc} so the positive peaks of E_{IN} cannot make the grid positive with respect to the cathode. Therefore, the grid varies in voltage but always remains more negative than the cathode.

*   *   *

8.   In an amplifier circuit like that of Figure 13, the peak value of E_{IN} must be less than grid bias E_{cc} to prevent the grid from becoming positive with respect to the cathode. True or False?

*   *   *

In the plate circuit of Figure 13, resistor R_L is connected in series between the plate of triode V_1 and the positive terminal of voltage supply B_2. Resistor R_L is called the PLATE LOAD RESISTOR. Triode V_1 can be thought of as a resistive device whose resistance varies with the grid voltage. As the grid voltage swings to a greater negative value, the triode presents greater resistance to plate current.

When the negative voltage on the grid is reduced, the tube has less resistance. Plate supply voltage E_{bb} is applied to the two resistive components, V_1 and R_L, in series. Therefore, the V_1 plate current depends on the value of R_L as well as the resistance of V_1.

*   *   *

9. When the grid of a triode tube becomes more negative, the resistance of the tube to plate current (a) decreases, (b) is not affected, (c) increases.

*   *   *

Triode V_1 and load resistor R_L form a voltage divider, dividing E_{bb} between them. As input voltage E_{IN} varies during each cycle, it causes the grid voltage to vary, changing the resistance through tube V_1. When the V_1 resistance is increased in this way, the total resistance of the plate circuit is increased also. However, since R_L remains fixed, the resistance of V_1 becomes a larger part of the total resistance and that of R_L becomes a smaller part. This change in the proportions of the resistances causes changes in their division of voltage E_{bb}. The part of E_{bb} across V_1 increases, while the part across R_L decreases. The sum of the two parts always remains equal to E_{bb}.

A 250 watt television transmitting tetrode. The envelope is of metal and ceramic, and the tube is forced-air cooled.
Courtesy General Electric Co.

When E_{IN} causes the resistance of V_1 to decrease (by making the grid less negative), the total resistance of the plate circuit decreases also. The resistance of V_1 becomes a smaller part of the total resistance, while that of R_L becomes a larger part. This changes the division of E_{bb} so that the

part across V_1 decreases while that across R_L increases.

Thus, the varying voltage E_{IN} makes the resistance of triode V_1 increase and decrease during each cycle. These V_1 resistance changes result in variations in the voltage across load resistor R_L. The voltage variations across R_L are represented in the figure as E_O. Voltage E_{IN} is the input to the circuit while E_O is the output. Normally, the circuit values are selected so that E_O has greater amplitude than E_{IN}. The circuit is then said to amplify because E_O is an amplified or enlarged version of E_{IN}. The circuit of Figure 13 is called a voltage amplifier.

*   *   *

10. When the input voltage causes the resistance of a tube to increase, the voltage across the load resistor (a) remains constant, (b) decreases, (c) increases.

*   *   *

As mentioned, when E_{IN} makes the grid of V_1 more negative the resistance of V_1 increases and the total resistance in the plate circuit is increased. Let us apply Ohm's Law to the plate circuit of V_1. Since E_{bb} remains the same and the resistance of V_1 increases, the plate current is reduced.

On the other hand, when E_{IN} makes the grid less negative, the V_1 resistance decreases, causing the total resistance in the plate circuit to decrease also. This permits the plate current to increase. Thus, the input voltage variations produce variations in plate current as well as in the voltage across the load resistor. However, in the voltage amplifier, the action of greatest importance is the production of the relatively large output voltage E_O when the input voltage E_{IN} is applied. The voltage variations, E_{IN} and E_O, are called the input and output signals, respectively.

As an example of the operation of a circuit like that of Figure 13, suppose E_{cc} equals -2 volts, E_{bb} equals 260 volts,

and R_L equals 100,000 ohms. At an instant when voltage E_{IN} is equal to zero, the grid voltage is equal to E_{cc}, or -2 volts. Suppose this grid voltage causes triode V_1 to have a resistance of 30,000 ohms. The total resistance in the plate circuit is then equal to $30,000 + 100,000$, or 130,000 ohms. The plate load resistance is 100,000/130,000, or 10/13 of the total resistance. Therefore, the part of E_{bb} that is across R_L is 10/13 of 260, or 200 volts.

If E_{IN} becomes 1 volt negative, it aids E_{cc}, making the grid voltage change to $(-2) + (-1)$, or -3 volts. Suppose this increases the resistance of V_1 to 40,000 ohms. The total resistance in the plate circuit is then $40,000 + 100,000$, or 140,000 ohms. The load resistance is now 100,000/140,000, or 5/7 of the total resistance. Hence, the part of E_{bb} across R_L is 5/7 of 260, which is about 186 volts.

If E_{IN} becomes 1 volt positive, it opposes E_{cc}, making the grid voltage change to $-2 + 1$, or -1 volt. If this decreases the V_1 resistance to 20,000 ohms, the total plate circuit resistance becomes $20,000 + 100,000$, or 120,000 ohms. R_L is then 100,000/120,000, or 5/6 of the total. Therefore, the voltage across R_L is 5/6 of 260, or about 217 volts.

In this example, input voltage E_{IN} varies from -1 to +1 volt, a total variation of 2 volts. The voltage across R_L varies from 186 volts to 217 volts, a total of 31 volts. Thus, the amplified output voltage, E_O, has a peak-to-peak value of 31 volts. This is a little over 15 times the peak-to-peak value of E_{IN}. E_O is normally much greater than E_{cc}.

*   *   *

11. Suppose the grid voltage is such that the tube presents a resistance of 10,000 ohms in an amplifier circuit like that of Figure 13. If $E_{bb} = 300$ volts and $R_L = 90,000$ ohms, what is the voltage across R_L?

*   *   *

TETRODES

Whenever two conductive objects are separated by an insula-
ting material, they form a capacitor. The electrodes in a
vacuum tube are an example. Figure 14 illustrates the
capacitance between the plate and cathode of a diode. This
capacitance is called **INTERELECTRODE CAPACITANCE**
since it appears between the electrodes of the tube. It is
designated C_{pk} to indicate the plate and cathode electrodes
that provide it. Usually, the value of C_{pk} is quite small,
ranging from about 1 to 10 picofarads in the various com-
mercial diodes. Due to its high reactance value at low and
medium frequencies, C_{pk} has very little effect on the oper-
ation of the diode. However, its reactance is less at the
high frequencies, and it therefore conducts high-frequency

ac to some extent. This con-
duction by C_{pk} defeats the
diode's purpose, which is to
conduct in one direction only.
Therefore, when you are selec-
ting a diode for use at high fre-
quencies, you will require one
that has very small plate-
cathode capacitance.

In the triode, the grid shields
the plate from the cathode to
some extent, thus reducing the
plate-cathode capacitance. The
grid is also a conductive object,
and is insulated from both the
cathode and the plate. It is also
closer to the cathode than the
plate is. Therefore, the triode
has interelectrode capacitance
between the grid and plate (C_{gp}),

A miniature glass tube containing two tetrode
sections designed for use at radio frequencies
up to 200 MHz.
Courtesy Amperex Electronic Corp.

between the grid and cathode (C_{gk}), and between the plate and
cathode (C_{pk}). These capacitances are indicated in Figure 15.

The capacitance between the grid and the plate often has

great effect on the operation of a triode. An input or signal
voltage applied to the grid causes the voltage on the plate of
the tube to change also due to plate current changes. The
plate voltage changes cause the grid-plate interelectrode
capacitance to charge and discharge. In this way, this ca-
pacitance couples the signal from the plate circuit back to
the grid circuit. If a great deal of the signal is coupled back
to the grid it interferes with normal tube operation. The
tube begins to amplify its own output signal instead of the
input signal. This action occurs more readily at high fre-
quencies than at low frequencies because capacitance has
less reactance at the higher frequencies.

*   *   *

12. Which interelectrode capacitance generally affects the opera-
tion of a triode the most?

*   *   *

To reduce the grid-to-plate capacitance, a tube called a
TETRODE has another grid which is located between the
control grid and the plate. This second grid is called the
SCREEN GRID. Its purpose is to shield the control grid
from the capacitive effect that the plate has on the control
grid. The name tetrode indicates that the tube has four
electrodes. The emitter is counted as one electrode whether
it is heated directly or indirectly.

*   *   *

13. The purpose of the screen grid in the tetrode is to reduce the
(a) grid-to-plate capacitance, (b) plate current, (c) emission
from the cathode.

*   *   *

Figure 16 gives the schematic symbol of a tetrode tube.
Here, grid G_1, nearest the cathode, serves the function of
the grid in the triode. For this reason, it is called the con-

trol grid. Grid G_2, nearest the plate, is the screen grid. The dashed-line capacitors indicate that the screen grid breaks up the capacitance between control grid and plate into two capacitances in series. These consist of the capacitance between screen grid and plate (C_{g_2p}) and the capacitance between control grid and screen grid ($C_{g_1g_2}$).

As shown in the figure, a large capacitor, C_1, is connected from the screen grid to ground. When the plate voltage varies, C_{g_2p} charges and discharges through capacitor C_1. Because of its large capacitance, C_1 has low reactance at signal frequencies. Therefore, this capacitor presents almost no opposition to the charge and discharge currents of C_{g_2p}. These currents take the path of least opposition, which is through C_1, instead of passing through the control grid circuit as happens with the triode. Thus, the plate circuit does not couple the output signal back to the control grid.

Figure 17 shows a cutaway view of a tetrode. Its structure is much like that of a triode. The electrodes are mounted on wire supports embedded in a glass holder called the stem press. The wires for external circuit connections extend down through the base pins. The cathode surrounds the heater, and the control grid surrounds the cathode. The screen is constructed in the same manner as the control grid, and is mounted around the outside of the control grid. The plate surrounds the screen grid. Finally, in this tube, a perforated metal shield is placed around the outside of the plate, and connected electrically to the screen grid. Its purpose is to shield the electrodes from external magnetic and electric fields.

Normally, the screen grid is operated at a positive potential, as shown in the basic tetrode circuit of Figure 18. Voltage divider R_1R_2 causes the screen voltage to be a little less positive than the plate voltage. The electric field of the plate ends at the screen grid. Therefore, the plate exerts very little pull on the electrons in the space charge near the cathode. However, the positive screen grid attracts the electrons, much like the plate attracts electrons in a triode.

As the electrons arrive at the screen grid, a few are cap-
tured by the grid.   This produces a screen current consist-
ing of a flow of electrons from the screen grid to the junction
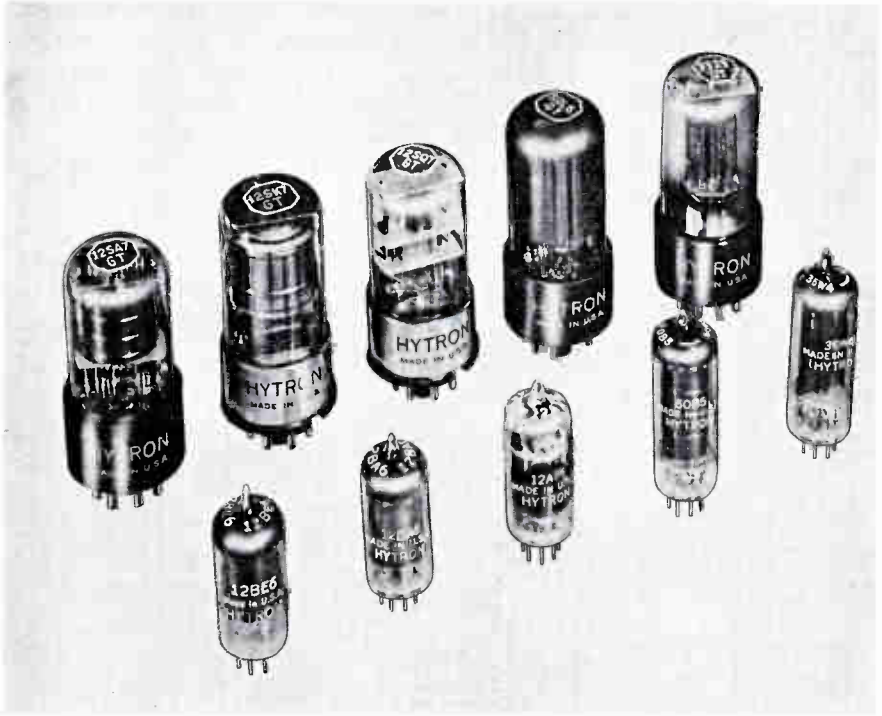
A comparison of octal tubes and miniature tubes with similar characteristics and functions.
Courtesy Hytron Radio and Electronics Corp.

of R_1 and R_2, through R_1 to B_2, and from B_2 to the cathode.
But most of the electrons pass through the screen grid, be-
cause of its open structure, and move into the plate's field,
which pulls them to the plate.

*   *   *

14. Normally, the potential of the screen grid is (a) equal to that
     of the cathode, (b) positive, (c) negative.

*   *   *

In a tetrode tube, the screen grid has a much greater effect on the plate current than the plate does. This is because the electric field of the plate does not extend into the region between the screen grid and cathode. With a given negative bias on the control grid, the screen grid potential determines the number of electrons attracted from the space charge. Large changes of plate voltage can occur without affecting this flow of electrons from space charge to screen grid. As mentioned, most of the electrons continue on to the plate, since the screen grid takes only a few electrons out of the stream. The screen current serves no useful purpose, and it is desirable that it be as small as possible.

PENTODES

When electrons strike a metal surface at high speed, they knock other electrons from the surface. The electrons knocked out in this manner are called secondary electrons. Since the action consists of electrons leaving a solid material, it is one type of electron emission. As the emitted electrons are secondary electrons, the action is known as SECONDARY EMISSION.

Secondary emission takes place in vacuum tubes as electrons strike the various electrodes. The most important of these emissions is that which occurs at the plate, since nearly all the electrons coming from the space charge strike this electrode. In diodes and triodes, all the secondary electrons are attracted back to the plate, so there is no loss of plate current. However, in the tetrode, large numbers of the "secondaries" emitted from the plate are attracted to the positive screen grid. This action increases the screen current while decreasing the plate current. Figure 19 shows the flow of secondary electrons from the plate to the screen grid. This flow is greatest when the screen grid is more positive than the plate.

As mentioned, the screen current is of no use so far as the tube operation is concerned. The collection of secondary electrons by the screen grid can be prevented by providing

a region of very low or zero potential at some point between the screen grid and the plate. This region is then highly negative with respect to the plate. The strong electric field between this region and the plate causes the secondary electrons to move back to the plate, thus preventing them from going to the screen grid.

One method of producing a zero potential region between the plate and screen is the use of a third grid situated at this point. This third grid is called the SUPPRESSOR GRID. Physically, it surrounds the screen grid and is in turn surrounded by the plate. Its zero potential is provided by electrically connecting it to the cathode. Since this tube has five active electrodes, it is called a PENTODE.

*   *   *

15. What electrode prevents the collection of secondary electrons by the screen grid in a pentode?

*   *   *

A cutaway drawing of the electrodes in a pentode is shown in Figure 20. The cathode in the center is surrounded in turn by the control grid, the screen grid, the suppressor grid, the plate and finally a shield. The three grids are generally designated G_1, G_2 and G_3 in the order of their positions outward from the cathode. These designations are given in Figure 21, which shows a pentode tube symbol, V_1, and the basic pentode circuit. In this example, the suppressor grid and cathode are connected externally. In some pentodes, this connection is made in the tube.

Except for the connection from the cathode to the suppressor grid, the pentode circuit is like that of the tetrode in Figure 18. That is, B_1 provides negative bias voltage for the control grid, source S applies a signal voltage to the control grid, and B_2 supplies positive voltage to the plate. The positive voltage for the screen grid is obtained at the junction of R_1 and R_2. R_L is the plate load resistor, across

which the output of the circuit is produced. The control grid exerts the greatest control over the plate current of a triode, tetrode or pentode. The circuits of Figures 18 and 21 amplify in the same way as the triode circuit of Figure 13.

BEAM POWER TUBES

The **BEAM POWER TUBE** is a special tetrode that has been designed to eliminate the flow of secondary electrons from the plate to the screen grid. Historically, it was developed later than the pentode. In the beam power tube, electrons flowing between the screen grid and plate form a space charge. With respect to the plate, the space charge is very negative, since it is made up of electrons. Therefore, secondary electrons coming from the plate are repelled back to the plate by the space charge. Thus, this space charge acts much like the suppressor grid in the pentode.

Special construction is necessary, however, to form a space charge with enough density to perform this function properly. A cutaway view of the beam power tube is given in Figure 22. The distance between the screen grid and the plate is made rather long. This allows time for the space charge to form. It permits maximum plate current and is the condition that led to the development of this tube.

The 6CD6GA is a beam power tube of the glass octal type.
Courtesy General Electric Co.

The density of the space charge is increased further by confining the electrons to relatively narrow beams. A beam

forming plate is located at each rounded side of the cathode.
These plates are electrically connected to the cathode, so
they repel electrons and force them to flow only between the beam forming plates. The cathode is flattened so that most of the emission occurs in the direction of the beams. Each screen grid turn is between a turn of the control grid and the plate. Thus, because of the control grid wires, the screen grid cannot be seen from the cathode. From the standpoint of the cathode, the screen grid is in the electrical shadow of the control grid. Therefore, the electrons that flow through the spaces between the wires of the control grid also flow through the

A combination tube, including a medium-mu triode and a sharp-cutoff pentode in the same envelope.

Courtesy RCA Electron Tube Division

spaces between the screen grid wires. This forms the electron beams into a series of sheets, one above the other. The result is that a very strong concentration of electrons produces the space charge between the plate and screen grid.

The space charge electrons move continually to the plate.
As with other tube types the number of electrons that enter
the plate at any instant depends on the voltage of the control
grid. Very few of the electrons moving toward the plate are
able to strike the screen grid directly. Therefore, the
screen current of a beam power tube is much lower than
that of a pentode tube with a suppressor grid.

The schematic symbol for the beam power tube commonly
takes either of two forms. One is shown in Figure 23A. This
is the same symbol that is used for a pentode tube in which the
suppressor grid is connected to the cathode internally. So
far as the beam power tube is concerned, the suppressor
grid in the symbol merely represents the action of the space

charge explained above. The other form of the beam power
tube symbol is shown in Figure 23B. Here, the beam form-
ing plates are represented by small curved lines shown con-
nected to the cathode. The basic circuit of the beam power
tube is like that of Figure 21.

*   *   *

16. Secondary electrons are repelled back toward the plate in the
    beam power tube by the space charge located between the
    (a) control grid and screen, (b) cathode and control grid,
    (c) screen grid and plate.

*   *   *

An advantage of the low screen current is that little power
is wasted by dissipation in the screen. Also, the tube can
be operated at high plate currents without causing the screen
grid to become so warm that it emits electrons. A further
advantage is that relatively low-wattage resistors can be
used in the divider that supplies the screen voltage.

MULTIGRID TUBES

A number of tubes with more than three grids have been
developed for special application. Of great importance
among these is the PENTAGRID TUBE, a unit having five
grids. Figure 24 shows the symbol of one pentagrid type.
Including the plate and cathode, there is a total of seven
active electrodes. The first and third grids are independent
control electrodes to which signals or other control voltages
may be applied. The second and fourth grids are internally
connected screen grids. The second grid shields the first
and third grids from each other. Finally, the fifth grid is
the suppressor grid which, as shown, connects internally to
the cathode.

One common application of the pentagrid tube is that of a
gated amplifier. The first and third grids each affect the
electron flow from the region of the cathode to the plate.

Therefore, the final plate current varies according to the signal or control voltages on both of these grids. A second common application is that of a pentagrid converter in receivers. In this case, the tube serves the double function of oscillator and mixer.

COMBINATION TUBES

To save space, the elements of two or more complete tubes are often placed in a single envelope. Some of these combinations use a common cathode. In others, there are separate cathodes. One such combination is the double triode,
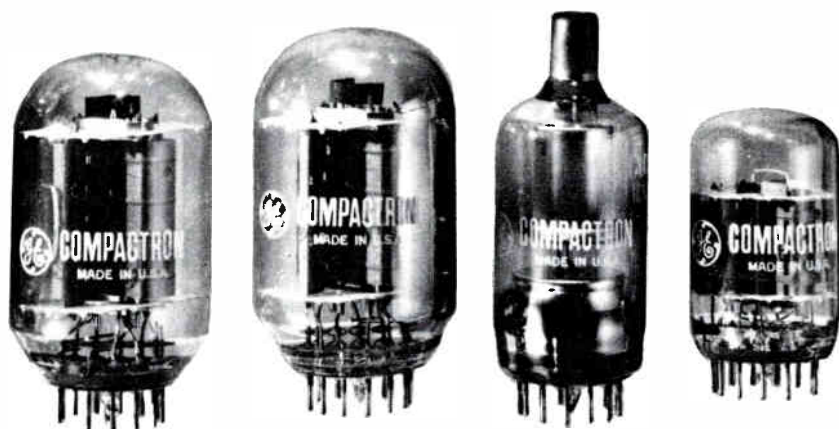
Compactrons are manufactured in a variety of sizes and shapes, depending on the combination of tube sections contained in the envelope.

Courtesy General Electric Co.

the symbol of which is shown in Figure 25. The two triodes are electrically independent of each other so they can operate without interfering with each other. Another example is the duo-diode-triode of Figure 26. This unit consists of three tubes (two diodes and a triode) which use the same cathode. Figure 27 shows a triode-pentode with a common cathode again serving for both sections.

More than one tube in one envelope is the basis of a relatively

new line of tubes called COMPACTRONS. The main differ-
ence between these and the other multiple-tube units is that
the compactrons are quite small in size despite the fact that
the envelope contains two or more tubes. Figure 28 shows
the symbol of one compactron type. As shown, this unit
consists of a pentagrid tube and a pentode tube. A second
compactron is shown in Figure 29. In this case, within one
envelope are a diode-triode, a pentode, and a larger recti-
fier type diode. Since the diode-triode is a double tube to
begin with, this compactron really contains four tubes. In
both compactrons shown, the heaters are connected in series
internally, as in the double-triode of Figure 25.

TUBE CLASSIFICATION

Electron tubes are classified in several ways. One method
is based on the number of active electrodes in the tube.
Thus, we have the diodes, triodes, tetrodes, and pentodes
already described. Also, tubes with six elements or elec-
trodes are called hexodes, those with seven electrodes are
heptodes, and those with eight electrodes are called octodes.
A second method of classifying tubes is according to their
use, as rectifier, amplifier, oscillator, picture tube, camera
tube and X-ray tube .

Diodes, triodes, tetrodes, pentodes, and beam power tubes
all can be found in a variety of envelopes and bases. Hence,
they are also designated as metal, ceramic, glass, glass
octal, miniature, subminiature, lock-in, glass lock-in,
novar, nuvistor, and glass noval.

A HARD TUBE is one which has been highly evacuated of air
and then sealed. Because nearly all of its air has been re-
moved, a hard tube is called a vacuum tube. A SOFT TUBE
is one that has been evacuated, and then a small amount of
some gas placed in it. It is also called a gas-filled tube.

Another tube classification describes the tube's ability to
amplify. The Greek letter mu (μ) represents the amplifica-
tion, or how many times greater the output voltage is com-

pared to the input voltage applied to the control grid. When
the control grid wires are wound close together, the ampli-
fication is high. A tube with this type of grid is called a
high-mu tube. In a low-mu tube, the grid wires are spaced
farther apart.

It is sometimes desirable that the amplification be variable.
For this purpose, a variable-mu tube is employed. It has
a grid wound like that shown in Figure 30. Here, the grid
has open spacing at the center and close spacing at the ends.
When a weak signal is applied to the grid, the close spacing
near the ends of the grid has the most control on the plate
current, and the amplification is high. With strong signals,
electron flow is cut off near the ends of the grid, and only
the open spacing at the center controls the plate current.
Amplification is then low.

                    *   *   *

17. In a vacuum tube, the spacing of the control grid wires affects
    the mu of the tube.   True or False?

                    *   *   *

MAXIMUM RATINGS

Certain maximum ratings must be observed to insure that a
tube operates properly. Exceeding these ratings shortens
the life of the tube. One important rating is the maximum
plate dissipation. Its value in watts indicates the maximum
electric energy that can be converted into heat and dissi-
pated safely and continuously by the plate. This heat is
generated by the electrons as they bombard the plate at high
velocity.

Another maximum rating is the peak heater-cathode volt-
age. It is important where high voltages are applied between
the heater and the cathode. This is the highest voltage that
can safely be applied between the heater and cathode without
breaking down the insulation.

*   *   *

18. Exceeding the maximum ratings of a tube (a) prevents the
     conversion of electric energy into heat, (b) shortens the life
     of the tube, (c) shows that ratings are not important.

*   *   *

SUMMARY

An electron tube is a group of two or more electrodes, called
elements, enclosed in an envelope, with leads extending
through the envelope or base for connecting the elements to
external circuits. The elements or electrodes are of metal
and are therefore conductive. They are electrically separ-
ated and physically supported by insulating materials. The
envelope is made of glass, metal or ceramic. An electron
tube from which the air has been removed is called a vacuum
tube. A tube is named according to the number of active
electrodes it contains. Thus, one with three such electrodes
is a triode, one with four is a tetrode, and so on.

Normally, the grid nearest the cathode in a tube is called
the control grid. It is called this because it has the greatest
control over the flow of electrons moving from the space
charge near the cathode to the plate. The plate current in
a vacuum tube is normally controlled by varying the potential
of the control grid. Voltage amplification is obtained by
applying a signal voltage to the control grid of a tube. This
results in a larger variation of voltage in the plate circuit.
The plate circuit voltage change follows the form of the sig-
nal applied to the control grid. Therefore, the voltage vari-
ation or signal in the plate circuit is an enlarged or ampli-
fied version of the signal applied to the control grid.

Progress in tube design in recent years has been in two
general directions. One is toward increased circuit capa-
bilities. These include operation at extremely high fre-
quencies, higher power efficiency, greater control by the
grid over plate current, and smaller size. The other direc-

tion is in the areas of greater tolerance to environment and greater reliability. These are obtained by the use of new materials and construction methods. They include synthetic micas for insulation, multiple-layer composite plate metals, new heater and cathode materials, and ceramic envelopes.

IMPORTANT DEFINITIONS

AMPLIFICATION - [am pli fi KAY sh'n] - The process of making larger or increasing amplitude.

BEAM POWER TUBE - A tetrode designed to eliminate the flow of secondary electrons from the plate to the screen grid.

COMPACTRON - [kum PAK tron] - A unit consisting of two or more tubes in one envelope. The envelope is smaller in size than in the older multi-tube units.

GRID - An electrode located between the cathode and plate.

HARD TUBE - A highly evacuated electron tube. A vacuum tube.

INTERELECTRODE CAPACITANCE - [in ter i LEK trohd]- The capacitance existing between the electrodes of an electron tube.

NUVISTOR - [new VIS ter] - A cylindrical tube in which the electrodes consist of concentric cylinders supported in an open-ended cantilever fashion by a series of tripod-like structures.

PENTAGRID TUBE - [PEN tuh grid] - A tube having five grids.

PENTODE - [PEN tohd] - A tube having five electrodes other than the heater.

SCREEN GRID - A grid located between the control grid and plate and having a positive potential applied to it.

SOFT TUBE - An electron tube containing gas at low pressure.

IMPORTANT DEFINITIONS (Continued)

SUPPRESSOR GRID - [suh PRESS'r] - A grid, located be-
  tween the screen grid and plate, which is normally
  operated at cathode potential.

TETRODE - [TET rohd] - A tube with four active electrodes
  other than the heater.

TRIODE - [TRIGH ohd] - A tube having three active elec-
  trodes.

PRACTICE EXERCISE SOLUTIONS

1. A triode is a tube having 3 active electrodes.

2. (a) the grid is between the cathode and plate.

3. (b) can be controlled by the grid.

4. (a) negative with respect to the plate. -- Since the grid is negative with respect to the filament, and the plate is positive with respect to the filament, the grid must be negative with respect to the plate.

5. -2.5 volts (approximately) -- Locate 2 ma on the scale at the left. Follow the horizontal line to the right to the curve. From this point, follow the vertical line down to where it meets the grid voltage scale slightly to the left of -2.5 volts.

6. (c) a given plate voltage only.

7. (a) negative.

8. True -- If the peak value of E_{IN} is greater than E_{cc}, the net grid voltage becomes positive during the positive peaks of E_{IN}.

9. (c) increases.

10. (b) decreases. -- A greater part of the E_{bb} voltage appears across the tube because of the tube's increased resistance, leaving less for the load resistor.

11. 270 volts -- The total plate circuit resistance is 10,000 + 90,000, or 100,000 ohms. R_L is 90,000/100,000, or 9/10 of the total. Therefore, the voltage across R_L is 9/10 of 300, or 270 volts.

12. The grid-plate interelectrode capacitance generally has the most effect on the operation of the triode.

13. (a) grid-to-plate capacitance. -- The screen grid shields the grid from the plate.

14. (b) positive. -- The screen grid is normally operated at a potential near or equal to that of the plate.

FIGURE 1
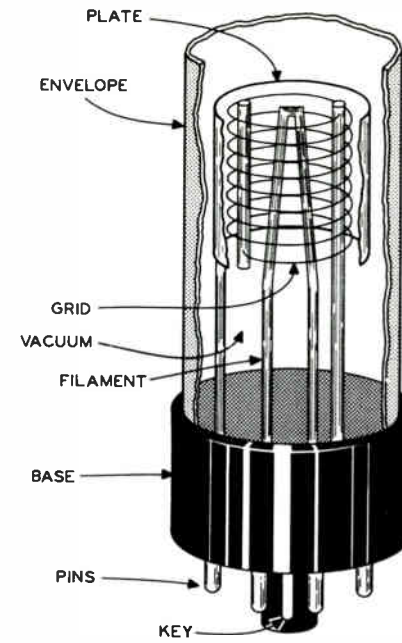
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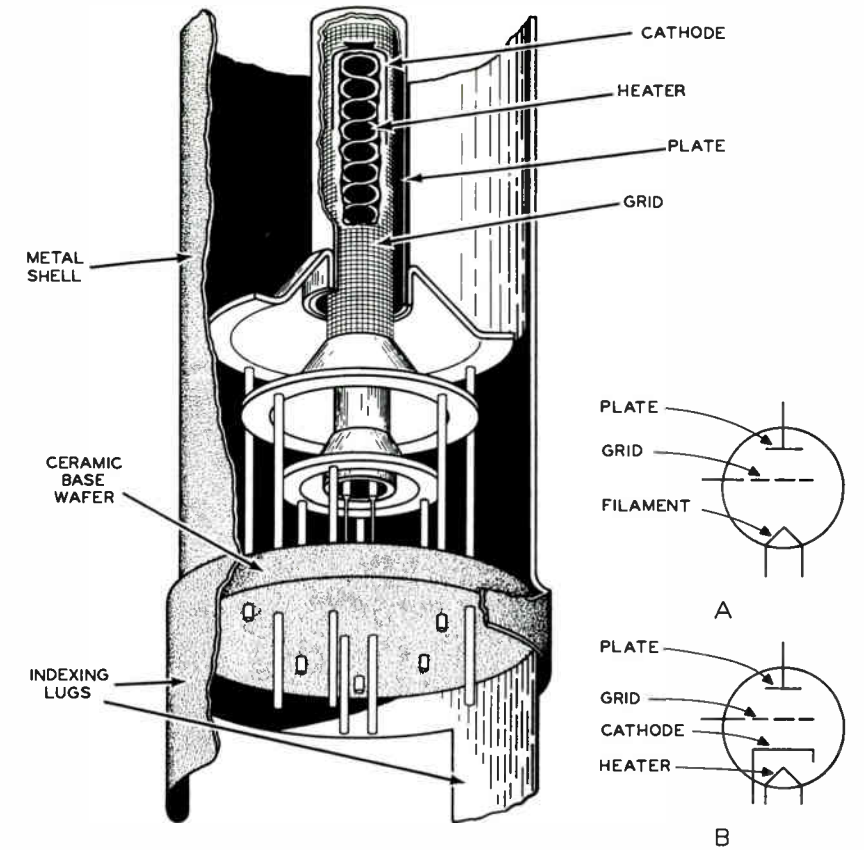
FIGURE 3

FIGURE 4
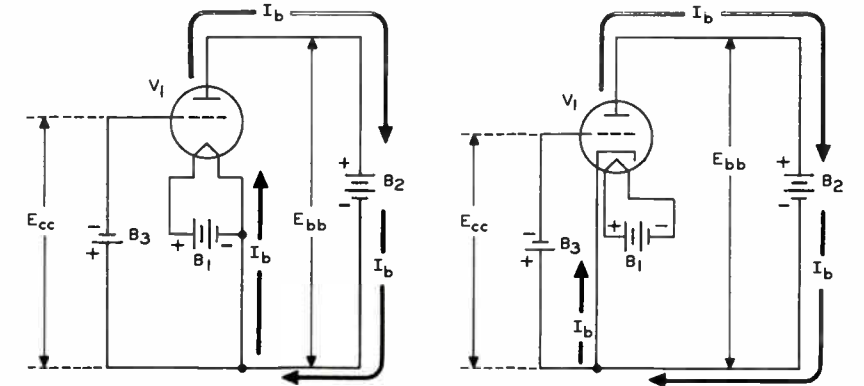
FIGURE 5

FIGURE 6

FIGURE 7

FIGURE 8

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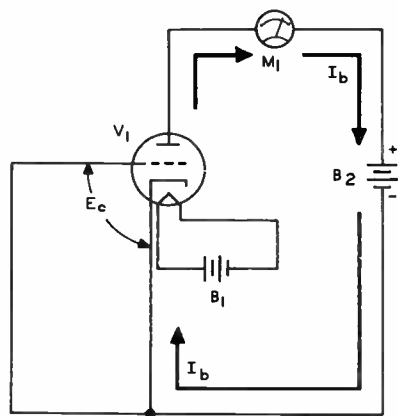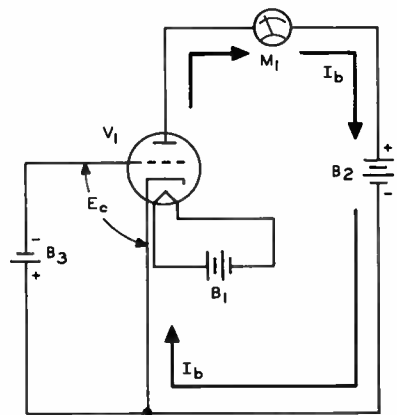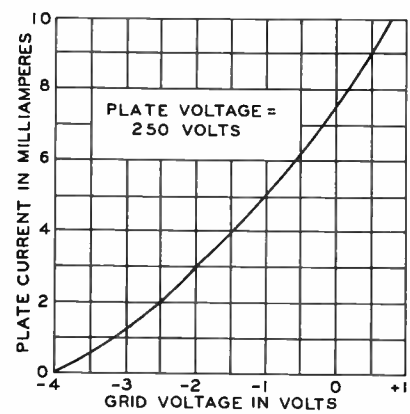
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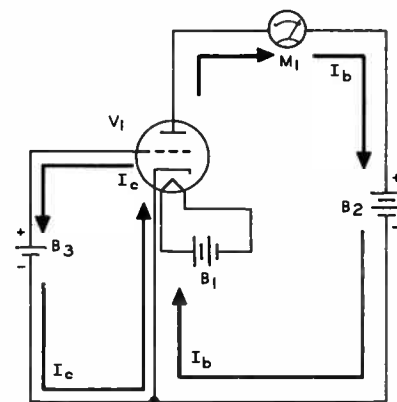
FIGURE 10

FIGURE 11

FIGURE 12

FIGURE 18

FIGURE 19

FIGURE 20

FIGURE 21

FIGURE 22

2153

A   B
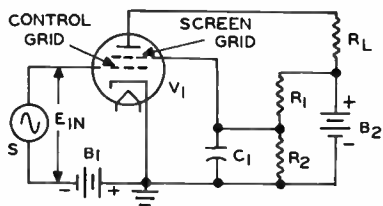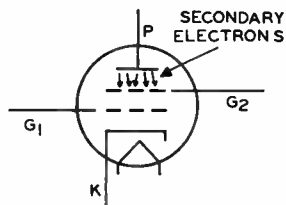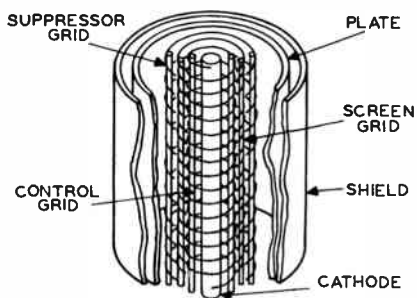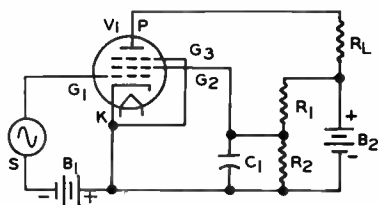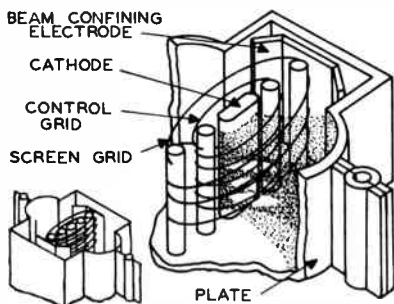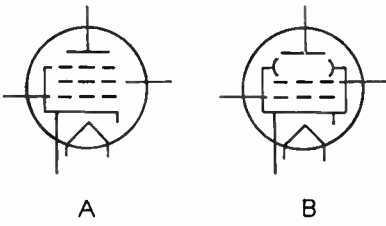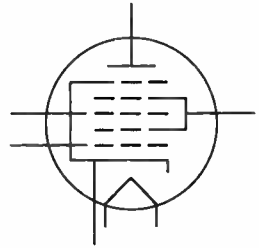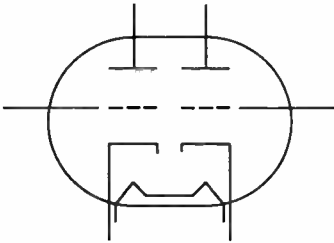
FIGURE 23

FIGURE 24

FIGURE 25
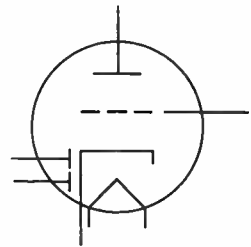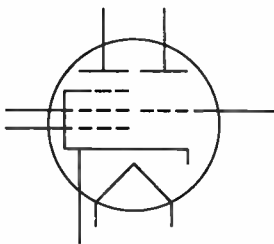
FIGURE 26

FIGURE 27

PRACTICE EXERCISE SOLUTIONS (Continued)

15. The suppressor grid prevents the collection of secondary electrons by the screen grid in the pentode.

16. (c) screen grid and plate.

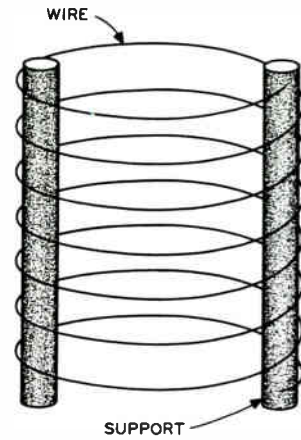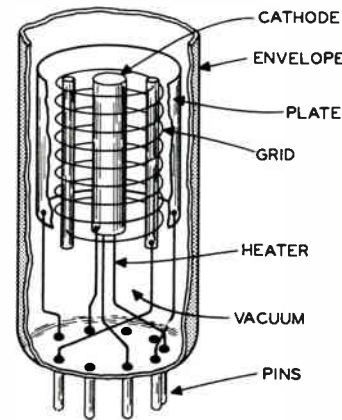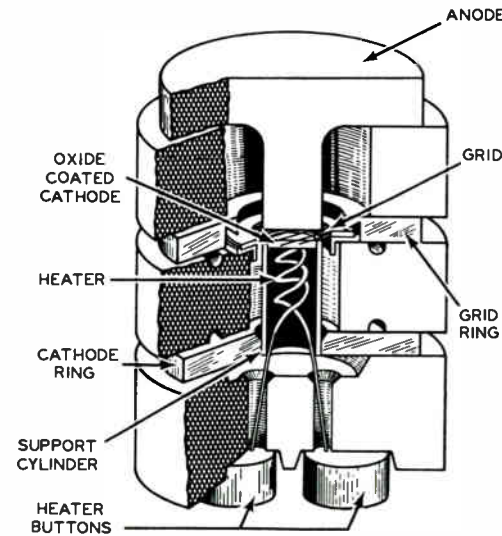17. True -- In general, the closer the spacing, the higher the mu.

18. (b) shortens the life of the tube.
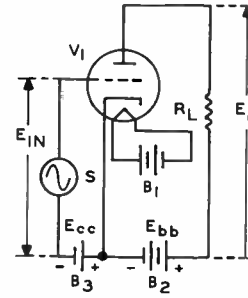
FIGURE 13
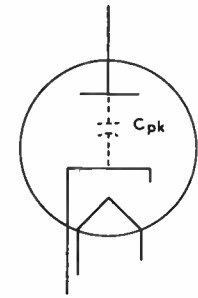
FIGURE 14
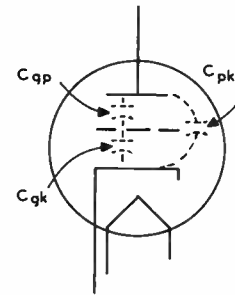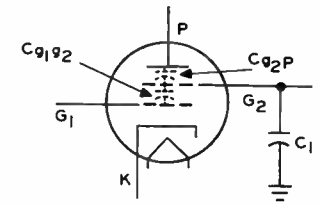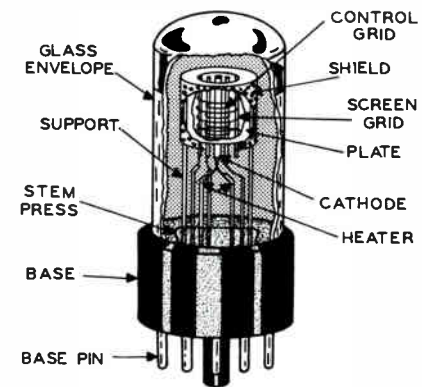
FIGURE 15

FIGURE 16

FIGURE 17

FIGURE 28

FIGURE 29

GRID

SUPPORTS

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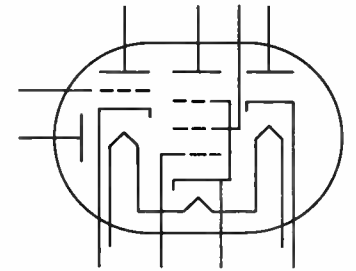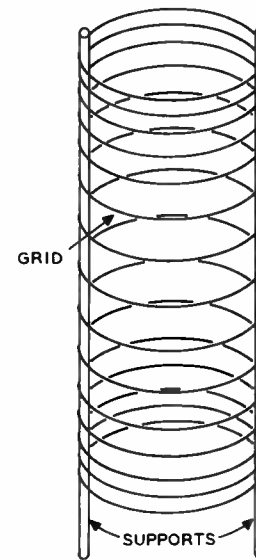
FIGURE 30

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question, as illustrated in the example below.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

Example: Most windows are made of
(A) wood. (B) steel. (C) glass. (D) iron.

LESSON CODE
2153A

A ☐
B ☐
C ■
D ☐

1. In a triode vacuum tube, the primary purpose of the grid is to
(A) emit electrons. (B) control the flow of electrons. (C) shield the plate from the cathode.
(D) prevent electrons from striking the cathode.

2. In Figure 7, the filament receives its heating current from
(A) E_{cc}. (B) B_2. (C) B_3. (D) B_1.

3. Supply battery B_2 in Figure 7 is connected so that it makes the plate of tube V_1
(A) negative with respect to the filament. (B) positive with respect to the filament. (C) have the same potential as the grid. (D) negative with respect to the grid.

4. In the circuit of Figure 8, the dc difference of potential between the grid and cathode is called
(A) the grid bias. (B) E_O. (C) E_{bb}. (D) the space charge.

5. The tube employed in Figure 8 is
(A) indirectly heated. (B) directly heated. (C) a type that employs no heating element. (D) a tetrode.

6. In a circuit like that of Figure 10, when we make the grid more negative
(A) the grid bias decreases. (B) the plate current decreases. (C) E_{bb} decreases. (D) the plate current increases.

7. Since the grid in a triode is closer to the cathode than the plate is, the grid
(A) is usually operated at a positive potential. (B) has less control over plate current than the plate. (C) collects all of the electrons coming from the space charge. (D) has more control over plate current than the plate.

8. The amplifying action of the circuit of Figure 13 results in an output voltage E_O which
(A) is always less than E_{cc}. (B) is larger than E_{IN}. (C) causes the plate current of V_1 to vary without any input signal. (D) is larger than E_{bb}.

9. The screen grid
(A) serves as the control grid in the pentode. (B) prevents secondary emission. (C) causes secondary electrons to move toward the plate. (D) reduces the control grid-to-plate capacitance.

10. In the beam power tube, SECONDARY electrons are prevented from flowing from the plate to the screen grid by the
(A) control grid. (B) space charge. (C) cathode. (D) screen grid.

2153A

CATHODE RAY TUBES
Lesson 2206A

DeVRY Technical Institute

CATHODE RAY TUBES

Revised 1965
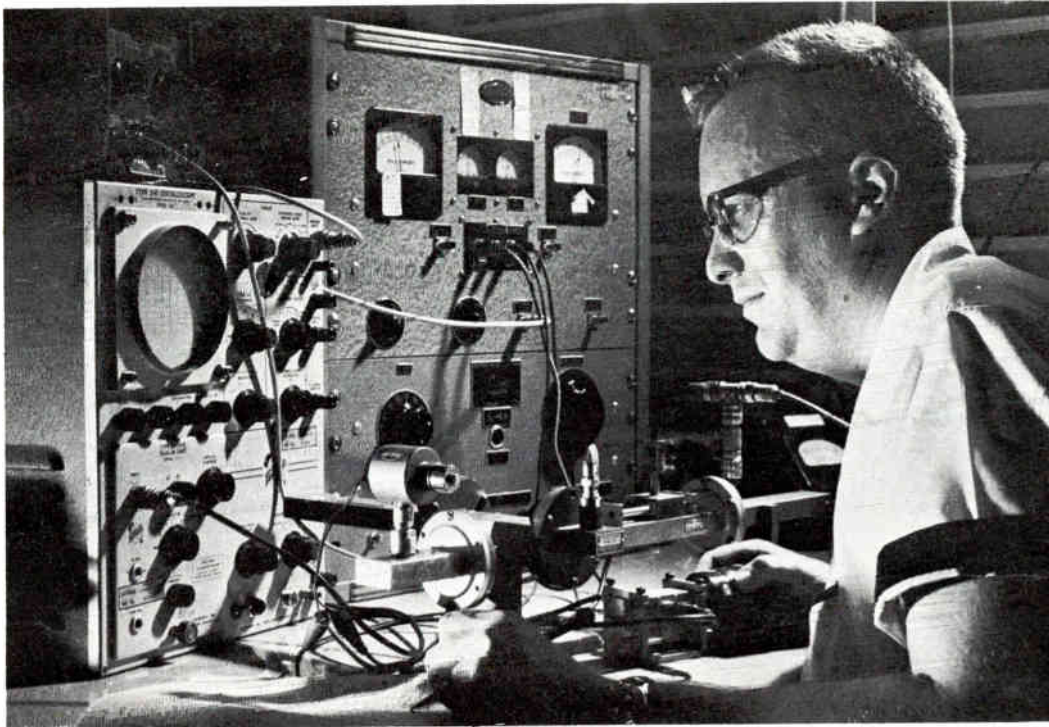
A technician uses a cathode ray oscilloscope to study the operation of a microwave test setup. Voltage waveforms are displayed on the cathode ray tube which serves as the indicator of the oscilloscope.

Courtesy Raytheon Company

CATHODE RAY TUBES

CONTENTS

****

STUDY

The man who has acquired the habit of study
though for only one hour every day in the year,
and keeps to the one thing studied till it is
mastered, will be startled to see the progress
he has made at the end of a twelvemonth.

-- Bulwer

CATHODE RAY TUBES

Have you ever wondered how a picture is formed on a television screen? How an image is formed on a radar screen? How voltage waveforms are displayed on the screen of an oscilloscope? These "pictures" are actually light images traced on the face of a special type of vacuum tube called a CATHODE RAY TUBE (crt).

A cathode ray tube develops a beam of electrons and focuses this beam to a fine point on the inside of the face of the tube. The tube face is coated with a thin layer of material that glows when it is struck by electrons. Thus, the electron beam produces a spot of light on the screen. By applying the proper voltages to the crt, we can shift the position of the electron beam, and thus move the light spot to trace out a picture on the screen.

*   *   *

1. What is the basic purpose of a cathode ray tube? *To visually display an electronic signal.*

2. How does a crt use electrons to draw pictures of different waveshapes? *The electrons strike the material on the screen thus giving off light. By moving ... as ... curved on the screen.*

GENERAL DESCRIPTION OF THE CATHODE RAY TUBE

A crt has only a few elements, and its overall operation is easy to understand. The tube elements are usually mounted in a glass envelope as in other tubes. Figure 1 shows a simplified diagram of one type of crt. Notice, this crt is divided into three sections: the electron gun, the deflection section, and the screen. Electrons from the gun pass between the deflection plates and strike the screen, causing a spot of light on the screen.

*   *   *

3.   Name the three major sections of a crt. *Electron gun, deflection section & screen.*

*   *   *

The electron gun is located in the neck of the crt, near the base of the tube envelope. The electron gun produces the beam of electrons and directs the electrons toward the screen. In many crt's, the electron gun also focuses the beam to produce a sharp image on the screen.

The deflection section lies next to the electron gun region. In Figure 1, deflection plates are shown mounted inside the glass envelope. The electron beam can be bent or deflected by applying different voltages to these plates. The voltages on the deflection plates attract or repel the electrons in the beam. In this way, the beam of electrons is moved up and down, and back and forth to trace out an image on the screen of the crt.

The screen lies beyond the deflection section, on the inside of the viewing end of the glass envelope. It contains a material that gives off light when struck by fast-moving electrons. The screen lets you watch any changes in the position and brightness of the electron beam.

*   *   *

4.   Producing an electron beam is the function of the (a) deflection plates, (b) screen, (c) electron gun.

5.   In what section of a crt is the electron beam bent from its normal path? *The deflection section.*

6.   The electron beam traces an image on the   *screen*   of the crt.

*   *   *

CONSTRUCTION AND OPERATION OF THE CATHODE RAY TUBE

The construction of a crt is similar to that of many receiv-
ing tubes. The crt envelope is usually a glass tube or bulb.
In a crt like that of Figure 1, this glass tube contains and
supports the three major tube parts (the electron gun,
deflection plates, and screen). In addition to holding the
crt parts, the glass envelope maintains the vacuum neces-
sary for tube operation.

To understand the operation of the crt, it is necessary to
study the functions of the major crt parts. Therefore, let's
take a closer look at the parts shown in Figure 1.

The Electron Gun

The electron gun produces the beam of electrons that traces
the pattern on the screen. It is made up of a heater, cath-
ode, control grid, first anode, and second anode. Figure 2
shows the construction of a typical electron gun. Notice the
locations of the gun electrodes. The operating voltages are
applied through the pins on the tube base to these electrodes.

*   *   *

7. Name the five elements that make up the electron gun shown in
    Figure 2. *heater, cathode, Control Grid,
    1st and 2nd Anode*

*   *   *

All of the gun electrodes except the heater are round tubes
or cylinders. The end of each cylinder is covered by a
plate normally called a baffle. As shown in the diagram,
there are holes in the centers of the baffles of the control
grid, first anode, and second anode. These holes lie along
the center line or axis of the tube.

The heater, cathode, and control grid have the same func-
tions as they do in a regular triode vacuum tube. That is,

the heater raises the temperature of the cathode. The cathode, in turn, emits electrons. The potential between the control grid and cathode determines the number of electrons that reach the screen, and thus controls the brightness of the image on the crt screen.

High positive potentials are applied to the first and second anodes. The high potential on the first anode attracts the electrons from the area near the control grid. The electrons are focused or shaped into a beam as they pass through the baffles of the first and second anodes. In addition to being focused, the beam electrons are speeded up or accelerated by the very high potential on the second anode.

*   *   *

8. Explain the functions of the following electron gun parts: cathode, control grid, and first anode.

9. Which element in the electron gun of Figure 2 speeds up the electrons as they move toward the screen?
The 2nd Anode (acceleration anode).

10. The second anode of a crt is normally operated at a negative potential with respect to the cathode. True or False?

*   *   *

To understand how the electron beam is focused, let's examine Figure 3. Here we see two plates having different potentials. There is an electric field between these two points of different potentials. The field is assumed to be made up of what we call ELECTROSTATIC LINES OF FORCE. Notice how the lines of force near the edges of the charged plates bow out. This is caused by a repelling effect between electrostatic lines.

*   *   *

11. Electrostatic lines of force exist between electrodes having equal potentials. True or False?

*   *   *

The electron gun shown in Figure 2 uses electrostatic lines of force to focus an electron beam. The beam is focused by applying different potentials to the first and second anodes. When the potentials are applied, an electrostatic field exists between the first and second anodes. Any electron passing through this field is influenced by the electrostatic lines of force.

The glass envelope of this partially assembled crt is cut away to show the screen. The electron gun is in the neck of the tube. In a complete assembly the neck is cut to the proper length, a base is installed, and the leads from the gun elements are connected to the base pins.
Courtesy North American Philips Co., Inc.

Figure 4 shows how the electrostatic lines of force are used to focus an electron beam. Here you see a cross-sectional view of the junction between the first and second anodes. Because of the difference of potential between the two anodes, electric fields exist between the baffle of the first anode and the baffle of the second anode. Notice how the electrostatic lines of force are bowed out at the outer edges of the anodes, and at the inner edges formed by the baffle holes.

Assume three electrons, a, b and c, are passing through the first anode on their way to the second anode. As these electrons pass through the hole in the first anode baffle, they are influenced by the lines of force. The electrons tend to follow the paths of the lines of force. Therefore, electrons a and c are forced in toward the center. Since electron b is already traveling through the center, it remains in its straight line path.

As electrons a, b and c approach the more positive second anode, their speeds increase. Because of this increased speed, the lines of force have less influence on the electrons.

Therefore, electrons a and c converge on electron b, and the three electrons are closer together than when they passed through the baffle of the first anode. This is the way a beam is focused by electrostatic lines of force.

*   *   *

12. Electrons tend to follow electrostatic lines of force. True or False?

13. In addition to helping focus the electron beam, what other important function does the second anode serve? *It accelerates the beam to a high speed.*

*   *   *

In Figure 4, electrons a and c are moving in toward electron b as the electrons leave the electric field and pass through the second anode. At some certain distance the three electrons will meet. This is the focal point of the beam. For good focus, the focal point should be exactly at the screen.

The focal point can be adjusted by adjusting the strength of the electric field in Figure 4. The field strength depends on the difference of potential between the first and second anodes, so the focus can be adjusted by simply varying the voltages on the anodes. Usually the voltage on the second anode is held constant and the voltage on the first anode or focusing electrode is varied to provide good focus.

*   *   *

14. When you change the setting of the focus control on the control panel of an oscilloscope, you change the focus of the image on the crt face. What electron gun voltage is being varied by the focus control? *The 1st anode voltage*

*   *   *

The second anode is called the accelerating electrode because it speeds up or accelerates the electrons so they strike the screen with enough force to cause light emission.

A uniform accelerating field exists in most modern crt's from the electron gun to the screen. This field comes from an extension of the second anode. This extension is in the form of an **AQUADAG** coating on the inside of the glass envelope.

Aquadag is a conductive material such as graphite painted on the inside of the glass tube as indicated in Figure 5. This coating is connected to the second anode by contacts called spiders. Besides producing a uniform accelerating field, the aquadag coating also serves as a collector for electrons which have struck the screen and thus served their purpose.

*   *   *

15. What is the name of the graphite coating on the inside of the glass envelope of a crt? What purpose does it serve?

Aquadag coating, Accelerating the electron
stream + collecting used electrons.

The Screen

The electrons emitted by the electron gun strike the crt screen to form an image. This screen is a coating of phosphor material on the inside of the glass tube face. The **PHOSPHORS** give off light when they are struck by high speed electrons. This type of light emission is called **LUMINESCENCE.**

*   *   *

16. What property produces a visible image on the crt screen?

Luminescence

*   *   *

Luminescence is a general term used to describe the emission of light by the phosphor screen. There are two types of luminescence. They are called fluorescence and phosphorescence. **FLUORESCENCE** is a term used to describe

the light given off while the phosphor is actually being struck by the beam electrons. The term **PHOSPHORESCENCE** refers to the light given off after the electron beam has been removed.

*   *   *

17. When applied to crt screens, what is the difference between the terms fluorescence and phosphorescence? *[It gives o... light when struck, and continues to give off light ... the election beam has left the ...]*

The lights given off during fluorescence and phosphorescence may have different colors. The color depends on the type of phosphor used on the screen. Some phosphors give off the same colored light during fluorescence and phosphorescence. Others give off different colors during fluorescence than they do during phosphorescence. Thus, crt's are available with phosphors that will satisfy many different applications.

A list of phosphors appears in the appendix at the back of this lesson. Some numbers are not shown because they are no longer in common use. Each phosphor has its most important properties listed along with its most common applications.

A crt with a rectangular screen used in oscilloscopes and other test equipment. This tube uses electrostatic deflection and focusing.
Courtesy Waterman Products Co.

An important property of a crt is the **PERSISTENCE** of the screen. Persistence is the length of time a phosphor glows after it is struck by an electron beam. In other words, it is a measure of the duration of phosphorescence in a crt. Persistence is des-

cribed as being short, medium or long. A phosphor with short persistence glows from a few microseconds to about a millisecond. Medium persistence describes an afterglow from a few milliseconds to 1 or 2 seconds. Long persistence describes any afterglow that lasts longer than 1 or 2 seconds.

A short persistence crt is desirable for viewing fast changing images. Medium persistence screens are desirable in applications where the image does not change rapidly. If the same signal is repeated time after time and needs to be observed and studied, a long persistence screen is used.

For certain applications, two or more types of phosphors can be combined. For example, you may need a crt that has a very bright image for a long period of time. Since no single phosphor offers these characteristics, two different phosphors are coated on the same screen. A layer of phosphors with a bright light characteristic is coated over a layer of phosphors having long persistence. When the electron beam strikes the screen, the result is a bright image with long persistence. When more than one type of phosphor is used on a screen, the screen is said to be CASCADE.

Most crt's are coded for easy identification. The code is a combination of letters and numbers. It describes the size of the screen, its registration date, and the type of phosphor used on the screen. For example, one crt is coded 5AP1. The first number represents the screen size. (This number would be the diameter of a round face screen or the distance from corner to corner of a rectangular crt.) In this case, 5 represents a 5 inch diameter screen. The letter A tells us that this tube was the first 5 inch tube to be registered as a standard.

The last letter-number combination tells us the type of phosphor used on the crt screen. According to the table in the appendix, a P1 phosphor produces green light and has medium persistence. The main uses of the 5AP1 tube are in oscilloscopes and radar indicators.

*   *   *

18. What characteristics would you expect from the screen of a
     5UP1 crt? How would this screen compare to that of a 5BP1?
     Green w/medium presistance, Same

*   *   *

ELECTROSTATIC DEFLECTION

In order to produce a picture of an applied voltage, we must
have some way to move the electron beam across the screen.
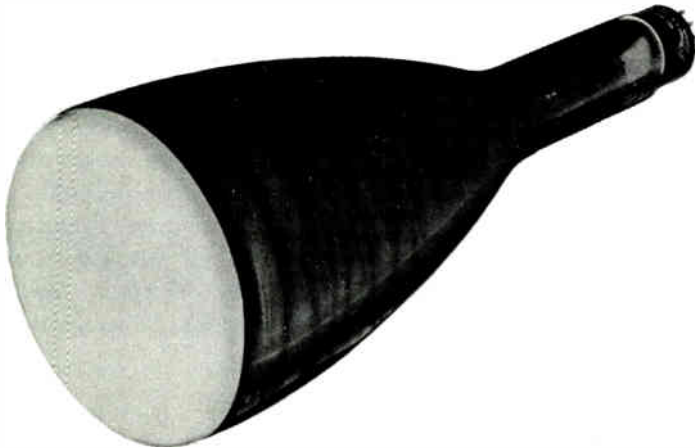
The 5DEP1 is a 5 inch crt using electrostatic deflection and focusing. Its P1 phosphors produce
green light of medium persistence.

Courtesy Waterman Products Co.

Deflection is the general term used to describe this move-
ment of the electron beam. The deflection section of the
tube lies between the electron gun and the screen.

*   *   *

19. After the focused beam leaves the vicinity of the electron gun,
     the beam enters the *deflection* region.

*   *   *

ELECTROSTATIC DEFLECTION is used in the crt of Figure 1. With this type of deflection, the beam is deflected by electrostatic fields between two sets of deflection plates. One set of plates is positioned vertically and the other horizontally. A voltage is applied between each set of plates. Electrons passing between the plates on their way to the screen are attracted by a positive plate and repelled by a negative plate, causing the electron beam to be deflected.

*   *   *

20. Why does a set of charged plates shift the position of an electron passing between them? *like charges attract.*
    positive charges repel

*   *   *

Figure 6 shows a front view of the two sets of deflection plates. The deflection plates are labeled according to the direction they force the electron beam to move. The horizontal deflection plates are mounted on either side of the electron beam. The potentials on these plates cause the beam to move from side to side. The vertical deflection plates are mounted above and below the beam, and their potentials deflect the beam up or down.

*   *   *

21. In Figure 6, which set of deflection plates causes an electron beam to move from right to left across the crt screen?
    Horizontal Reflection Plates.
22. Label the horizontal and vertical deflection plates in the following diagram.

Vertical

Horizontal

*   *   *
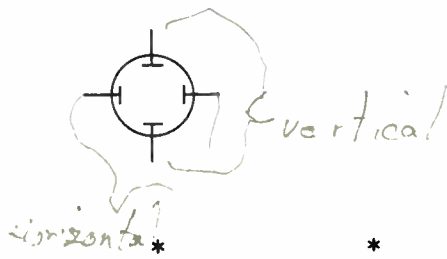
Figure 6 shows how the deflection plates appear from the screen end of the crt. Different voltages applied to the deflection plates move the electron beam across or around the screen. For example, when the left plate is positive with

The 3KP1 is an electrostatic crt with high deflection sensitivity. It provides a green image with medium persistence.

Courtesy Radio Corporation of America
Electron Tube Division

respect to the right plate in Figure 6, the beam is shifted to the left. This causes the image on the screen to move to the left. If the polarities on the plates are reversed, the beam moves to the right and causes the image to move to the right.

The voltages on the vertical deflection plates move the electron beam up or down. If the upper plate is positive with respect to the lower plate in Figure 6, the beam moves up. If the lower plate is positive with respect to the upper plate, the beam moves down.

*   *   *

23. If the electron beam is to appear at the top center of a crt screen, what polarity of voltages would you connect to (a) the vertical plates and (b) the horizontal plates?

When different potentials are applied to both sets of plates
at the same time, the electron beam moves horizontally and
vertically at the same time. In Figure 7, voltages are ap-
plied so the upper plate and the right plate are positive by
the same amount. The electron beam is attracted equally
by these plates. The beam is deflected at an angle, to the
right and upward. The result of these forces is a light spot
appearing in the upper right corner of the screen.

*   *   *

24. In the following diagram, show where the electron beam would
    be positioned if, at the same time, the upper plate is more
    negative than the lower plate, and the left plate is more neg-
    ative than the right plate.

*   *   *
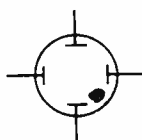
If continually changing voltages are applied to the deflection
plates, they cause the electron beam to move across the
screen in some pattern. The pattern of light on the screen
is often referred to as a TRACE. Because it is produced
by the changes of voltage applied to the crt, the trace is
actually a "picture" of the applied voltages.

<div align="center">

DEFLECTION SENSITIVITY AND
DEFLECTION FACTOR

</div>

Besides listing the size of a crt screen, the phosphor used,
and the type of deflection, most manufacturers list a tube's
DEFLECTION SENSITIVITY. Deflection sensitivity ex-
presses how far the beam moves across the screen for each
volt applied between one set of deflection plates.

The distance the image moves is expressed in terms of inches, centimeters, or millimeters. For example, one tube manufacturer may describe a crt as having a vertical deflection sensitivity of 0.2 inch per volt dc. This means that under proper operating conditions, the image will move 0.2 inch up or down for each volt dc applied between the deflection plates.

*   *   *

25. What does the term deflection sensitivity mean when applied to crt's? *It is the distance the spot will move with a certain voltage applied to the plates.*

26. What is the deflection sensitivity of a crt if 5 volts cause the beam to move .25 inch vertically from its undeflected position?
.05 in /v,

*   *   *

Another means of rating deflection systems is by **DEFLEC-TION FACTOR.** This term refers to the voltage needed between two deflection plates to move the image a specified distance (1 inch, 1 centimeter, etc.). Deflection factor is the reciprocal of deflection sensitivity. For example, a tube that has a deflection sensitivity of 0.2 inch per volt dc would have a deflection factor of 1/.2 or 5 volts dc per inch.

*   *   *

27. Some tube manuals listing crt's give the deflection factors of a tube. What does the term deflection factor mean? *It is the amount of voltage needed to move a given distance.*

28. What is the deflection factor of the cathode ray tube in Exercise 26? *20 v/in*

*   *   *

ELECTROMAGNETIC DEFLECTION AND FOCUSING

In the crt of Figure 5, the electron beam is focused and deflected by electrostatic fields. It is also possible to focus

and deflect an electron beam by using electromagnetic fields.
Most of the large screen crt's use ELECTROMAGNETIC
DEFLECTION, and many of them also use ELECTROMAG-
NETIC FOCUSING.

You will recall that a magnetic field is set up around a cur-
rent-carrying wire. This field is the result of the electron
flow in the wire. Since the electron beam in a crt consists
of electrons moving from the electron gun to the screen,
there is a magnetic field set
up around the beam just as
there is around the electrons
flowing in a wire. By using the
left hand rule, you can deter-
mine the direction of this mag-
netic field. Point your thumb
in the direction of the electron
motion (from electron gun to
screen). Bend your fingers
until a half fist is formed. The
magnetic field around the elec-
tron beam is in the direction
your fingers are pointing.

Figure 8 shows the field around
an electron passing through a
magnetic field. Assume the
direction of the electromag-

The trend in large screen electromagnetic
crt's is to shorten the screen-to-base length.
Notice the short neck on this 21 inch crt,
used as a picture tube in TV receivers.
Courtesy Radio Corporation of America
Electron Tube Division

netic field is from left to right,
and the electron is coming out
of the page. Magnetic lines
of force are set up around the
moving electron. According
to the left hand rule, the magnetic lines of force are in a
clockwise direction.

The field around the electron interacts with the applied
electromagnetic field. At the top of the electron the two
magnetic fields are in the same direction and therefore aid
each other. At the bottom of the electron the magnetic

fields are in opposite directions and tend to cancel each other. As a result, there is greater magnetic force above the electron than below it, so the electron moves downward.

By changing the direction of the electromagnetic field, the direction of the electron movement can be changed. For example, if the electromagnetic field is changed so it goes from right to left, there will be a cancellation of magnetic force at the top and a strengthening of force at the bottom, and the electron will move upward.

*   *   *

29. Explain how a moving electron can be deflected by a magnetic field.

*   *   *

Figure 9 shows a simplified diagram of a crt that uses electromagnetic deflection and focusing. It has the same three main sections as the electrostatic crt of Figure 1 -- an electron gun, a deflection section, and a screen. However, the deflection section requires a set of deflection coils around the neck in Figure 9 compared to the deflection plates inside the envelope in Figure 1. Also, the crt of Figure 9 has a focus coil whereas the focus was provided by elements of the electron gun in the tube of Figure 1.

Figure 10 shows the construction of a typical electron gun used in an electromagnetic crt. This electron gun has four elements -- the heater, cathode, control grid, and accelerating anode. Basically it is similar to the gun of Figure 2, but there is no focus anode in the gun of Figure 10.

*   *   *

30. Describe one difference in construction between the electron gun of Figure 9 and that of Figure 1. *The gun in figure 9 has no focusing anode.*

*   *   *

The indirectly heated cathode in Figure 10 produces the electrons for the beam. The control grid is usually negative with respect to the cathode. A control connected between the grid and cathode varies the grid voltage, and thus controls the number of electrons in the beam. By making the grid less negative, more electrons are in the beam and a brighter image appears on the screen. In television receivers or oscilloscopes this control is located on the front control panel or where the control is easily reached.

A high positive potential is placed on the accelerating anode. This high potential attracts the electrons emitted by the cathode and accelerates them toward the screen. As in the electrostatic crt, an aquadag coating on the inner wall of the electromagnetic crt envelope provides a uniform accelerating field. Figure 11 shows the location of the aquadag with respect to the other tube parts. Here, the accelerating anode and aquadag are connected by spider connections. The high positive potential is then applied to the electron beam from the electron gun to the screen.

The accelerating anode is not used to focus electrons. The electron beam is focused by a magnetic field. This field is generated by current passing through the FOCUS COIL.

Figure 12 shows the location of the focus coil with respect to the accelerating anode. Assume current is flowing in the focus coil. The direction of current is indicated by the x's and dots in the circles representing the coil turns. The x's represent tails of arrows or current flowing into the page, and the dots represent heads of arrows, or current flowing out of the page. An electromagnetic field is generated by this current. This field is indicated by dashed lines. The solid lines show the paths of the beam electrons on their way from the gun to the screen.

Electromagnetic focusing is illustrated in Figure 12. Three electrons, (a, b and c) are shown leaving the accelerating anode and traveling in the direction of the screen. Electron b travels along the tube axis and is not deflected by

the electromagnetic field.   Electrons a and c are shown
leaving the desired path along
the tube axis. Interaction be-
tween the field of the coil and
the field of the moving elec-
tron takes place. Electrons a
and c are then forced back
toward the tube axis and even-
tually hit the focal point on the
screen.

This interaction is shown in
more detail in Figure 13.
This figure represents a cross
section of the neck of the tube
inside the focus coil. Imagine
that current flows through the
focus coil in a clockwise di-
rection, producing an electro-

Focus coils are made to be mounted around
the neck of a crt.
                Courtesy Syntronic Instruments, Inc.

magnetic field.   The lines of force that pass through the
neck of the crt would be coming out of the page.

Electrons moving along the tube axis are not affected by the
focus coil field.   However, suppose an electron tends to
diverge or move away from the center axis, in the direction
of path A.   The divergent electron has a magnetic field set
up around it. This field is represented by a small circular
arrow in Figure 13. Because of the interaction between the
field around the electron and the field of the focus coil, the
electron is forced upward, as represented by the arrow and
letter F.   This force causes the electron to curve into a
path similar to B and C.   The result is a spiral movement
back to the axis and in the direction of the screen.

The electron beam can be focused so an image on the screen
appears sharp and clear.   Focusing is accomplished by
changing the amount of current flowing in the focus coil.
When more current flows through the coil, the electromag-
netic field becomes stronger and has a greater effect on the
electrons.   With less current flowing through the coil, the

electromagnetic field becomes weaker and has less effect on the electrons.

*   *   *

31. How can electric current through a focus coil be used to focus the image on a crt?

*   *   *

A crt that uses electromagnetic deflection requires a **DE-FLECTION YOKE.** A deflection yoke consists of two pairs of coils placed around the neck of the crt.   The yoke is located in the deflection area, near the bell shaped portion of the envelope. This is shown in Figure 11.

Figure 14 shows the general arrangement of a deflection yoke. A pair of vertical deflection coils and a pair of horizontal deflection coils are contained within a supporting case.   These coils have the same function as the deflection plates in electrostatic deflection crt's.   One pair of coils deflects the beam in the horizontal direction and the other pair deflects the beam in the vertical direction.

With current in the coils, there is an electromagnetic field between each pair of coils. The horizontal deflection coils, mounted above and below the beam, are in series with a source of horizontal deflection current.   When the current flows in one direction, a magnetic field is set up in one direction between the horizontal deflection coils.   When the current changes direction, the magnetic field also changes direction.   An electron passing through this field is moved to the right or left by the interaction of the electron field and the coil field.

The vertical deflection coils, to the right and left of the beam, are in series with a source of vertical deflection current.   The field between these coils interacts with the field around the electron to move the electron up or down.

*   *   *

32. Explain how an electromagnetic field can deflect an electron beam.

*   *   *

Figure 15 shows how the interaction of fields causes the electron beam to change positions. Assume the direction of current through the horizontal deflection coils is such that the lines of force extend from the lower coil to the upper coil. According to the left hand rule the field around an electron coming out of the page would be in a clockwise direction. Thus, the electron field and the coil field aid each other at the left of the electron and oppose each other at the right of the electron. The electron moves in the direction of the weaker field, which is to the right.

The deflection yoke contains the deflection coils which shift the position of the beam across the screen of the crt.
Courtesy Chicago Standard Transformer Corp.

If the vertical deflection current produces a field from the left coil to the right coil, the electron field aids the coil field above the electron and cancels the coil field below the electron. The electron in this case moves downward.

If electromagnetic fields exist between both sets of coils at the same time, the resultant force applied to the electrons is a combination of the horizontal and vertical forces. For example, assume an electromagnetic field exists from the lower horizontal coil to the upper coil, and from the left vertical coil to the right coil as indicated in Figure 15. An electron passing through these fields, along the tube axis, would be forced downward and to the right.

*   *   *

33. The diagram below shows the center axis position of an elec-
tron beam coming toward you, out of the page.   Show the di-
rection of beam deflection when the indicated magnetic fields
are applied.

*   *   *
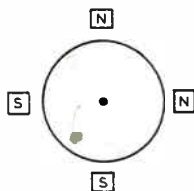
A defect known as ION SPOT or ION BURN can occur in an
electromagnetic crt.   This is a permanent dark spot on the
crt screen.   Ion burn is caused by heavy negative ions hit-
ting one spot on the phosphor screen. These ions are emitted
by the cathode along with useful electrons. They are heavier
than the electrons, and are not as easily deflected by a
magnetic field. Although the electrons are deflected to dif-
ferent positions on the screen, the heavy ions keep bombard-
ing the center of the crt until they actually destroy the screen
phosphors.

The problem of ion burns is not as serious in electrostatic
crt's.   An ion is deflected easily by an electrostatic field,
so the ions are moved across the screen along with the
electrons.   Since there is no concentrated bombardment of
the center of the screen, there is little danger of ion burns
in an electrostatic crt. The problem exists mainly in elec-
tromagnetic crt's.

One method used to prevent ion burn in an electromagnetic
crt is to use a bent electron gun and an ion trap as shown in
Figure 16.   Parts of the electron gun are actually bent so

the beam is "aimed" at the wall of the tube instead of down the axis of the tube toward the screen. Before the electrons strike the wall, however, they are affected by the ion trap
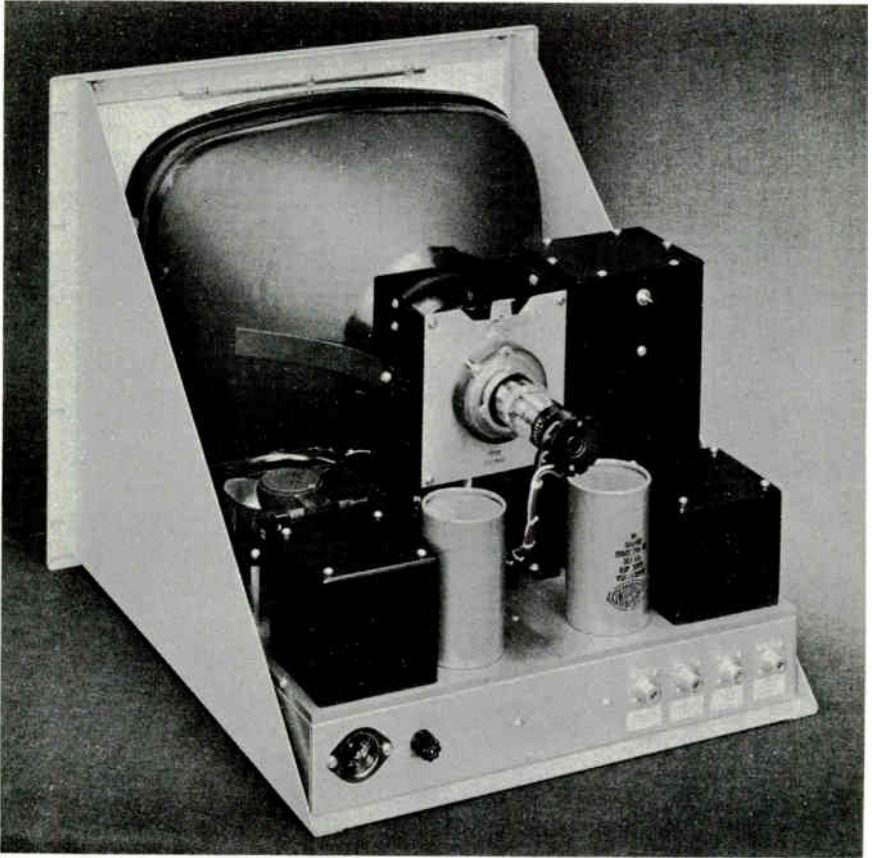
This data display scope uses a 17 inch electromagnetic crt as the indicating device. Notice the deflection and focus assembly mounted around the neck of the tube.

Courtesy Kauke and Company, Inc.

magnet, which is usually in the form of a small permanent magnet clamped to the neck of the tube. The field of the magnet bends the beam of electrons back along the tube axis as shown by the dashed lines in Figure 16. The ions, however, are affected very little by a magnetic field, so they continue in their original path. They usually strike the

inside wall of the accelerating anode as indicated by the dotted line. Thus, the trapping action removes ions from the beam so that only the electrons are directed to the screen.

The ion trap magnet bends the electron beam so the electrons will travel through the accelerating anode along the tube axis. With no deflection signal, the beam should be at the center of the crt screen. The ion trap must be carefully adjusted to meet this requirement. You adjust an ion trap by moving it toward the screen or toward the tube base while rotating it. The position is correct when the image on the screen appears the brightest. Also, with deflection voltages applied, the light on the screen should be uniform over the full face of the tube.

*   *   *

34. What is the purpose of the ion trap magnet in an electromagnetic deflection crt? *It Bends the electron beam so its moves in a straight line.*

35. Explain how you would adjust an ion trap magnet. *By sliding it forward and backward on the neck of the tube while at the same time rotating it for the brightest image.*

Another method of preventing ion burn is to coat the inner side of the phosphor screen with a thin film of aluminum. Many types of crt's are manufactured in this way. The aluminum stops the relatively large ions from reaching the phosphor screen. However, the smaller, faster moving electrons pass through the aluminum film and hit the screen.

An important side effect of aluminized screens is the mirror effect. When an electron strikes a phosphor, the phosphor gives off light. Some of this light is reflected back into the tube. If the phosphor is backed by aluminum, the metal will reflect the light forward and out at the screen. This action actually increases the light output of the crt. Thus, an aluminized screen offers protection from ion burn and provides greater light output.

COMPARISON OF ELECTROSTATIC AND
ELECTROMAGNETIC CRT's

Both electrostatic and electromagnetic deflection crt's have wide commercial, industrial and military applications. Each type of tube has certain advantages and disadvantages. These characteristics deter- mine the best use for each tube.

Electrostatic deflection crt's are used almost entirely for oscilloscope or oscillograph applications, and in various other types of test equipment that require a visual display. In some cases, they are used as radar indicators. Televi- sion receivers, data display outputs for computers, and most radar systems use electromagnetic deflection crt's.
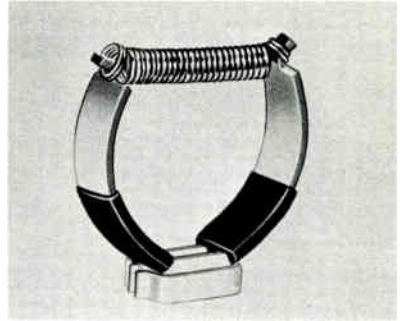
An ion trap magnet assembly. The spring holds the assembly firmly on the neck of the crt.

Courtesy Quam-Nichols Co.

*   *   *

36. The crt's in most oscilloscopes are designed for (a) electro- static deflection, (b) electromagnetic deflection.

37. The crt's in most television receivers use electrostatic de- flection.   True or False?

*   *   *

An electromagnetic crt is generally shorter than an elec- trostatic crt of equal screen size. The electron guns used in electromagnetic crt's have fewer parts. They are simpler and more rugged than the electron guns used in electrostatic crt's. In addition, this type of tube offers a brighter image by using high accelerating voltages without a great loss of deflection sensitivity.

The electromagnetic crt has a few disadvantages. Large, bulky coils are used in the focus and deflection systems. This makes an instrument using this tube heavier than an instrument using an electrostatic tube. In turn, more power is needed to operate the focus and deflection systems. Fairly heavy currents are needed for the deflection coils. They limit the type and frequency of deflection signals which can be used.

The electrostatic crt has no large and bulky coils to focus and deflect an electron beam. Therefore, the circuits that supply voltages for focusing and deflection are simpler than those used with electromagnetic crt's. Because this type of tube uses voltage to focus and deflect a beam, only low power is needed. In addition, higher deflection frequencies and more complex signals can be applied with simpler deflection circuits.

There are several disadvantages of electrostatic deflection crt's. The electron gun is longer and it has more parts. The deflection plates must be mounted and supported along with the electron gun. This makes the gun structure longer and more subject to damage. Because of the length of the gun, the neck of the tube must be longer. In turn, the over-all length of the tube is increased. In addition, very small images in the overall pattern tend to be defocused by an electrostatic tube and bright images cannot be produced over large areas without losing deflection sensitivity.

*   *   *

38. List two advantages of an electrostatic deflection crt compared to an electromagnetic deflection crt? *less weight, less power is needed for the deflection systems*

*   *   *

VARIATIONS IN CATHODE RAY TUBES

Manufacturers have developed a number of variations or modifications to improve the operation of crt's and to make

them more suitable for various applications. Sometimes the advantages of electrostatic systems are combined with the advantages of electromagnetic systems to meet the requirements of a particular application.

For example, the crt's in many of the modern large screen television receivers use electromagnetic deflection and electrostatic focusing. Electromagnetic deflection is used because the beam can be deflected over a greater area and still remain in focus. Also, a brighter image can be produced. Electrostatic focus is desirable because its power requirements are lower than those of the electromagnetic focus system. Also, the receiver is lighter in weight because the focus coil is not needed.

Figure 17 shows a crt designed for electromagnetic deflection

A 5 inch crt used in radar and oscilloscope applications. This tube uses electrostatic focus and electromagnetic deflection.
Courtesy Radio Corporation of America
Electron Tube Division

and electrostatic focusing. The electron gun is similar to that described for the electrostatic crt of Figure 5, and the deflection system is similar to that described for the electromagnetic crt of Figure 11. A high voltage anode is added next to the regular accelerating anode. The potential on this electrode is applied through the glass envelope by way of a button connection. From the button, the potential is applied to the aquadag coating inside the envelope. The aquadag connects to the high voltage anode by spider connections. The high voltage anode assembly is often referred to as an ULTOR.

Notice in Figure 17 that the outer surface of the wide portion

or bell of the tube envelope is covered with a conductive material. That is, the tube has both an inner conductive coating and an outer conductive coating. These two conductive coatings separated by the glass envelope serve as a filter capacitance for the high voltage power supply. Usually the outer coating is grounded by the metal assembly used to mount the crt on the chassis.

To produce a bright image when they strike the screen, the electrons must be accelerated to a high velocity. However, if the electrons are traveling at high velocity through the deflection region they are affected less by the deflection fields. Thus, increasing the acceleration to obtain brighter images results in a loss in deflection sensitivity in a conventional crt.

Some crt's have one or more **INTENSIFIER ANODES** in the form of conductive coatings on the inside of the envelope, near the screen. An example of a single intensifier anode is shown in Figure 18. The coating makes contact with a metal terminal that extends through the envelope wall and connects to a high voltage supply.

As the electrons move toward the screen in Figure 18, they receive normal acceleration from the second anode and the aquadag coating that serves as an extension of this anode. Deflection takes place with normal efficiency as the electrons pass between the deflection plates. The electrons are then speeded up by the intensifier anode so they are traveling at very high velocity as they strike the screen. Because the added acceleration occurs after the beam has been deflected, the system is referred to as POST-DEFLECTION ACCELERATION (the word "post" meaning "after").

*   *   *

39. Why is an intensifier anode used in some electrostatic crt's?

To increase the velocity of the electron beam to make a brighter image. It does this after the deflection system so that it will not decrease no deflection sensitivity.

One way to accelerate the beam electrons gradually as they pass from the gun to the screen is to use a coating of re-
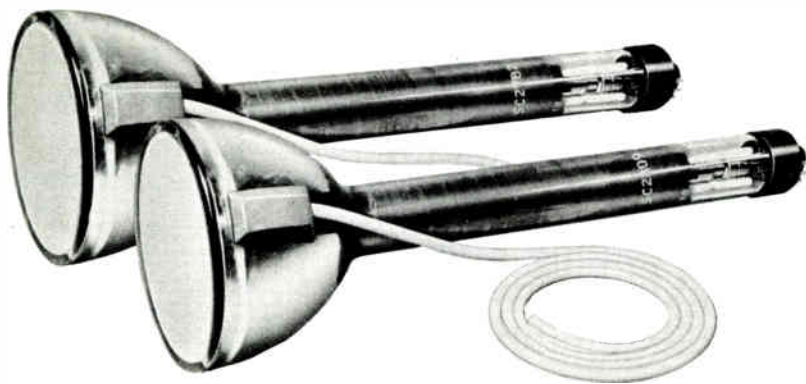
These small screen crt's produce very bright images which may be photographed to provide permanent records. Intensifier anodes supplied by well insulated connectors provide the high electron acceleration to produce the bright image.

Courtesy Sylvania Electric Products, Inc.
Electron Tube Division

sistance material instead of conductive material on the inside of the envelope. A very high positive potential is applied to the screen end of the resistance coating. A lower potential exists at the end of the coating near the electron gun. Thus, there is a large difference of potential between the two ends of the resistance coating. Beginning at the low potential end, the potential becomes higher and higher as you move toward the screen.

An electron moving toward the screen is thus exposed to higher potentials as it approaches the screen. With this method the electrons are moving at a relatively low velocity as they pass through the deflection region, and reach a high velocity by the time they strike the screen. The result is a bright image with no sacrifice in deflection sensitivity.

Some crt applications may require more than one image to be displayed on the screen at the same time. To accomplish this, some crt's have more than one electron gun. This type of tube is called a MULTI-GUN CRT. Multi-gun

crt's are used in some radar indicators and in various types of test equipment.

Probably the most common application of multi-gun crt's is in present day color television receivers. The color TV crt uses three electron guns to produce color pictures on the screen of the tube.

*   *   *

40. What is the purpose of a multi-gun crt? *It Has the ability of presenting more than one Image at a time or its screen.*

*   *   *

Figure 19 shows an example of a two-gun crt. The electron guns are mounted next to each other in the neck of the tube. There is a set of deflection plates for each gun. For all practical purposes we have two crt's in one, producing independent images on a single screen.

Because there is more than one electron gun, the neck of the tube is much wider than that of a single-gun crt. A larger tube base is also necessary because of the wider neck plus the greater number of pin connections.

A multi-gun crt usually requires extra space because of its larger size. Also, there must be additional circuits to operate the independent sections of the tube. If there is a need to conserve space, other methods can be used to display multiple images. One method is to use a "time share" tube. In this system, the same electron gun is used to form a dual image on the screen. At one instant of time, the gun draws one image. The next instant it draws another image. A tube used in this way must have a screen with medium or long persistence so that one image stays on the screen while the other is being formed.

The time sharing system requires additional external circuits. These circuits are timing circuits. They govern the length of time that the single electron gun produces each

picture. The switching circuits can also be made to separate the two pictures. One picture can then be displayed above the other.

The features described in this section are only a few of the many variations in crt's. No matter what changes are made, the basic operation of the crt remains the same. That is, a focused electron beam is deflected across a phosphor-coated screen to produce a light image.

HANDLING THE CATHODE RAY TUBE

Cathode ray tubes, like other types of electronic equipment, should be handled with care.

A three-unit electron gun that can produce three individual traces on a crt.
Courtesy Electronic Tube Corp.

Excessive vibration or jarring could cause misalignment of the elements, and could even cause these elements to short out or open. This would make the tube unusable and would require a costly replacement.

Because of the high vacuum inside the envelope, crt's can be dangerous if they are not handled with care. If the glass envelope breaks, the pressure from the air around the crt can cause the tube to implode (burst inward). Safety glasses and gloves are recommended in handling larger crt's to prevent injury from flying glass in case of implosion.

When installing the crt, avoid undue pressure on the leads extending out of the tube base. Attempts to bend them by forcing on a bad connector may break the glass-to-metal seal around these connectors. This would cause a loss of vacuum in the tube. When installing the crt, support it at the screen end while holding the neck only for guiding the base pins into the socket. If you hold it by the neck, the

weight of the screen end of a large crt may be enough to snap the neck.

*   *   *

41. What are some of the precautions to take when handling crt's?

[handwritten] wear gloves of safety ropes, support work on the bench

SUMMARY

Cathode ray tubes are used to draw pictures of signals by forming an electron beam, focusing it, and deflecting it across a screen. These signals may be used in television receivers, radar indicators, oscilloscopes, and other types of equipment.

There are two general types or classifications of crt's -- electrostatic and electromagnetic. They are grouped in this manner by the way their electron beams are focused and deflected.

In general, each type of crt can be divided into three sections; the electron gun, the deflection section, and the screen. An electrostatic crt has an electron gun to produce an electron beam, a set of deflection plates to deflect the beam, and a screen to view the movement of the beam. In this tube type, the electron beam is focused by the electrostatic field between gun electrodes. Electrostatic fields between the deflection plates deflect the beam across the screen.

A crt that uses electromagnetic focusing and deflection has an electron gun to produce the electron beam, a focus coil to focus the beam, and deflection coils to deflect the beam across the screen. By varying the current in the focus coil, and thus varying the magnetic field around this coil, the electron beam can be focused to a sharp point on the crt screen. The beam is deflected across the screen by varying the currents through the deflection coils, thus vary-

ing the magnetic fields produced by these coils.

Images are produced when electrons strike the phosphor coating that serves as the screen. The energy from the high speed beam electrons is changed to light energy as the electrons hit the phosphors. There are many types of phosphor materials. Each type of phosphor has its own characteristics. One important characteristic is persistence. This is the length of time the screen glows after it has been struck by the beam of electrons. Another characteristic is the color of light given off by the screen.

There are different types of crt's. A tube may have more than one electron gun so more than one image is drawn on the screen. Other tubes have special circuits to draw more than one image with only one gun. In many cases, a crt may use both electrostatic and electromagnetic fields to produce, focus, and deflect an electron beam.

It must be remembered, that no matter what variations are made, the basic operation of a crt is the same. The crt produces an electron beam, focuses it so it will appear sharp and clear, and deflects it to produce a pattern of light on the screen.

IMPORTANT DEFINITIONS

ACCELERATING ELECTRODE - [ak SEL uh rayt ing] - An electrode normally operated at a high positive potential to increase the velocity of electrons in the electron beam. Also referred to as the SECOND ANODE.

ALUMINIZED SCREEN - [a LOO: min ighz'd] - A screen which has a thin coating of aluminum on its electron beam side. This type of screen is used to prevent ion burns and to increase the light output in tubes using electromagnetic deflection.

AQUADAG - [AK wuh dag] - A conductive material used to coat the inside of the envelope of a cathode ray tube. The aquadag coating is an extension of the accelerating electrode and is also used to collect electrons that have struck the phosphor screen.

CASCADE SCREEN - [kas KAYD] - A screen that has more than one layer of phosphors to obtain a certain light characteristic. For example, two phosphors may be combined to give the advantage of high light output and long persistence.

CATHODE RAY TUBE (CRT) - A vacuum tube in which electrons are formed into a beam and used to draw or trace an image of some desired pattern on a phosphor screen.   The movement of the electron beam produces an image as in TV picture tubes, radar indicators, and oscilloscope indicators.

DEFLECTION FACTOR - [di FLEK shun] - A factor which indicates the voltage required on the deflection plates of an electrostatic crt to produce a unit (1 inch, 1 centimeter, etc.) deflection on the screen.

IMPORTANT DEFINITIONS (Continued)

DEFLECTION PLATES - In an electrostatic deflection sys-
     tem, the plates mounted inside the tube envelope to
     deflect the electron beam across the crt screen.

DEFLECTION SENSITIVITY - An indication of how far the
     spot or image on the screen of an electrostatic crt
     is deflected for each volt applied to the deflection
     plates.

DEFLECTION YOKE - In an electromagnetic deflection sys-
     tem, the arrangement of coils mounted around the
     neck of the tube to deflect the electron beam across
     the crt screen.

ELECTROMAGNETIC DEFLECTION - [i LEK troh mag NET
     ik] - The deflection of an electron beam by inter-
     action between the magnetic field around the moving
     electrons and the magnetic fields of the deflection
     coils.

ELECTRON GUN - The group of electrodes in a crt that
     supplies the electrons, forms them into a beam,
     directs them along the tube axis, and accelerates
     them so they hit the phosphor screen with enough
     force to cause the screen phosphor to emit light.

ELECTROSTATIC DEFLECTION - [i LEK troh STAT ik] -
     A deflection system that uses varying electric poten-
     tials on a set of deflection plates to deflect the elec-
     tron beam across the screen of the crt.

FIRST ANODE - See FOCUSING ELECTRODE.

FLUORESCENCE - [floo: uh RES'ns] - The emission of
     light by a substance only during excitation. An ex-
     ample is the light emission at the time the screen

IMPORTANT DEFINITIONS (Continued)

phosphors are being struck by the beam electrons.

FOCUS - The point at which the electrons in the electron beam converge. The focal point should be where the beam electrons strike the screen.

FOCUS COIL - A current carrying coil mounted on the neck of a crt. It provides a magnetic field that focuses the electron beam to a very fine point as it strikes the screen.

FOCUSING ELECTRODE - An electrode to which a potential is applied to control the focusing of the electron beam. Also referred to as the FIRST ANODE.

INTENSIFIER ANODE - [in TEN sih figh er] - A strip of conductive coating near the crt screen which accelerates the electrons after the beam has been deflected. Thus, it provides greater light output without decreasing the efficiency of the deflection system.

ION BURN - A darkened area on the screen of a crt using electromagnetic deflection. Ion burn is caused by the bombardment of the screen by negative ions from the electron gun.

ION TRAP MAGNET - A magnet mounted on the neck of an electromagnetic crt as part of a method to prevent ion bombardment of the screen. It bends the electron beam so that it travels along the tube axis, but does not affect the ions, which are dissipated against the gun walls.

LUMINESCENCE - [loo: mi NES' ns] - The emission of light by a substance due to the absorption of energy. For

IMPORTANT DEFINITIONS(Continued)

example, the light emitted by a phosphor material which is struck by fast moving electrons.

PERSISTENCE - [per SIS t'ns] - The property of a phosphor to glow after it has been struck by an electron. The longer the persistence, the longer the phosphor glows after it is initially struck.

PHOSPHOR - [FAHS fuhr] - A material that emits light when struck by electrons. The material that forms the screen of the crt.

PHOSPHORESCENCE - [fahs fuh RES'ns] - The emission of light which persists for a time after electrons strike a fluorescent material.

SCREEN - The coating which is excited by the electron beam, producing the visible pattern on the face of a crt.

SECOND ANODE - See ACCELERATING ELECTRODE.

TRACE - The pattern produced on the screen of a crt by the movement of the electron beam.

ULTOR - [UHL t'r] - A high voltage anode arrangement used in addition to the second anode in some crt's.

APPENDIX

TYPICAL PHOSPHOR CHARACTERISTICS

PHOSPHOR	COLOR	PERSISTENCE	APPLICATION
P1	Green	Medium	Radar, oscilloscopes
P2	Green	Medium	Oscilloscopes
P4	White	Medium	TV picture tubes
P5	Blue	Medium-Short	Photographic recording
P7	Yellow	Medium-Long	Radar, oscilloscopes
P11	Blue	Medium-Short	Photographic recording, oscilloscopes
P12	Orange	Long	Radar
P14	Orange	Medium	Military displays
P15	Green	Very short	TV cameras
P16	Violet	Very short	TV cameras
P17	Yellow	Long	Military displays
P19	Orange	Long	Radar
P21	Orange	Long	Radar
P22	Three-color	Medium	Color TV picture tubes
P23	White	Medium	TV picture tubes
P24	Green	Short	TV cameras
P25	Orange	Medium	Military displays
P26	Orange	Very long	Radar
P27	Orange	Medium	Color TV monitors
P28	Green	Long	Radar
P29	Two-color	Medium	Aircraft instruments
P31	Green	Medium-Short	Oscilloscopes
P32	Green	Long	Radar
P33	Orange	Very long	Radar
P34	Green	Very long	Radar, oscilloscopes

STUDENT NOTES

STUDENT NOTES
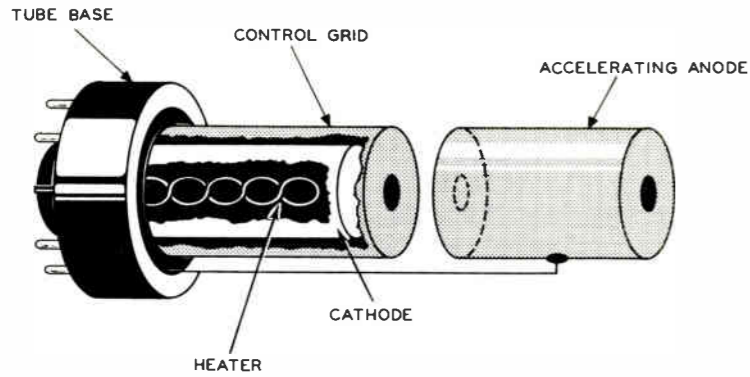
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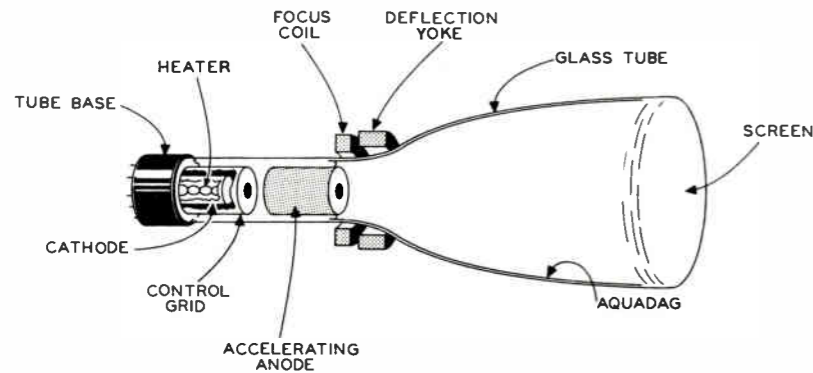
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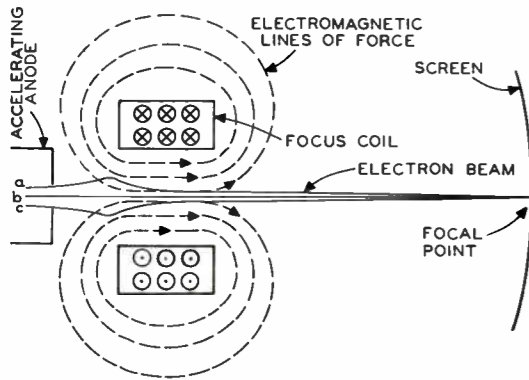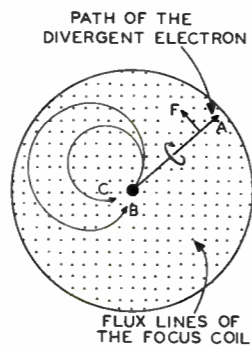
FIGURE 12

FIGURE 13

PRACTICE EXERCISE SOLUTIONS (Continued)

13. Besides helping to focus the electron beam, the second anode acts to accelerate the electrons in the beam. This is because the high positive potential applied to this anode attracts the negatively charged electrons.

14. To change the focus of an electron beam, the voltage on the first anode is varied. A potentiometer is mounted on the control panel of the oscilloscope and the focus anode voltage is varied by adjusting this control.

15. The graphite coating on the inside of the crt envelope is called aquadag. It is part of the second anode and helps maintain a uniform accelerating field. It also collects the electrons after they strike the screen.

16. luminescence -- The screen is coated with a material which gives off light whenever it is excited (struck) by a moving electron.

17. The term fluorescence refers to light given off while the screen phosphor is being struck by electrons. Phosphorescence is a term applied to any light given off by the phosphor after it is struck by the electron beam.

18. The phosphors on the 5UP1 screen would provide medium persistence and would produce a green image. The image of the 5UP1 would be the same color and have the same persistence as that of the 5BP1. Both are 5 inch tubes and both have P1 phosphor screens.

19. deflection -- In this region the electron beam is moved right or left and up or down, depending on the polarities of the voltages applied to the deflection plates.

20. A set of charged plates attracts or repels an electron because of the interaction between the charges on the plates and the negative charge on the electron. Making one plate negative and the other positive causes the electron to be repelled by the negative plate and attracted by the positive plate. The electron is attracted to the more positive plate. Thus, by varying the voltages between a set of plates the beam may be deflected to trace an image on the crt screen.

PRACTICE EXERCISE SOLUTIONS (Continued)

21. The horizontal deflection plates shown in Figure 6 cause the electron beam to move right or left across the crt screen.

22.
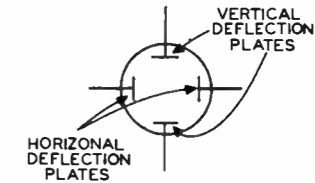
23. (a) The upper vertical plate must be more positive than the lower vertical plate so the beam moves upward. (b) The horizontal plates must be at equal potentials so the beam is in the center as far as horizontal position is concerned.

24. The electron beam would be forced downward and to the right. The lower vertical deflection plate and the right horizontal deflection plate attract the electron.
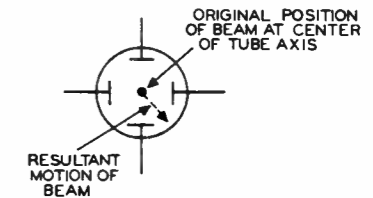
25. Deflection sensitivity is an indication of how far the spot moves on the crt screen for each volt applied to a set of deflection plates. This distance may be expressed in inches, centimeters, or millimeters.

26. .05 inch per volt.

$$\frac{.25 \text{ inch}}{5 \text{ volts dc}} = \frac{.05 \text{ inch}}{1 \text{ volt dc}} = .05 \text{ inch per volt dc}$$

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PRACTICE EXERCISE SOLUTIONS

1. The basic purpose of a cathode ray tube is to draw a picture which is determined by voltages applied to the tube.

2. A crt uses electrons to draw pictures by focusing an electron beam on a thin layer of material deposited on the face of the crt. This layer of material gives off light as it is struck by the electron beam and, in effect, leaves a drawing on the tube screen.

3. The three main sections of a crt are: the electron gun, the deflection section, and the screen.

4. (c) electron gun. -- The deflection plate voltages cause the electron beam to move up or down and left or right, while the screen shows a picture by fluorescence -- the giving off of light.

5. The electron beam is bent or caused to move from its normal path by the deflection section.

6. screen or face -- The screen is coated with material which gives off light when it is struck by fast-moving electrons.

7. The five electron gun elements are: the heater, cathode, control grid, first anode, and second anode.

8. The cathode emits the electrons that form the electron beam. The control grid determines the number of electrons that will make up the electron beam. The first anode is used to focus the electron beam so that the trace of light appears sharp and clear on the crt screen.

9. the second anode, often called the accelerating anode or accelerating electrode.

10. False -- The second anode is normally operated at a high positive potential with respect to the cathode.

11. False -- Electrostatic lines of force exist only between points that are at different potentials.

12. True
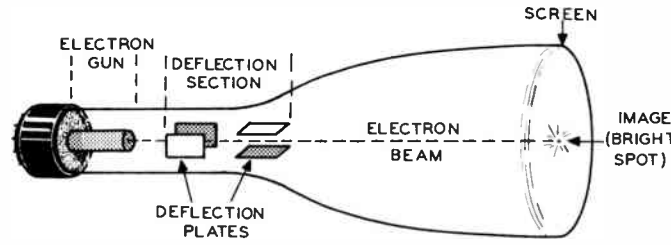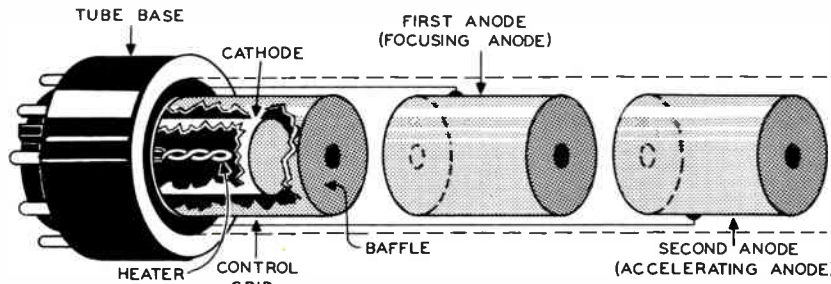
FIGURE 1

FIGURE 2
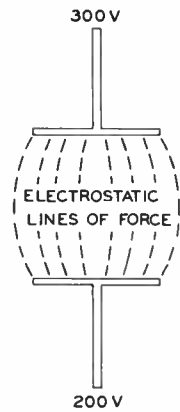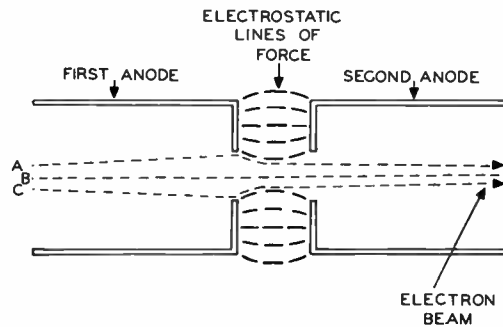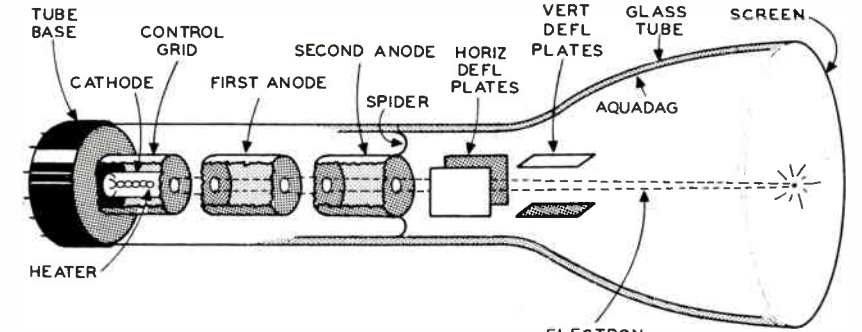
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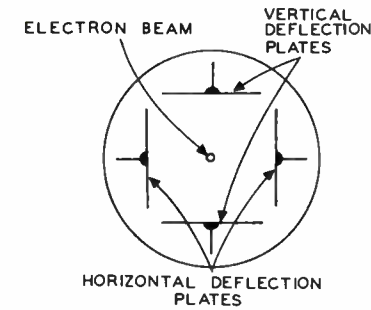
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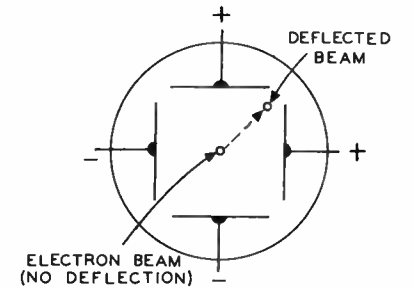
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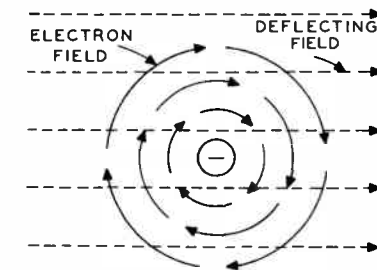
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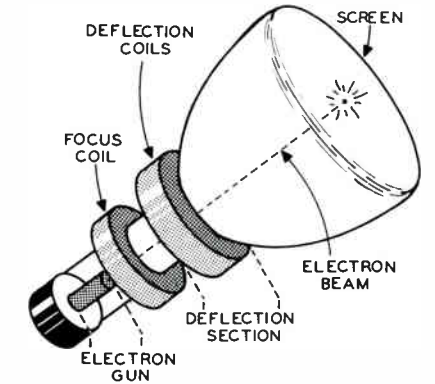
FIGURE 7

FIGURE 8

FIGURE 9

PRACTICE EXERCISE SOLUTIONS (Continued)

27. Deflection factor indicates the voltage required between the deflection plates to produce a certain deflection on the screen. It is the reciprocal of deflection sensitivity.

28. 20 volts dc per inch. Dividing 1 by the deflection sensitivity of Exercise 26, we get $1/.05 = 20$ volts dc per inch.

29. A moving electron has a magnetic field about it. When the moving electron enters a region of other magnetic fields, the magnetic fields aid or oppose each other. The electron tends to move in a direction where the field is weak and away from the region where the field is strong.

30. The electron gun used in most electrostatic crt's (Figure 1) has two anodes. One anode is used to focus the beam and the other anode is used to accelerate the beam. The electron gun in an electromagnetic crt such as that of Figure 9 has only an accelerating anode. An external coil mounted around the tube neck is used to focus the electron beam.

31. Electric current applied to the focus coil produces magnetic lines of force in the electron gun region. The interaction between the magnetic fields of the electron and focus coil cause the beam to be focused. The current in the focus coil is varied until the electron beam is properly focused on the screen.

32. An electromagnetic field between coils on either side of the electron beam interacts with the field around the electron beam. This interaction causes the beam to deflect from its original position according to the strength and direction of the electromagnetic field.

33.
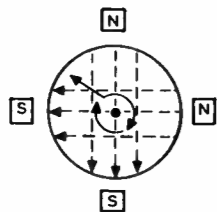
The resultant forces would move the electron beam upward and
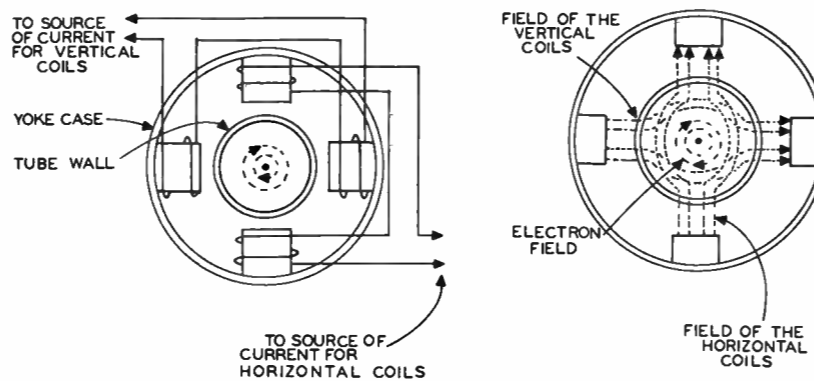
FIGURE 14   FIGURE 15
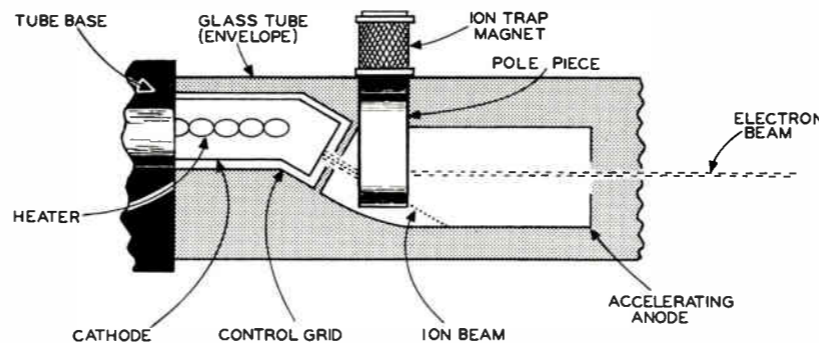
FIGURE 16

FIGURE 17

2206

FIGURE 18

FIGURE 19

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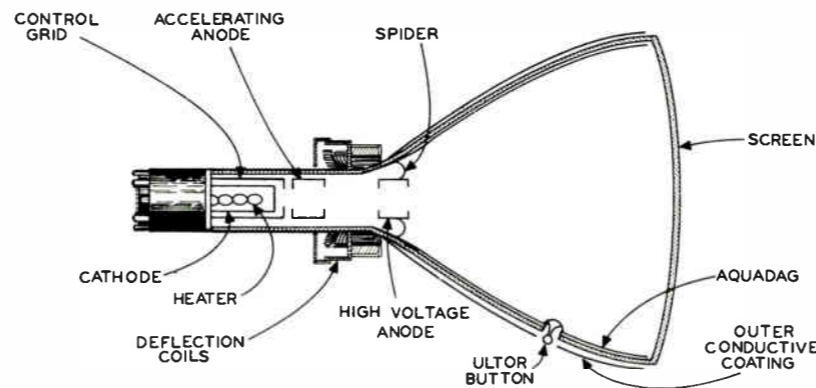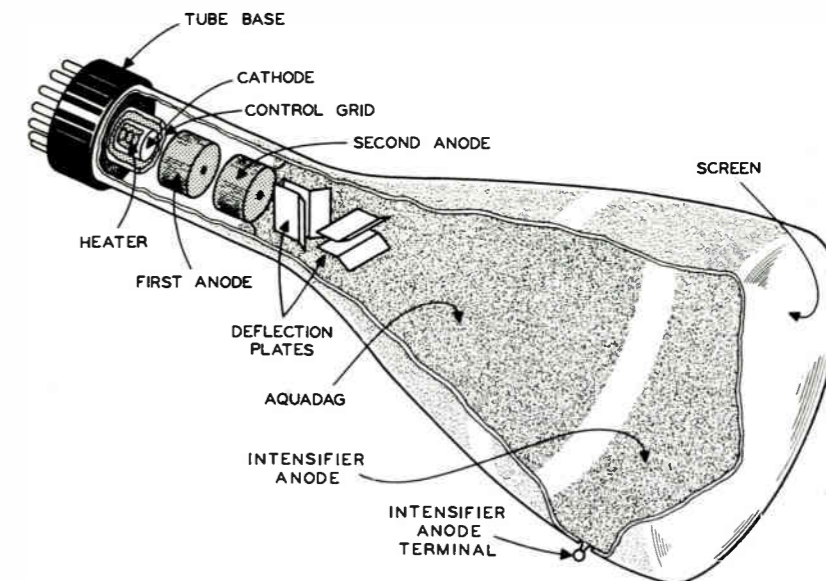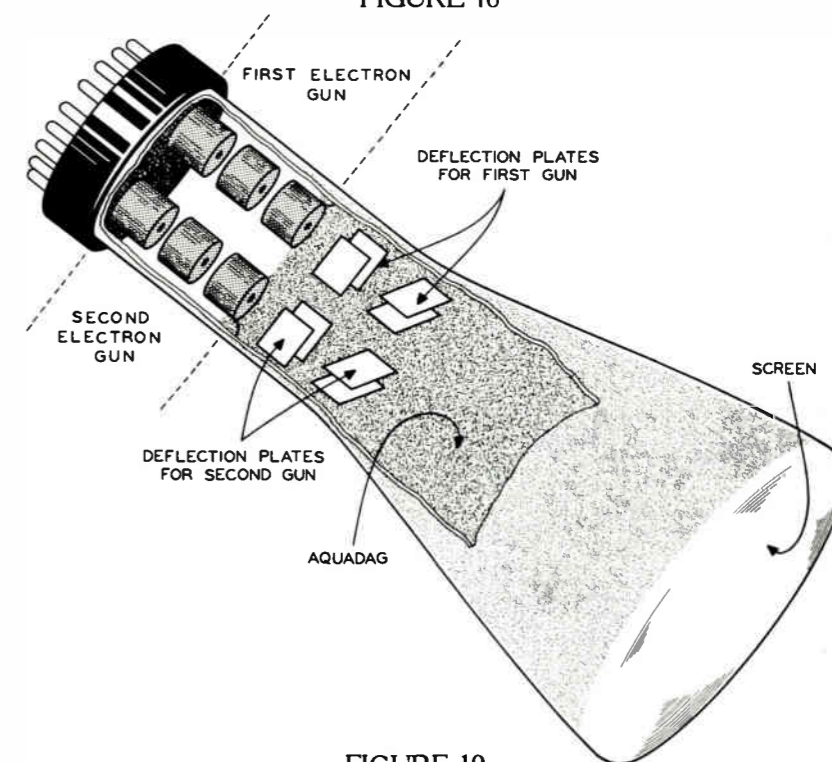
to the left as shown by the arrow. The horizontal deflection field aids the field around the electron on the right and cancels the field on the left of the electron, moving the electron to the left. The vertical deflection field aids the electron field on the bottom and cancels at the top, forcing the electron upward.

34. An ion trap magnet is used to bend the electron beam so it will strike the screen of an electromagnetic crt. The ions do not reach the screen, however, and ion spot burns are avoided.

35. An ion trap magnet is adjusted by moving it closer to or farther away from the crt screen while rotating it. The ion trap is adjusted until the image on the screen is brightest over the full face of the tube.

36. (a) electrostatic deflection.

37. False -- Electromagnetic deflection is used in most television receivers.

38. (1) No bulky external coils are used; (2) low deflection power is required because this type of crt is a voltage operated device; (3) higher deflection frequencies and more complex waveforms can be applied without being distorted or defocused; (4) simpler deflection circuits are needed.

39. An intensifier anode is used in some electrostatic crt's to increase the brightness of the image on the crt screen without a loss of deflection sensitivity.

40. Multi-gun crt's are used to display more than one image on the screen at any one time.

41. Handle the crt with care to prevent breakage or implosion. Support large crt's at the large end rather than the neck. Don't force connectors onto the base pins, or try to bend the pins to fit a faulty connector.

QUESTIONS

LESSON CODE

2206A

Example: A pulley is a

A
B
C
D

(A) young hen. (B) railroad car. (C) heating apparatus. (D) mechanical device.

1.
A B C D
In a crt, the unit that supplies the electrons, forms them into a beam, directs them toward the screen, and accelerates them so they hit the screen at a high velocity is called the
(A) deflection yoke. (B) electron gun. (C) ion trap. (D) control grid.

2.
A B C D
To shift the position of the beam in an electrostatic deflection crt, varying electric potentials are applied to the
(A) aquadag coating. (B) deflection plates. (C) deflection yoke. (D) ion trap.

3.
A B C D
The aquadag coating on the inside of a crt envelope is used to
(A) focus the electron beam. (B) deflect the electron beam across the screen. (C) collect electrons after the beam electrons strike the phosphor screen. (D) reflect screen light forward to increase the light output.

4.
A B C D
What is the deflection sensitivity if a deflection voltage of 3 volts dc causes the spot to move a distance of 0.3 inch on the screen of a crt?
(A) 10,000 inches per volt dc, (B) 1.0 volt dc per inch, (C) 0.9 inch per volt dc, (D) 0.1 inch per volt dc.

5.
A B C D
In a crt that uses electromagnetic deflection, which of the following electrodes normally is not used?
(A) deflection plates, (B) deflection yoke, (C) an internal conductive coating, (D) an electron gun.

6.
A B C D
Electromagnetic focusing is accomplished by applying dc current to
(A) a focus coil. (B) a focus anode. (C) an accelerating anode. (D) a control grid.

7.
A B C D
The characteristic of a phosphor to emit light for a certain length of time after it is struck by an electron is called
(A) persistence. (B) luminescence. (C) fluorescence. (D) deflection sensitivity.

8.
A B C D
The crt shown in Figure 17 uses
(A) electromagnetic focusing and deflection. (B) electrostatic focusing and electromagnetic deflection. (C) electromagnetic focusing and electrostatic deflection. (D) electromagnetic focusing and deflection.

9.
A B C D
In some crt's, the beam electrons are accelerated after they leave the deflection region by a high positive voltage on the
(A) ion trap. (B) intensifier anode. (C) control grid. (D) deflection plates.

10.
A B C D
A multi-gun crt would be used in an oscilloscope to
(A) produce more than one trace at a time. (B) provide a brighter image on the crt screen. (C) eliminate the need for deflection plates. (D) eliminate the need for focus coils.
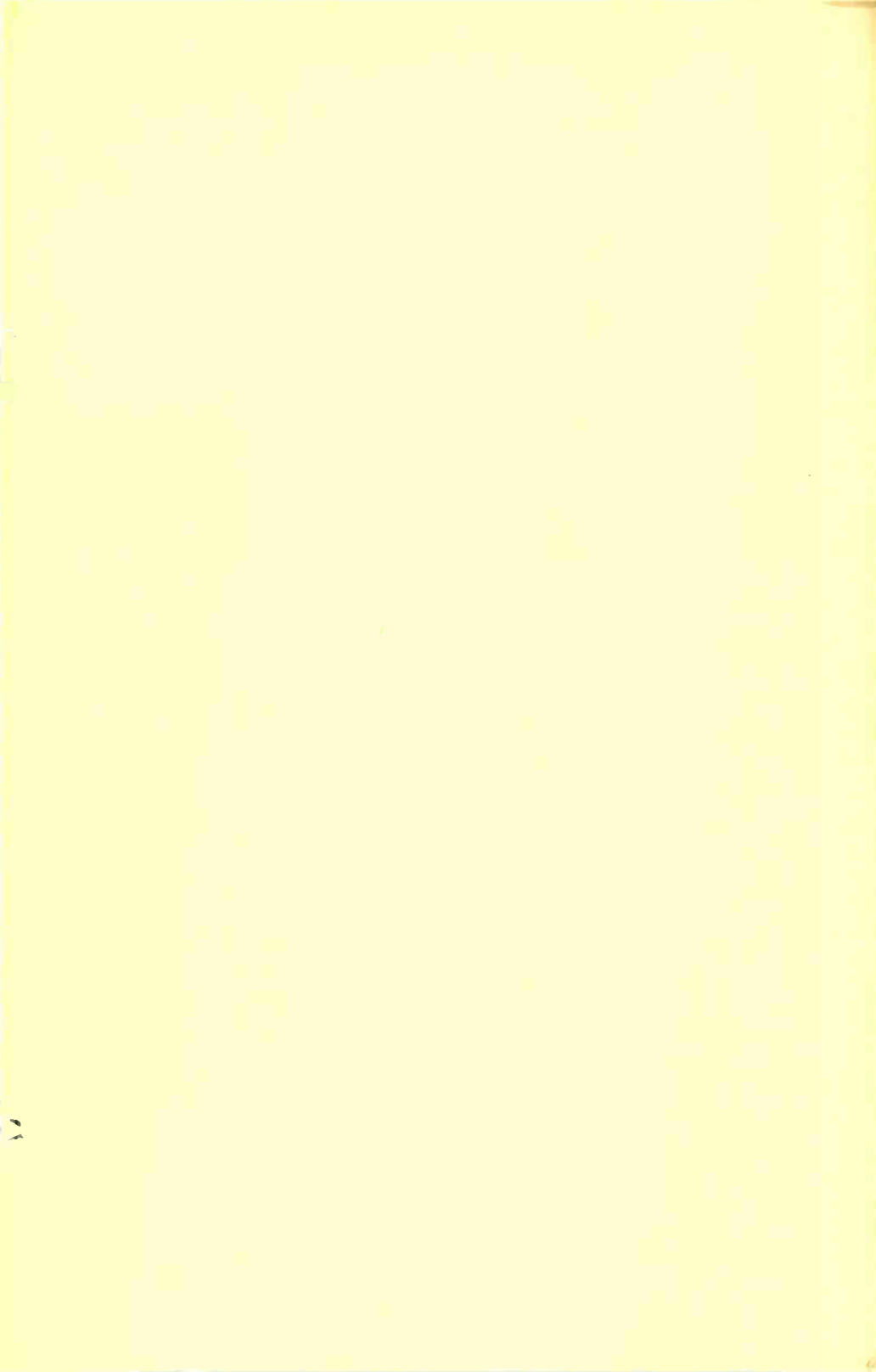
DEDICATED TO PROGRESS THROUGH EDUCATION

Oscilloscopes

Lesson 2209A

DeVRY Technical Institute

CHICAGO   TORONTO

OSCILLOSCOPES

Revised 1967

OPPORTUNITY
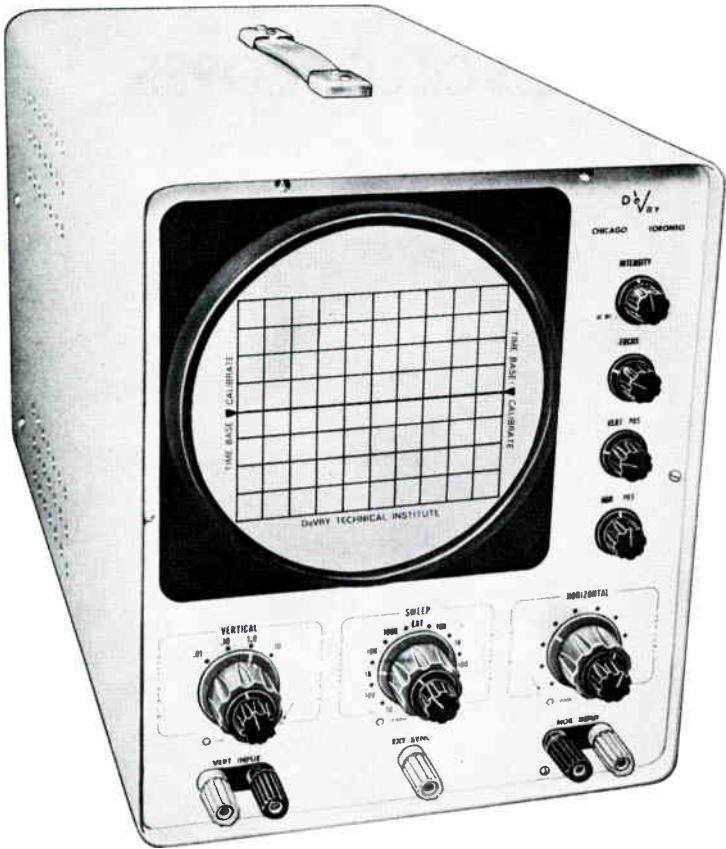
A modern portable oscilloscope with a screen diameter of 5 inches. The oscilloscope is a versatile instrument widely used throughout the electronics industry.

DeVRY Tech Photo

OSCILLOSCOPES

CONTENTS

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Experience shows that success is due less to
ability than to zeal. The winner is he who
gives himself to his work, body and soul.
                           -- Charles Burton

OSCILLOSCOPES

A modern CATHODE RAY OSCILLOSCOPE (CRO) is a very useful electronic test instrument. It uses a cathode ray tube to display a "picture" of the voltage applied to its input. Thus, it allows an operator to view the waveforms of currents or voltages generated by electronic equipment.

The screen of an oscilloscope can be calibrated to measure voltage. Also, by applying signals to its vertical and horizontal inputs and studying the resultant waveforms, it is possible to measure frequency and phase. And because the waveform of the signal under test is displayed on the screen, it is possible to check for signal distortion. Because of these many features, the oscilloscope, or scope, as it is often called, is one of the most useful test instruments available to the electronics technician.

GENERAL DESCRIPTION OF THE OSCILLOSCOPE

Most cathode ray oscilloscopes in use today can be represented by the block diagram of Figure 1. Here we see the basic scope sections and their relation to each other. In this diagram the oscilloscope is divided into six sections: the cathode ray tube, the high voltage power supply, the low voltage power supply, the vertical amplifier, the horizontal amplifier, and the horizontal sweep section. All of these sections have one end purpose -- to display a pattern on the face of the cathode ray tube.

*   *   *

1. Name the six sections that make up a general purpose oscilloscope. *CRT, High & Low voltage power supplies, Vert. & Horiz. Amp., and Horiz. Sweep circuit.*
2. What is the end purpose of all the sections of Figure 1? *To display a pattern on the screen.*

*   *   *

The signal under test is usually applied to the vertical am-
plifier section. The main function of this section is to am-
plify the test signal. After the test signal is amplified, it
is applied to the vertical deflection system of the crt. This
signal causes the trace to move up or down on the screen of
the crt.

The signal applied to the horizontal amplifier section is
supplied by the sweep section of the oscilloscope or by an
external source. The horizontal amplifier section supplies
an amplified signal to the horizontal deflection system of the
crt. This signal causes the trace to move from side to side
on the screen of the crt.

*   *   *

3.   In a general purpose oscilloscope, the voltage to be observed
     is usually applied to the (a) electron gun, (b) vertical deflec-
     tion system, (c) horizontal deflection system.

4.   What is the purpose of the horizontal deflection system of a
     crt?

*   *   *

For many tests, it is convenient to deflect the electron beam
at a uniform rate and constant frequency from left to right
across the screen. For this purpose the horizontal sweep
circuit supplies a sawtooth voltage at a controlled frequency.
When the sawtooth voltage is amplified by the horizontal
amplifier and applied to the horizontal deflection system,
the beam is deflected from left to right across the screen
at a constant speed.

*   *   *

5.   The signal from the horizontal sweep section is applied to the
     (a) horizontal amplifier, (b) vertical amplifier.

*   *   *

In Figure 1, switch SW$_1$ makes it possible to employ either the vertical amplifier output or a signal from the EXT SYNC terminal as a synchronizing voltage for the horizontal sweep section. Switch SW$_2$ connects either the output of the sweep section or the signal at the HORIZ INPUT terminal to the horizontal amplifier section.

The high and low voltage power supplies provide the dc operating voltages for the crt and the other sections of the scope. In Figure 1 the power supply blocks are joined to the sections they supply by dashed lines.

                    *   *   *

6.   Usually an oscilloscope contains both a high and a low voltage
      power supply. True or False?

                    *   *   *

To fully understand the operation of an oscilloscope it is necessary to study the functions of the different scope sections in more detail. Let's begin with the cathode ray tube, and then see how the other sections are used to provide the desired image on the screen of this tube.

THE CATHODE RAY TUBE

Most general purpose oscilloscopes use cathode ray tubes designed for electrostatic focus and deflection. This type of tube offers several advantages over crt's that use electromagnetic lines of force to focus and deflect the electron beam. For one thing, no bulky deflection or focus coils are needed; the entire focusing and deflection system is contained within the tube envelope. Also, simpler circuits can be used to produce the deflection signals.

Because of these features, an electrostatic crt and its deflection system weighs less than a comparable electromagnetic crt with its heavier, bulkier deflection system. A light, portable oscilloscope can be built with an electrostatic crt.

*   *   *

7. Why is an electrostatic crt more suitable than an electro-
   magnetic crt for light, portable oscilloscopes? *It Doesn't*
   Have the added weight of the deflection
   and focus coils.

*   *   *

Figure 2 shows the relative positions of the electrodes in
an electrostatic crt. The base of the crt is assumed to be
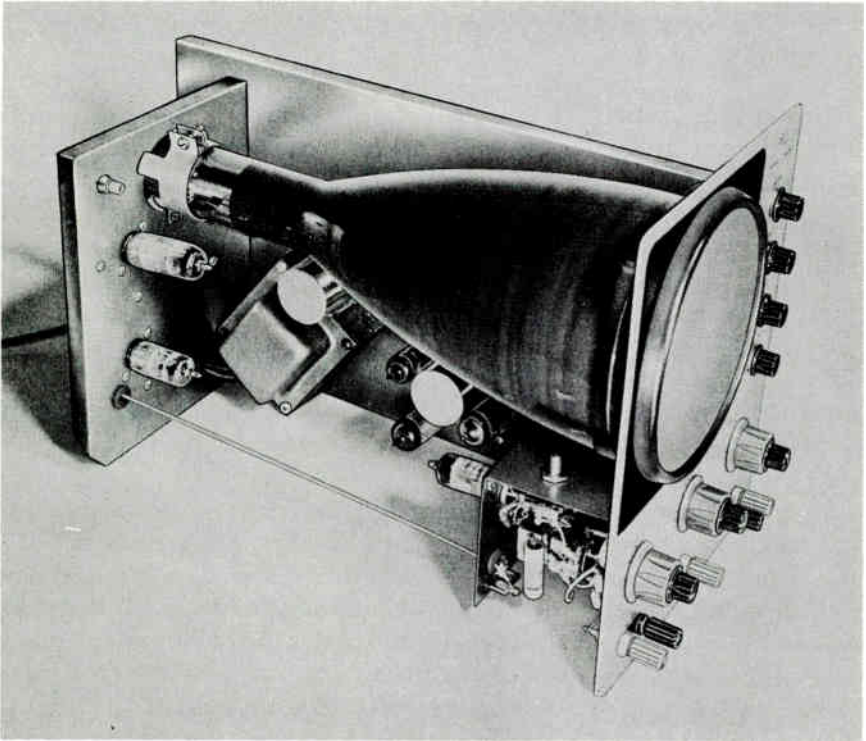
A cathode ray tube serves as an indicating device in an oscilloscope. By tracing a light pattern on
the screen of the cathode ray tube, the oscilloscope displays the waveform of the voltage under test.
DeVRY Tech Photo

at the left, and if shown the screen would be at the right.
The cathode, control grid, focus anode and accelerating
anode are shown connected to different points on a voltage

divider to give an idea of the relative voltages at which they operate.

The heater, cathode, control grid, focus anode and accelerating anode make up the electron gun. The heater is covered by the cathode which, in turn, is covered by a cylindrical control grid. The focus and accelerating anodes are also cylinders which lie along the tube axis. There are openings or holes in the ends of the control grid, the focus anode, and the accelerating anode. The electron beam is formed as it passes through these openings on the way to the crt screen.

The cathode emits electrons when heated by the filament. The control grid, as in most tubes, operates at a negative potential. In Figure 2 the grid is connected to a more negative point than the cathode on the voltage divider. Varying the bias voltage on the grid varies the number of electrons forming the beam and striking the crt screen. This, in turn, controls the brightness or intensity of the spot on the screen. The **INTENSITY CONTROL** or **BRIGHTNESS CONTROL** varies the dc voltage between the cathode and control grid to vary the brightness of the image on the screen. This control is usually found on the front panel of the scope.

The electrons which pass through the control grid are attracted by the more positive focus anode. Electrons traveling along the tube axis pass through the focus anode and are accelerated by the more positive potential of the accelerating anode. There is a strong electrostatic field between these two electrodes because of the difference of potential between them. This field provides electrostatic focusing of the beam. There is a slight focusing action between the focus anode and the control grid, but most of the focusing takes place between the focus anode and accelerating anode.

You can focus the electron beam to produce a small spot on the crt screen by varying the potential difference between the focus anode and accelerating anode. In most scopes, the **FOCUS CONTROL** is a potentiometer that varies the potential

on the focus anode. This control is usually found on the
front panel of the scope.

                    *   *   *

8.   In most general purpose oscilloscopes, the brightness or in-
      tensity of the spot is varied by varying the bias on the crt.
      True or False?

9.   A common method of focusing the pattern on the screen of a
      scope is to vary the voltage on the (a) control grid, (b) focus
      anode, (c) cathode of the crt.

                    *   *   *

In some oscilloscopes, the potential on the accelerating
anode can be changed over a small range to keep the beam
in focus at all positions on the crt screen. The potentiom-
eter that serves this purpose is called the ASTIGMATISM
CONTROL or SPOT SHAPE CONTROL. This control may
be found on the front panel in some scopes. However, an
astigmatism control does not require frequent adjustment,
and some manufacturers mount it on the chassis or on the
rear of the cabinet.

After the electrons leave the electron gun region they enter
the deflection region. This region contains two sets of de-
flection plates which are used to bend the electron beam.
The outputs of the vertical and horizontal amplifiers are
applied to the deflection plates. Varying potentials from
the vertical and horizontal sections, applied to the vertical
and horizontal deflection plates, move the beam from its
path along the tube axis.

The voltage changes on one set of plates cause the beam to
move vertically. The voltage changes on the other set of
plates cause the beam to move horizontally. The position
of the spot on the crt screen depends on the voltages applied
to each set of plates.

*   *   *

10. How is the electron beam deflected to trace an image on the screen of an electrostatic crt? *By varying the potential on the deflection plates.*

*   *   *

The deflected electron beam strikes the fluorescent screen, which is a coating of phosphors on the inner surface at the large end of the tube envelope. The phosphors emit light whenever the electron beam strikes them. The type of phosphors used on the screen determines the color of the display and the persistence, or the length of time the image is visible.

POWER SUPPLIES

An oscilloscope has both a high voltage and a low voltage supply. Each of these supplies contains a rectifier and filter to provide ripple-free dc voltages for the various sections of the scope.

Figure 3 shows a typical arrangement of the high and low voltage supplies. A single transformer is used to provide the ac voltages for both power supplies. The on-off power switch and fuse are in series with the primary winding of the transformer. The secondary windings include a high voltage winding and three filament windings.

High voltage winding S_3 is tapped to provide ac voltages for both rectifier tubes. Notice that V_1 and the upper section of the secondary form a conventional full wave rectifier. R_1, C_1 and C_2 form a pi-type filter to smooth the output of this rectifier.

The low voltage supply develops about 300 to 400 volts. The current flow is from ground through the load to the upper end of C_2, and through R_1 and the conductive section of V_1 to the more positive tap on the secondary. Thus, the low voltage supply provides a positive voltage as indicated. As

shown by the dashed lines in Figure 1, this voltage is applied

An oscilloscope is used as an indicator in this test setup, which is used to check the characteristics of magnetic tape cores.

Courtesy Arnold Engineering Co.

to the vertical and horizontal amplifiers, to the horizontal sweep section, and to various elements of the crt.

*   *   *

11. The output of the low voltage power supply in Figure 3 is negative with respect to ground.   True or False?

*   *   *

The high voltage power supply uses a directly heated half wave rectifier tube, V_2.   The ac voltage for this supply is obtained between the ground tap and a point near the lower end of high voltage secondary S_3. R_2, C_3 and C_4 form a

pi-type filter for the high voltage supply.

Notice that the filament of V_2 is connected to the lower end of S_3, and the plate connects through the filter and load components to ground. Thus, the tube conducts when the ground tap is positive with respect to the lower end of S_3. The rectified current flows from the lower end of the secondary through V_2 and the filter and load to ground. This produces a negative output voltage as indicated in Figure 3. The value is about -800 to -1500 volts. As shown in Figure 1, this voltage is applied to the crt.

Most scopes use a negative high voltage supply as illustrated in Figure 3. The accelerating anode is operated at or near ground potential, and a high negative potential is applied to the cathode. (Making the cathode negative with respect to the anode is the same as making the anode positive with respect to the cathode.)

With this arrangement there is only a small difference of potential between the accelerating anode and the deflection plates, which operate at relatively low voltages. A large difference of potential here would present insulation problems in mounting the electrode. It would also create a strong electric field between the accelerating anode and the deflection plates which would affect the beam and distort the pattern on the screen.

*   *   *

12. To what part of a general purpose oscilloscope is the high voltage power supply connected?

13. The output of the high voltage supply in Figure 3 is (a) positive, (b) negative with respect to ground.

*   *   *

Filament winding S_1 in Figure 3 supplies heater current for all the tubes except the crt and the two rectifier tubes.

Winding S_4 supplies the heater current for the crt. S_2 supplies the heater current for low voltage rectifier V_1.

Filament voltage for high voltage rectifier V_2 is obtained from the lower tapped portion of secondary S_3. Although the voltage across the entire secondary may be well over 1000 volts, the voltage across this small section of the winding is only a fraction of the total. For example, the winding may be tapped to provide 6 volts or less, which is typical filament voltage for rectifier tubes used in this service.

AMPLIFIER SECTIONS

An oscilloscope uses an electron beam to draw pictures of voltages applied to its input terminals. It does this by applying signals to the deflection system of a crt, thus causing the beam to trace a pattern of light on the screen. The signals fed into the scope are usually too small in amplitude to deflect the electron beam directly. Therefore the signals must be amplified before they are applied to the deflection plates.

Both the horizontal and vertical deflection systems contain amplifiers. These amplifiers increase the sensitivity of the cathode ray tube by increasing or amplifying the signals applied to them.

                    *   *   *

14. What are the purposes of the horizontal and vertical deflection amplifiers in an oscilloscope? *They increase the amplitude of the signals so they can be applied to the deflection plates.*

Vertical Deflection Amplifier

Usually, the unknown test signal is applied to the vertical amplifier section of the oscilloscope. The vertical amplifier must provide high gain so that low-amplitude signals can be observed, or small parts of a signal can be studied in detail.

A good oscilloscope should be able to reproduce voltage waveforms with a minimum of distortion. To pass signals with minimum distortion, the vertical amplifier must have a wide frequency response. If the amplifier does not have
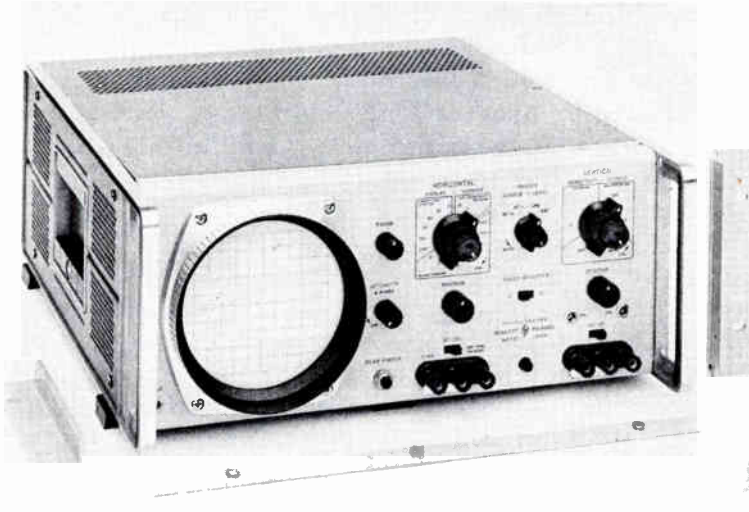
The oscilloscope shown above can be mounted permanently in a rack or equipment cabinet. This scope has a bandwidth from dc to 450 kHz. It can be used in the laboratory or on production lines.
Courtesy Hewlett-Packard Co.

good frequency response it does not amplify all frequencies by the same amount, and the pattern on the screen may not be a true picture of the signal under test.

A scope should have a high input impedance and low shunt capacitance. These features are necessary for the proper reproduction of an input signal. The high input impedance prevents the scope from loading the test circuit. The low shunt capacitance prevents distortion of signal waveforms.

*   *   *

15. To produce a waveform of adequate size when small signal voltages are being viewed, the vertical amplifier of an oscilloscope should provide high gain. True or False?

16. Why is a wide frequency response necessary for the vertical amplifier of an oscilloscope? *So the trace on the screen will be an accurate picture of the signal*

17. It is desirable for the vertical amplifier of a scope to have high input impedance and low shunt capacitance.   True or False?

*   *   *

Figure 4 shows the vertical amplifier section of an oscilloscope. V_1 is a high gain triode amplifier. The test signal is coupled from the input terminals through C_1 and potentiometer R_1 to the grid of V_1. R_1 makes it possible to vary the amplitude of the input signal, and is often referred to as a VERTICAL AMPLITUDE CONTROL or VERTICAL GAIN CONTROL.

The amplified signal at the V_1 plate is further amplified by a push-pull stage (V_2V_3) and then applied to the vertical deflection plates. The push-pull stage serves as a phase inverter, voltage amplifier, positioning circuit, and push-pull driver for the deflection plates.

A signal coupled from the plate of V_1 through C_2 to the grid of V_2 causes a change of V_2 plate current. The change of plate current causes a change in voltage across cathode resistor R_6. The change in R_6 voltage is in phase with the signal voltage applied to the grid of V_2. R_6 is a common cathode resistor for both V_2 and V_3. The grid of V_3 is placed at signal ground potential by capacitor C_3, so any signal voltage across R_6 is applied between the grid and cathode of V_3.

Let's see how this arrangement provides the 180° out-of phase signals necessary for push-pull operation of V_2 and V_3. On the positive alternation of the V_2 grid signal, the V_2 plate current increases and causes a larger voltage across R_6. This makes the cathode of V_3 more positive with respect to ground. Making the cathode of V_3 more positive is the same as applying a negative-going voltage to

its grid. Therefore, the plate current of V_3 decreases.

A negative signal alternation at the grid of V_2 cause a de-crease of V_2 plate current and a decrease in voltage across R_6. The cathode of V_3 becomes less positive. This is the same as making the grid of V_3 less negative, so the V_3 plate current increases.

To summarize the action, increases in V_2 plate current are accompanied by decreases in V_3 plate current, and decreases in V_2 plate current are accompanied by increases in V_3 plate current. Thus, the V_2V_3 stage provides push-pull operation. The amplified signals at the plates of V_2 and V_3 are applied to the vertical deflection plates.

R_5 serves as a VERTICAL POSITIONING CONTROL. Chang-ing the setting of R_5 varies the dc bias on the grid of V_3, and thus varies the dc plate current and plate voltage of V_3. Since the plates of V_2 and V_3 are directly coupled to the deflection plates, a change in the plate voltage of V_3 causes a change in the dc voltage on the deflection plate connected to V_3. In the case of a vertical deflection amplifier, this shifts the position of the beam vertically on the screen.

*   *   *

18. In the circuit of Figure 4, the signal voltage at the plate of V_2 is (a) in phase, (b) 180° out of phase with the signal volt-age at the plate of V_3.

19. What function does R_5 serve in the circuit of Figure 4?
    vert Positioning

*   *   *

Horizontal Deflection Amplifier

In most scopes the horizontal amplifier circuit is similar to the vertical amplifier circuit. Vertical deflection signals are fed through one amplifier such as that of Figure 4 to the vertical deflection plates. Horizontal deflection signals are

fed through the other amplifier, which is also a circuit like that of Figure 4, to the horizontal deflection plates.

When used as a horizontal deflection amplifier, the plates of V_2 and V_3 in Figure 4 connect to the horizontal deflection plates. Thus, signals applied to the input cause the beam to sweep left and right across the screen. R_5 again serves
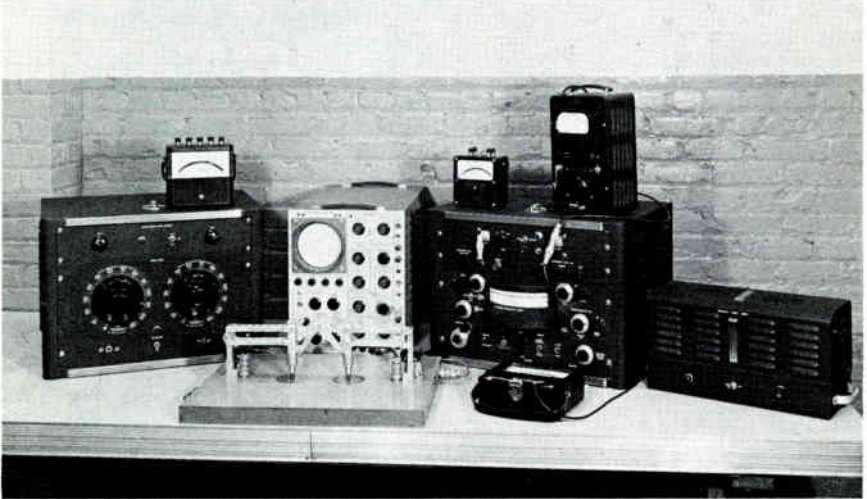
The oscilloscope is a key instrument in many types of measurements. Here you see a scope flanked by power supplies and meters in a setup for testing magnetic materials.

Courtesy Arnold Engineering Co.

as a positioning control by varying the dc plate voltage of V_3. In a horizontal amplifier this would be the HORIZONTAL POSITIONING CONTROL. R_1 serves as the HORIZONTAL AMPLITUDE CONTROL or HORIZONTAL GAIN CONTROL.

Usually, the horizontal amplifier section is not required to have as much gain or as wide a frequency response as the vertical section. However, the horizontal gain should be great enough to sweep the beam across the entire screen, with enough gain left so that the pattern can be expanded to study small sections of a waveform.

The internal horizontal sweep frequencies of a general pur-

pose scope are usually less than 700 kHz. The response of this section is wide enough to pass these frequencies with little distortion.

*   *   *

20. If the circuit of Figure 4 is used as a horizontal deflection amplifier, what is the function of R_1?

21. In a general purpose oscilloscope the gain of the horizontal amplifier is normally (a) greater, (b) less than the gain of the vertical amplifier.

*   *   *

Attenuator Networks

If the signal applied to the grid of a vertical or horizontal amplifier stage is too large, it overdrives the tube. This causes distortion in the output signal waveform, and the pattern on the scope screen is not a true picture of the test signal. Overdriving is prevented by limiting the signal amplitude to a level that can be easily handled by the amplifier. In the amplifier of Figure 4, this is accomplished by potentiometer R_1. By varying the setting of R_1, it is possible to feed some desired fraction of the input signal to the grid of V_1.

When signal level is reduced in any manner, the action is called ATTENUATION. Any component or network of components used for this purpose is called an ATTENUATOR. A simple form of attenuator is a potentiometer such as R_1 of Figure 4.

Referring to Figure 4, the test signal is applied across the entire resistance element of R_1. The amount of the signal applied to the amplifier depends on the setting of the movable arm. The entire resistance element of R_1 is across the input terminals regardless of the setting of the movable arm. Thus, the scope presents a fairly constant load to the

signal source under test. If the resistance of the poten-
tiometer is high, the scope does not load down the test cir-
cuit to any great extent.

A simple potentiometer arrangement has one serious draw-
back when used as an attenuator. It combines with circuit
capacitances to form a network that attenuates some fre-
quencies more than others. This results in a form of dis-
tortion called **FREQUENCY DISCRIMINATION.**

Figure 5 shows a potentiometer in the grid circuit of a tube.
Dashed line capacitor C_1 represents the capacitance between
the movable arm and lower terminal of potentiometer R_1.
This includes the capacitance of the potentiometer leads,
the wiring capacitance in the grid circuit, and the grid-
cathode capacitance of the tube. Capacitor C_1 is in series

with the upper portion of the
potentiometer (R_{1A}), and in
parallel with the lower portion
(R_{1B}). C_1 and R_{1A} form a
low-pass network which atten-
uates high frequencies more
than low frequencies, and thus
produces frequency discrimi-
nation.

There is no way to completely
do away with C_1, so the solu-
tion to the problem is to deli-
berately attenuate the low fre-
quencies to match the attenua-
tion of the highs. One way to
do this is to connect a capaci-
tor across the R_{1A} section of
the potentiometer. This capa-
citor and R_{1B} form a high-pass

This wide band, high sensitivity scope has a
vertical attenuator plus vertical gain control
to attenuate the vertical input signal.
Courtesy Jackson Electrical Co.

network which compensates for the effect of the C_1R_{1A} low-
pass network. This is not practical with a simple poten-
tiometer arrangement, since the capacitance must be varied
every time the setting of the potentiometer is varied. How-

ever, it can be done very easily by using a switch type attenuator in place of the potentiometer.

Figure 6 shows how fixed resistors and capacitors may be used with a switch to form an attenuator. As the switch contact is moved from position 1 to position 2 and to position 3, smaller portions of the input signal are applied to the grid of V_1. A capacitor is placed in parallel with each resistor. The value of each capacitor is chosen to compensate for the distributed capacitance that exists at that position.

*   *   *

22. Why are capacitors usually connected across the resistors in an attenuator such as that of Figure 6? *To attenuate the low frequencies in a manner the attenuator so the high frequencies.*

A switch-type attenuator does not give smooth, continuously variable control over the signal applied to the amplifier input. The amplitude of the signal coupled to the amplifier varies in steps as the attenuator is switched from one position to the next. In fact, an attenuator of this type is often referred to as a STEP ATTENUATOR. For continuously variable operation, a potentiometer is often used in addition to the step attenuator.

Figure 7 shows an input circuit that offers high input impedance, good frequency response, and smooth control over the signal applied to an amplifier. This network is composed of a step attenuator, a cathode follower stage, and a continuously variable gain control. Many oscilloscopes use similar systems in the vertical input circuit.

The step attenuator changes the amplitude of a test signal applied to the amplifier in large steps. The compensating capacitors across the attenuator resistors overcome frequency discrimination. The signal from the step attenuator is applied to the grid of V_1. The output of this stage is taken

across cathode resistor R_4. This signal is fed through coupling capacitor C_4 to gain control R_5. The gain control supplies a continuously variable signal to the V_2 stage.

In a cathode follower such as V_1, the output signal (from cathode to ground) is in phase with the signal applied to the grid. There is a slight loss in the amplitude of the signal, because a cathode follower always has a signal voltage gain of less than 1. However, this circuit offers a high input impedance to the test circuit. This high impedance helps to prevent loading of a test circuit. Also, the low output impedance reduces the effects of shunt capacitance.

*   *   *

23. The signal at the slider of R_5 in Figure 7 is (a) in phase, (b) 180° out of phase with the signal at the grid of V_1.

24. The purpose of V_1 in Figure 7 is to provide a large voltage gain. True or False?

*   *   *

HORIZONTAL SWEEP CIRCUITS

Most oscilloscopes have an internal circuit for developing a signal that can be applied to the horizontal deflection plates. This signal voltage is used to sweep the electron beam across the screen. The circuit that produces this voltage is called the **HORIZONTAL SWEEP CIRCUIT.** The sweep voltage is applied to the horizontal amplifier section at the same time a test signal is applied to the vertical amplifier section.

To use an oscilloscope as a graphical measuring device, the electron beam should be swept horizontally across the screen in a straight line at a linear rate. The test signal is then represented on the crt screen as a graph. That is, the changes in amplitude of the test signal are "plotted" with respect to time. In effect, the scope uses a beam of electrons to draw a waveform on the screen just as you use

a pencil to draw a waveform on a piece of paper.

So that equal amounts of horizontal deflection represent
equal intervals of time, a LINEAR sweep is required. The
linear sweep voltage used in an oscilloscope changes uni-
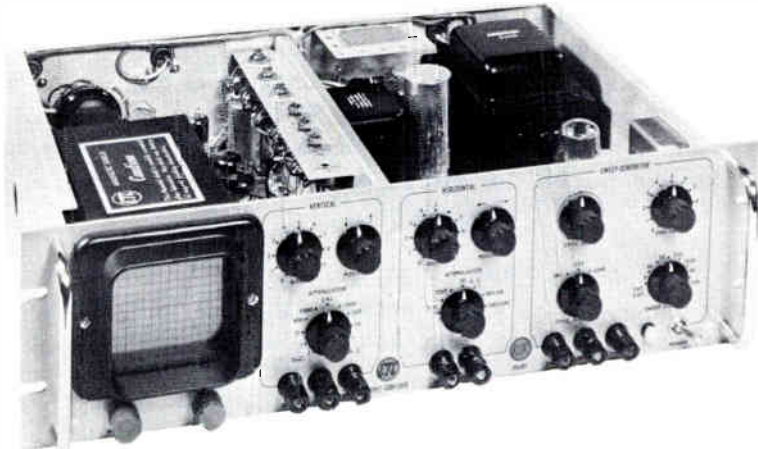
An oscilloscope designed for mounting in a rack of equipment. Notice how the controls for the
vertical amplifier, horizontal amplifier and sweep generator are grouped for convenience on the
panel.

Courtesy Electron Tube Corp.

formly from minimum to maximum and then drops instantly
to minimum and repeats the cycle. This voltage is applied
to the horizontal deflection plates. It causes the electron
beam to move horizontally at a constant speed, return
rapidly to the starting point, and then begin another sweep.

*   *   *

25. A linear sweep is required in an oscilloscope so that equal
     amounts of horizontal deflection represent equal periods of
     time. True or False?

*   *   *

A common type of signal used to produce a linear sweep is

a SAWTOOTH wave. Figure 8 shows a sawtooth wave. The slow, linear rise from minimum to maximum occurs from point A to point B. The rapid decrease from maximum to minimum occurs from point B to point C. A second saw-tooth cycle begins at point C, increasing slowly to maximum and then dropping rapidly to minimum. The slow, rising portion of the sawtooth produces the forward or scanning motion of the beam. The rapid decrease from maximum to minimum produces the return or retrace motion.

The most common method of developing a sawtooth voltage is to charge a capacitor through a high resistance, then discharge it through a low resistance. The capacitor charges slowly through the high resistance, as represented by the slowly rising voltage between points A and B of the sawtooth of Figure 8. Then, the capacitor is discharged quickly through a low resistance. This is represented by the rapid fall in voltage between points B and C in Figure 8.

*   *   *

26. The type of waveform that is commonly used to produce a linear sweep in an oscilloscope is a (a) sine wave, (b) saw-tooth, (c) straight line.

27. Figure 8 is the voltage waveform produced by charging a ca-pacitor through a high resistance and discharging it through a low resistance. True or False?

*   *   *

Figure 9 shows one circuit that can be used to produce a sawtooth voltage. The tube in this circuit is a gas-filled triode, or thyratron. As we shall see, it permits a sawtooth forming capacitor to charge through a high resistance, and then fires to form a low resistance discharge path for the capacitor. The sawtooth forming capacitor (C_3, C_4 or C_5) is selected by switch SW_1. The resistance through which the capacitor charges is R_4, a variable resistor in the V_1 plate circuit.

Suppose the circuit is turned on, and SW_1 is in the position shown. R_2 and R_3 form a voltage divider between B+ and B-, and the voltage across R_3 makes the cathode of V_1 positive with respect to ground. The grid returns to ground through R_1, so the voltage across R_3 serves as a bias which prevents V_1 from firing at low plate voltages. Bypass capacitor C_2 keeps the voltage across R_3 constant.

With V_1 cut off, capacitor C_4 begins to charge through R_4 toward the B+ voltage. When the voltage across C_4 reaches the ionizing potential of V_1, the tube fires and forms a low resistance across C_4. C_4 discharges rapidly, until the voltage across C_4 is so low that it cannot keep the tube ionized. Then V_1 de-ionizes, and C_4 starts to charge through R_4 to begin another cycle.

Figure 10 shows the changes in voltage across the sawtooth forming capacitor. The curved dashed line is the charge curve of the capacitor. The ionization and de-ionization points of the thyratron are indicated. The output wave is shown as a solid line having a sawtooth shape.

*   *   *

28. In the sawtooth generator of Figure 9, the slow, linear rise of the sawtooth occurs when V_1 is (a) conducting, (b) cut off.

*   *   *

The resistance of R_4 and the capacitance selected by SW_1 determine the rate at which the voltage rises from minimum to the ionization point. Thus, the settings of SW_1 and R_4 determine the frequency of the sawtooth. SW_1 serves as a COARSE FREQUENCY CONTROL, which changes the frequency in large steps. R_4 is a FINE FREQUENCY CONTROL or FREQUENCY VERNIER CONTROL, permitting a continuous variation of frequency in the range selected by SW_1. The sawtooth is coupled through C_6 to the horizontal amplifier of the scope.

*   *   *

29. At a given setting of SW_1 in Figure 9, what do you suppose
    would happen to the sawtooth frequency if R_4 was set to a
    higher resistance? *the frequency would decrease*

*   *   *

A thyratron sawtooth generator is suitable for low sweep
rates. However, for higher sweep rates a multivibrator
sweep generator is preferred. Most scopes manufactured
today use multivibrators to produce the linear sweep volt-
age. A multivibrator is basically a square wave generator,
but its output can be shaped into a sawtooth by a capaci-
tor.

Figure 11 shows the circuit of a multivibrator used to pro-
duce a sawtooth output. With the circuit in operation, V_1
and V_2 alternately conduct and cut off. The circuit time
constants are selected so that V_2 is held in cutoff much
longer than V_1. Sawtooth forming capacitor C_6 charges
through R_5 toward the B+ voltage when V_2 is cut off. This
produces the slow, linear rise of the sawtooth.

When V_2 conducts, it forms a low resistance in series with
R_3 to discharge C_6. The conduction time of V_2 is short,
producing a short retrace interval.

*   *   *

30. In the multivibrator sawtooth generator of Figure 11, the re-
    trace portion of the sawtooth occurs when V_2 is (a) conducting,
    (b) cut off.

*   *   *

The sawtooth frequency in Figure 11 depends on the settings
of SW_1 and R_4. Switch SW_1 selects one of four capacitors
in the coupling circuit between the plate of V_1 and the grid
of V_2. Thus, SW_1 serves as a coarse frequency control.

Variable resistor R_4 permits continuous adjustment of the
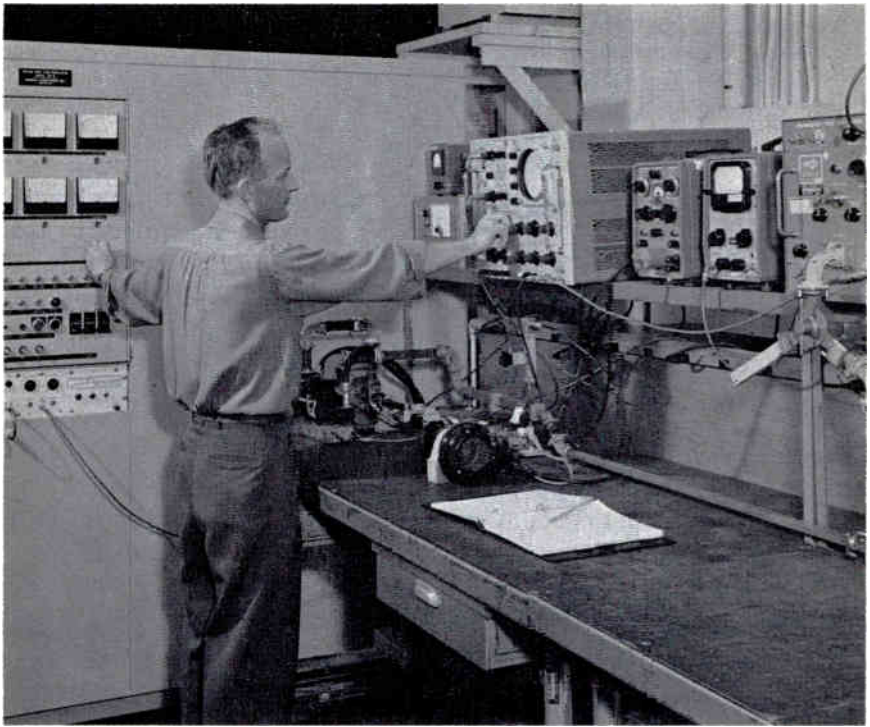
Oscilloscopes are valuable in checking waveforms in various sections of electronic systems. Here a technician observes an oscilloscope pattern in testing an experimental microwave setup such as those used in radar equipment.

Courtesy Hughes Microwave Div.

frequency within the range selected by SW_1. Thus, R_4 serves as a fine frequency control.

*   *   *

31. To produce a sawtooth waveform in the circuit of Figure 11, V_2 must be cut off for a longer period of time than it is conductive.   True or False?

*   *   *

SYNCHRONIZATION

In order for a stationary pattern to appear on the scope screen, there must be some exact relationship between the frequency of the test signal and the horizontal sweep frequency. If the frequencies of the test signal and the horizontal sweep voltage are exactly equal, one complete cycle of the test signal appears on the screen. If the frequency of the test signal is exactly twice the frequency of the horizontal sweep voltage, two complete cycles of test signal appear on the screen, and so on.

The proper phase relationships must also exist between the test signal and the sweep voltage. That is, the sawtooth sweep voltage must begin at exactly the same time the cycle of test signal voltage begins. When the phase relationship is right, the cycle of the pattern on the scope screen begins at the left of the screen and ends at the proper point at the right of the screen.

*   *   *

32. What two relationships between the test signal and the horizontal sweep voltage must be maintained to produce a stationary pattern on a scope screen?

*   *   *

Any change in the frequency or phase relationship causes the pattern to drift across the screen, or to break up into patterns that are not true pictures of the test signal waveform. The horizontal sweep generator tends to drift during operation. If there were no way to lock it in step with the test signal, the operator would have to constantly adjust the fine frequency control to hold the pattern stationary.

Most oscilloscopes include a means of synchronizing the sweep generator and test signal to avoid this problem. In Figures 9 and 11, a SYNCHRONIZING SIGNAL fed into the sync input terminal "trips" the oscillator so it begins a cycle

of oscillation at the exact time the signal to be viewed is beginning its cycle. The idea is to set the coarse and fine frequency controls for a stationary pattern with the desired number of cycles on the screen, and then apply the synchronizing voltage to hold the pattern stationary. Potentiometer R_1 in Figure 9 or 11 serves as a SYNC AMPLITUDE CONTROL, which may be advanced until the pattern remains stationary or "locks in" on the screen.

*   *   *

33. A synchronizing signal is normally applied to the (a) horizontal amplifier, (b) vertical amplifier, (c) horizontal sweep generator of an oscilloscope.

34. A sync signal replaces the horizontal sweep circuit in an oscilloscope. True or False?

*   *   *

The most common sync signal is the test signal itself. This sync signal is taken from the vertical amplifier section and applied to the sweep circuit. The sync signal triggers the sweep generator, causing the sawtooth to be in step with the test signal. The synchronizing sawtooth is, in turn, amplified by the horizontal amplifier section and applied to the horizontal deflection plates. This method of synchronizing is often referred to as internal synchronization.

Some scopes use the ac line as a sync source. Since the frequency of the ac line voltage is very closely regulated by the power company, the line voltage can be used as an accurate synchronizing standard for many scope applications.

In some cases it may be desirable to use some external source for synchronization. For example, the output of an accurate signal generator may be used as the sync signal. Most oscilloscopes have a set of binding posts or other external connections to which this external signal is applied.

A sync signal switching arrangement, or SYNC SELECTOR
SWITCH, is included in most scopes. This switch allows
the scope operator to select the desired sync signal source,
either internal or external. The sync amp control is adjusted
so that just enough sync voltage is used to trigger or fire the
horizontal sweep generator at the proper instant.

*   *   *

35. List three possible sources of sync voltage for an oscillo-
    scope. *Ics signal, A.C, Line, External
    Sync Generator.*

36. What is the purpose of the sync amplitude control in an oscil-
    loscope? *To adjust the amount of
    Sync signal applied to the horizontal
    oscillator.*

*   *   *

COMPLETE OSCILLOSCOPE SCHEMATIC

The oscilloscope has been discussed in block diagram form.
We have studied some typical circuits which make up these
blocks. Now let's look at a complete oscilloscope schematic
and see how the various sections work together to display a
waveform.

Figure 12 is the schematic diagram of a complete oscillo-
scope. This schematic includes all of the sections repre-
sented in the block diagram of Figure 1. V_1, V_2, V_3 and
V_4 and their related parts form the vertical amplifier. V_7,
V_8 and V_9 and their related parts make up the horizontal
amplifier. V_5 and V_6, with their related parts, form the
horizontal sweep generator. V_{11} and V_{12} are the rectifiers
for the low and high voltage power supplies, and V_{10} is the
cathode ray tube.

*   *   *

37. Name the six main sections of the oscilloscope of Figure 12,
    and indicate which tube or tubes is/are included in each.

*   *   *

The signal to be viewed is applied to the vertical input ter-
minals. With vertical atten-
uator switch SW_1 in the posi-
tion shown, the full input sig-
nal is coupled through capaci-
tor C_4 to the grid of V_1. As
explained for Figure 7, V_1 in
Figure 12 is a cathode follower
stage, and the output appears
across cathode resistor R_5.
This signal is coupled through
C_5 to potentiometer R_6, which
serves as the vertical ampli-
tude or vertical gain control.

From the slider of R_6, the
signal is fed to voltage ampli-
fier V_2. The amplified signal
at the plate of V_2 is coupled
through C_6 to the push-pull
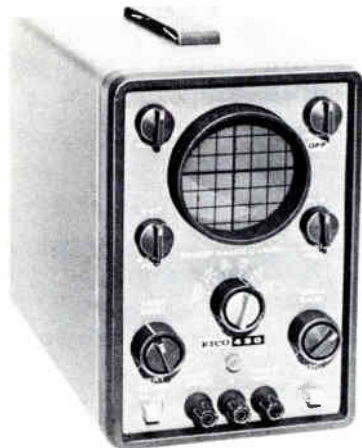
A 3" oscilloscope such as the one shown here
is ideal for use in field maintenance.
    Courtesy Electronic Instrument Co., Inc.

deflection amplifier. Due to the push-pull action, the volt-
age changes at the plates of V_3 and V_4 are equal and oppo-
site. These plate voltage changes are fed directly to the
vertical deflection plates of the crt. As explained for Fig-
ure 4, potentiometer R_{10} in Figure 12 serves as the verti-
cal positioning control.

*   *   *

38. Changing the setting of SW_1 from the position shown in Fig-
ure 12 to one of the other positions will cause the amplitude
of the signal applied to V_1 to (a) increase, (b) decrease.

39. In the circuit of Figure 12, a positive-going signal on one of
the vertical deflection plates is accompanied by a negative-
going signal on the other vertical deflection plate. True or
False?

*   *   *

The horizontal sweep generator in Figure 12 is a multivi-

brator similar to that of Figure 11. Tubes V_5 and V_6 alter-nately conduct and cut off at a frequency determined by the setting of coarse frequency switch SW_4 and fine frequency control R_{19}. Sawtooth forming capacitor C_{13} charges slowly through R_{18} when V_6 is cut off and discharges rapidly when V_6 conducts.

The multivibrator can be synchronized by either an internal or external sync signal. With sync selector switch SW_2 of Figure 12 in the INT position, a portion of the vertical input signal is fed from the plate of V_2 through R_{14} to the hori-zontal sweep generator. This vertical amplifier signal becomes the sync signal which is coupled through C_8 to potentiometer R_{15}, the sync amplitude control. By adjust-ing R_{15} we can feed a desired amount of the sync signal to the grid of V_5.

If switch SW_2 is set to the EXT position, an external syn-chronizing signal can be used to control the sweep generator. The sync source is then connected to the sync input termi-nals.

*   *   *

40.   What are the functions of SW_4 and R_{19} in Figure 12?

*   *   *

With horizontal input switch SW_3 in the INT position, the sawtooth from the horizontal sweep generator is fed to the horizontal amplifier. The horizontal amplifier in Figure 12 is similar to that of Figure 4. The sawtooth is coupled through C_{15} to potentiometer R_{20}, which serves as a hori-zontal amplitude or horizontal gain control. The signal from the slider of R_{20} is applied to the grid of V_7, which produces an amplified sawtooth at its plate.

The V_7 plate signal is coupled through C_{16} to the push-pull horizontal deflection amplifier. The signals at the plates of V_8 and V_9 are applied to the horizontal deflection plates of the crt. R_{23} serves as the horizontal positioning control.

To use an external source of horizontal sweep, horizontal input selector SW_3 is set to the EXT position. The external source is connected to the horizontal input terminals.

*   *   *

41. Which control would you adjust in the circuit of Figure 12 to increase the amount of horizontal sweep? R 20

42. Which control would you adjust in the circuit of Figure 12 to move the pattern from side to side on the screen?
R 23

*   *   *

As explained for Figure 3, the power supply in Figure 12 consists of a high voltage section and a low voltage section.

A modern general purpose oscilloscope which features a vertical amplifier frequency response of 5 MHz and provides horizontal sweep frequencies of from 10 Hz to 500 kHz.
Courtesy Heath Campany
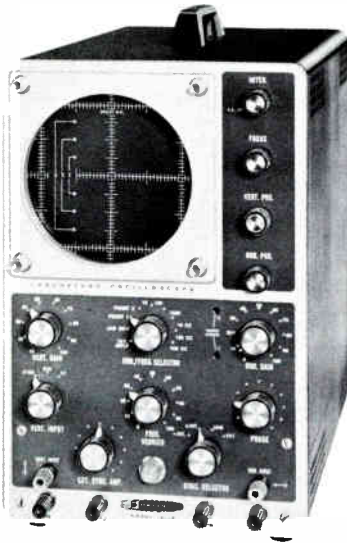
T_1 provides the ac voltages for low voltage rectifier V_{11} and high voltage rectifier V_{12}, and also provides filament voltages for all of the tubes in the oscilloscope. The primary of T_1 connects to the ac line through fuse F_1 and on-off switch SW_5.

V_{11} is a full wave rectifier used to provide the dc plate currents for all tubes except the crt. The output of this low voltage supply is filtered by C_{18}, R_{28} and C_{19}. Bleeder resistor R_{27} helps to improve regulation, and also forms a discharge path for the filter capacitors when the scope is turned off.

Half wave rectifier V_{12} provides the high dc voltage for the crt. The rectified voltage

is filtered by C_{20}, R_{34} and C_{21}. Resistors R_{29} - R_{33} form a combination bleeder and voltage divider across the output of the filter.

R_{33} is the intensity control. By changing the setting of this control you vary the bias on the crt. R_{31} determines the voltage on the focus anode, and thus serves as the focus control. R_{29} controls the voltage on the accelerating anode, serving as the spot shape or astigmatism control.

Secondary S_1 of T_1 provides the filament voltage for low voltage rectifier V_{11}. S_3 is the filament voltage source for the crt. The filament voltage for high voltage rectifier V_{12} is obtained from the small tapped portion of the S_2 winding. S_4 supplies filament voltage for the rest of the tubes.

*   *   *

43. R_{31} in Figure 12 serves as the (a) intensity control, (b) focus control, (c) spot shape control.

44. Examine the high voltage supply circuit of Figure 12.   Is the grid of V_{10} positive or negative with respect to the cathode?

*   *   *

The schematic diagram we have studied is not only used to trace signal paths, it is used to locate components by showing circuit connections and the relationship of one stage to another. Many of the problems of repairing or constructing electronic equipment are overcome by knowing how to use a schematic properly.

TYPES OF MEASUREMENTS

Because an oscilloscope is not limited by a fixed calibrated scale and a mechanical pointer and meter movement, it can be used to make many different measurements. A scope can be used to measure voltage, frequency, phase and distortion. All of these measurements are made by observing

the waveform drawn on the screen of a crt.

Voltage Measurements

An oscilloscope can be used as a peak-to-peak ac voltmeter. When the scope is used to measure voltage, the test signal is normally applied to the vertical amplifier section. The electron beam is deflected an amount proportional to the voltage applied to the vertical deflection plates. Thus, the height of the pattern on the screen is proportional to the peak-to-peak amplitude of the voltage applied to the vertical input terminals.

For voltage measurements of this type, the scope must be calibrated. Calibration is accomplished by applying a known voltage to the vertical input and adjusting the vertical gain controls so that the trace has a certain height. Knowing how much deflection is caused by a known voltage, an unknown voltage can be measured by comparing the amount of deflection caused by the unknown voltage to the deflection caused by the known voltage.

Let's try an example. Suppose an oscilloscope is calibrated so that 1 volt peak-to-peak produces a trace with a height of 1 centimeter on the screen. Then an unknown voltage is applied to the vertical amplifier section. If this signal produces a pattern that measures 4 centimeters from peak to peak, the amplitude of the unknown voltage is 4 volts peak-to-peak. Thus, the unknown voltage is equal to the peak-to-peak amplitude, in centimeters, of the pattern it produces multiplied by the calibration voltage required to produce a deflection of 1 centimeter.

*   *   *

45. How is an oscilloscope calibrated to measure peak-to-peak voltage?

*   *   *

The oscilloscope can also be used to measure the gain of an

amplifier or other electronic device. Gain measurements are made by comparing the amplitude of the waveform at the output to the amplitude of the waveform at the input. For
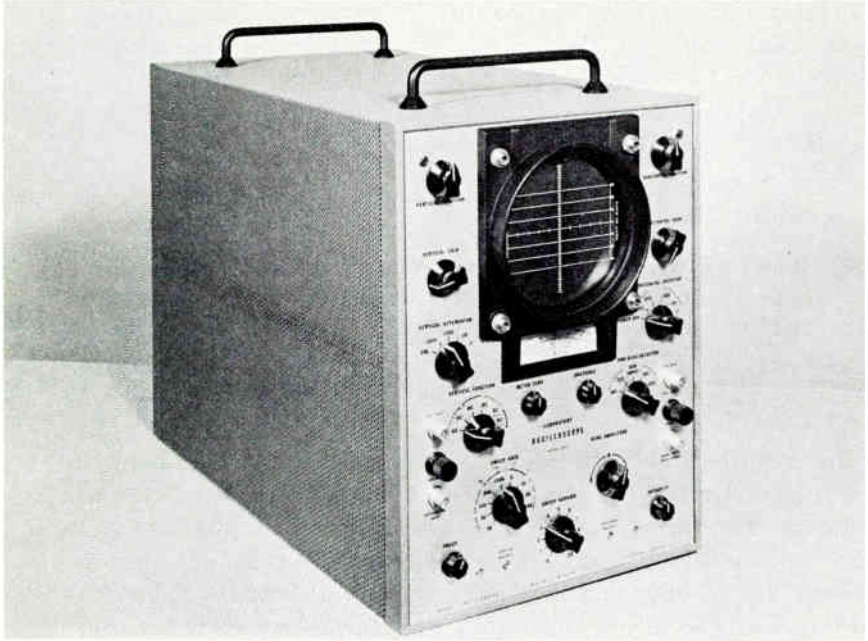
This wide band 5" scope includes a built-in voltmeter directly under the crt screen. The meter may be used in calibrating the screen for peak-to-peak voltage measurements.

Courtesy Bach-Simpson Ltd.

example, suppose a scope is connected to the grid of an amplifier tube, and a waveform with a peak-to-peak amplitude of 1 cm appears on the screen when the amplifier is carrying a normal signal. The scope is then connected to the plate of the amplifier tube, and a waveform with a peak-to-peak amplitude of 10 cm appears on the screen. The output waveform is 10 times larger than the input waveform, so the amplifier gain is 10.

Frequency Measurements

An oscilloscope can also be used to measure frequency.

Frequency measurements are made by applying a signal of known frequency to the horizontal amplifier, and the signal of unknown frequency to the vertical amplifier, and observing the pattern on the screen. The known frequency can be obtained from the horizontal sweep generator or from an external source. When an external signal is used, it is normally applied to the horizontal input terminals. This externally generated signal may be obtained from a signal generator or some other external source.

*   *   *

46. When an oscilloscope is used for frequency measurement, both the unknown and known frequencies are applied to the vertical input terminals. True or False?

*   *   *

The simplest way to measure frequency is to use the inter-nally generated sweep voltage as a standard. With the unknown frequency applied to the vertical input terminals and no sync applied, adjust the coarse and fine frequency controls for a stationary pattern on the screen. To find the unknown frequency, multiply the frequency of the horizontal sweep generator by the number of cycles on the screen. For example, if the sweep generator of the scope is set at 500 Hz and two cycles of a test signal appear on the screen, the frequency of the test signal must be $500 \times 2 = 1000$ Hz.

This is an easy method of checking frequency, but it gives only an approximation of the unknown frequency. The sweep controls on an oscilloscope are not accurately calibrated, so the sweep generator frequency used in the calculation is only approximate.

A more accurate way to measure frequency is to compare the pattern of the unknown frequency to the pattern produced by an accurate signal generator. You apply the unknown test signal to the vertical input and adjust the sweep frequency controls until one or more complete cycles appear on the crt. When these adjustments are made, the sync amplitude

control should be set at zero and only the sweep frequency controls should be used to stop the pattern on the screen. This pattern might look like the one shown in Figure 13.

To proceed with the measurement, you count the number of cycles on the screen. Without touching the sweep frequency controls, remove the test signal from the vertical input. Now apply the output of the signal generator to the vertical input of the scope. Adjust the signal generator frequency until the same number of cycles appear on the crt as when the unknown signal was applied. This means the signal generator frequency is the same as the frequency of the unknown signal. You can determine this frequency by simply reading the dial on the signal generator.

Another method of frequency measurement is to interpret various patterns which are produced on the crt when sine waves are applied to each set of deflection plates. These patterns are called LISSAJOUS FIGURES. Frequency ratios may be obtained from these patterns. By knowing the frequency of one of the voltages, the frequency of the other voltage may be found.

The scope sweep frequency is not used in this method of frequency measurement. The horizontal amplifier is switched to the external input position. Then the unknown test signal is applied to the vertical input and the known frequency signal is applied to the horizontal input. The pattern produced on the screen may be like that shown in Figure 14.

The frequency ratio of the vertical to the horizontal signal voltage is equal to the ratio of the number of points at which the Lissajous pattern touches the line labeled X-X to the number of points touching the line labeled Y-Y in Figure 14.

When a voltage of known frequency is applied to the horizontal input, you can find the unknown frequency by dividing the number of loops touching line X-X by the number of loops touching Y-Y, and multiplying the result by the horizontal input frequency. That is:

$$f_v = f_h \times \frac{\text{loops touching X-X}}{\text{loops touching Y-Y}}$$

where f_h is the horizontal input frequency and f_v is the vertical input frequency.

Let's use Figure 14 to illustrate this system of frequency measurement. Three complete loops are touching the horizontal line X-X, and one loop touches the vertical line
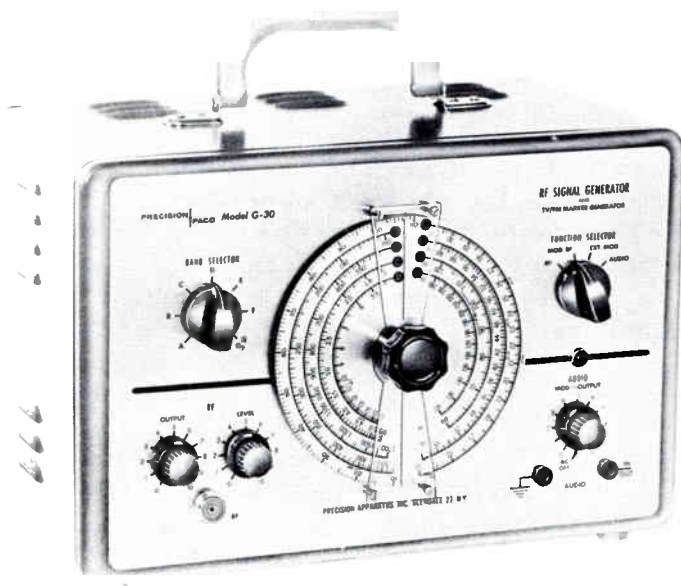
An accurate signal generator such as the one shown above can be used as a frequency standard for measuring unknown frequencies with an oscilloscope.

Courtesy Paco Electronics Co., Inc.

Y-Y. Suppose the frequency of the signal applied to the horizontal input is 1000 Hz. In this case, the frequency of the vertical input signal would be $f_v = 1000 \text{ Hz} \times 3/1 = 3000$ Hz.

As the frequency ratio increases, it is hard to interpret the

figures. Usually a ratio of 10 to 1 is about the largest ratio that can be easily read. Probably the main problem in using Lissajous figures is in obtaining two voltages whose frequencies have an exact whole number relation to each other and whose frequencies do not drift. If either frequency drifts, the patterns will be in constant motion.

*   *   *

47. Suppose a 6000 Hz signal is applied to the horizontal input of an oscilloscope. What is the frequency of a signal applied to the vertical input if the following pattern appears on the screen?

*   *   *
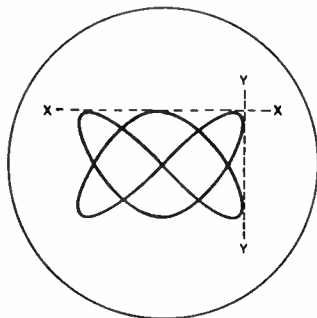
Phase Measurements

In the design or maintenance of electronic equipment, it may be necessary to make phase measurements of voltages or currents. These phase measurements are made by comparing two ac voltages of the same frequency and noting their relationship to each other.

To measure phase angle one signal is applied to the vertical amplifier and the other signal is applied to the horizontal amplifier. The result is a Lissajous pattern on the screen.

Figure 15 shows some typical Lissajous patterns obtained by comparing signals of various phases. When two signals are in phase, a straight line, slanted to the left (or to the right, depending on the scope), will be produced. This pattern is shown in Figure 15A. Figure 15B shows the pattern for two signals that are 45° out of phase with each other. Two signals 90° out of phase produce a circle as in Figure 15C. The pattern of Figure 15D is the result of two signals 135° out of phase, and the straight diagonal line of Figure 15E is the result of a phase difference of 180°

Notice that the pattern changes from a diagonal line to an elliptical pattern that widens into a circle, and then becomes elliptical and ends up as a diagonal line in the opposite direction as the phase angle is increased from 0° to 180°. If the angle is increased from 180° to 360°, the pattern goes through the same changes, this time from Figure 15E to Figure 15A.

*   *   *

48. What phase relationships are illustrated by the following Lissajous patterns?
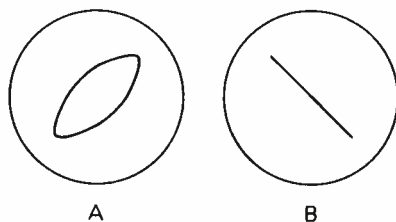
A   B

*   *   *

Distortion

Any unwanted change in the signal being amplified or coupled from one stage to another is called DISTORTION. Because an oscilloscope displays the actual waveform of the signal under test, it is an excellent device for detecting distortion.

To determine if electronic equipment is distorting a signal, first observe the input signal on the oscilloscope screen. Then observe the output signal. In an amplifier, the output may be much greater in amplitude than the input, but it should have the same shape as the input waveform. Any difference between the shape of the input and output signals indicates some form of distortion.

If distortion is present in a multi-stage amplifier, the stage producing the distortion can be found by examining the input and output waveforms of each stage. Additional tests, such as voltage and resistance measurements, can then be used to find the cause of the distortion within the stage.
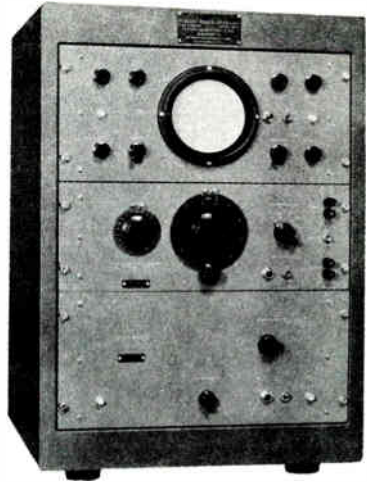
An oscilloscope is built into this rack of equipment for checking and adjusting phase relationships in electronic equipment.
Courtesy Acton Laboratories, Inc.

*   *   *

49. Why is an oscilloscope an excellent means of detecting distortion?

*   *   *

SUMMARY

The oscilloscope is a very useful test instrument. It can be used to display circuit waveforms when designing or trouble-shooting electronic equipment. It can be used as a peak-to-peak ac voltmeter. It can also be used to measure phase shift and find unknown frequencies.

The heart of an oscilloscope is a cathode ray tube. Most

scopes use crt's with electrostatic deflection and focusing. A sweep generator is used to provide a linear time base for the crt. The test signal is then applied to the vertical input of the scope, and a picture of the signal waveform appears on the screen. When the frequency of the input signal is equal to some exact whole number or multiple of the horizontal sweep frequency, the image on the screen of the crt is stationary. Synchronizing circuits are used to maintain a stationary pattern on the screen.

Both the vertical and horizontal sections of the oscilloscope contain amplifiers. The output signals of the vertical and horizontal amplifiers are applied to the deflection plates to deflect the electron beam. Depending on the combination of voltages on the deflection plates, the electron beam of the crt may be moved to any point on the screen, tracing out a pattern of the test signal.

The power supply of a scope is made up of two sections; the low voltage power supply and the high voltage power supply. The low voltage supply furnishes the operating voltages for all stages. The high voltage supply furnishes the voltages for the electrodes of the crt.

Lissajous figures can be used to measure the phase difference between signals of the same frequency. These figures appear as a sloping line, an ellipse, or a circle, depending on the phase difference between the two signals. The ratio between two different frequencies can also be determined. If one of these frequencies is known, then the other frequency can be found.

Many practical measurements can be made by general purpose oscilloscopes. The general purpose oscilloscopes described in this lesson are suitable for most measurements of amplifier gain, frequency response, distortion, and phase relationship. Some scopes are more specialized, designed to handle particular types of applications.

IMPORTANT DEFINITIONS

ASTIGMATISM CONTROL - [uh STIG muh tiz 'm] - An os-
cilloscope control that insures proper focus of the
beam at all positions on the crt screen. This con-
trol usually varies the voltage on the accelerating
anode of the crt. Also called a SPOT SHAPE CON-
TROL.

ATTENUATION - [uh TEN yoo: AY sh'n] - The process of
reducing the level of a signal.

ATTENUATOR - [uh TEN yoo: ay ter] - A component or
network of components used to reduce the level of a
signal.

BRIGHTNESS CONTROL - In an oscilloscope, the control
that varies the brightness or intensity of the image
on the screen. It usually varies the dc difference
of potential between the cathode and control grid.
Also called an INTENSITY CONTROL.

CATHODE RAY OSCILLOSCOPE (CRO) - [ah SILL uh
skohp] - An electronic instrument consisting of a
cathode ray tube and its associated circuits, used
to display a picture of the voltage applied to its input.

COARSE FREQUENCY CONTROL - A control which varies
the frequency of the horizontal sweep generator in
an oscilloscope in large steps. Usually a multi-
position switch which selects one of a number of
capacitors to control the sweep frequency.

DISTORTION - Any unwanted change in the signal being
amplified or coupled from one stage to another.

FINE FREQUENCY CONTROL - A continuously variable
control which varies the frequency of the horizontal

IMPORTANT DEFINITIONS (Continued)

sweep generator in an oscilloscope. Usually a po-
tentiometer which provides a continuously variable
frequency control within the range selected by the
coarse frequency control.

FOCUS CONTROL - A control used to focus the electron
beam to produce a small spot on the screen of a crt.
This control usually varies the potential on the focus
anode of the crt, and thus varies the difference of
potential between the focus anode and accelerating
anode.

FREQUENCY DISCRIMINATION - A form of distortion in
which some frequencies are attenuated more than
others.

FREQUENCY VERNIER CONTROL - [vuhr N: YEER] - See
FINE FREQUENCY CONTROL.

HORIZONTAL AMPLITUDE CONTROL - A control used to
vary the amplitude of the horizontal sweep signal
applied to the horizontal deflection section of a crt.
Also called a HORIZONTAL GAIN CONTROL.

HORIZONTAL GAIN CONTROL - See HORIZONTAL AM-
PLITUDE CONTROL.

HORIZONTAL POSITIONING CONTROL - A control used to
shift the beam from side to side, and thus shift the
spot horizontally on the screen of a crt.

HORIZONTAL SWEEP CIRCUIT - A circuit that produces a
sawtooth voltage to sweep the beam at a linear rate
from side to side on the screen of a crt. The circuit
that provides a linear time base for the oscilloscope
when a waveform is to be viewed on the screen.

IMPORTANT DEFINITIONS(Continued)

INTENSITY CONTROL - [in TEN si tee] - See BRIGHTNESS
    CONTROL.

LISSAJOUS FIGURES - [LISS uh zyoo] - Patterns obtained
    when sine waves of equal amplitude but different
    frequency or phase are applied to the vertical and
    horizontal inputs of an oscilloscope.

SAWTOOTH - A waveform consisting of a slow, linear rise
    from minimum to maximum and a rapid drop from
    maximum to minimum, usually obtained by charging
    a capacitor through a high resistance and discharg-
    ing it through a low resistance. In oscilloscope
    applications, the waveform commonly used to provide
    a linear horizontal sweep for waveform observations.

SPOT SHAPE CONTROL - See ASTIGMATISM CONTROL.

STEP ATTENUATOR - A switch type control that varies the
    amount of signal attenuation in steps, as compared to
    the smooth, continuously variable control of a po-
    tentiometer.

SYNC AMPLITUDE CONTROL - [SINK] - A control that
    varies the amplitude of the synchronizing signal
    applied to the horizontal sweep generator of an os-
    cilloscope.

SYNC SELECTOR SWITCH - A switch used to select the
    source of the synchronizing signal fed to the hori-
    zontal sweep generator of an oscilloscope. In many
    scopes, a two position switch which permits selec-
    tion of either a sync signal from the vertical ampli-
    fier circuit or a signal from some external source.

SYNCHRONIZING SIGNAL - [SING kroh nigh zing] - A signal

IMPORTANT DEFINITIONS (Continued)

used to keep the horizontal sweep generator of an oscilloscope in step with the waveform to be viewed. This signal insures that the sweep generator begins a cycle of oscillation at the same time the cycle of the test waveform begins, so that the pattern remains stationary on the screen.

VERTICAL AMPLITUDE CONTROL - A control used to vary the amplitude of the signal applied to the vertical deflection section of a crt. Also called a VERTICAL GAIN CONTROL.

VERTICAL GAIN CONTROL - See VERTICAL AMPLITUDE CONTROL.

VERTICAL POSITIONING CONTROL - A control used to shift the beam up and down, and thus shift the spot vertically on the screen of a crt.

PRACTICE EXERCISE SOLUTIONS

1. The six sections are: the high voltage power supply, the low voltage power supply, the vertical amplifier section, the horizontal amplifier section, the horizontal sweep section, and the cathode ray tube.

2. To display a pattern on the face of a crt. Some circuits power the crt and others develop deflection voltages or currents using amplifiers or oscillators; but the final result is a pattern for viewing.

3. (b) vertical deflection system.

4. Signals applied to the horizontal deflection system move the trace from side to side on the crt screen.

5. (a) horizontal amplifier.

6. True

7. An electrostatic crt does not require external coils for deflection and focusing.

8. True

9. (b) focus anode

10. The electron beam is forced to move up, down, and across the crt screen by the electrostatic fields between the two sets of deflection plates. These fields are produced by the voltages applied to the plates.

11. False

12. The high voltage power supply is usually connected to certain elements of the crt.

13. (b) negative

14. The horizontal and vertical deflection amplifiers are used to increase the amplitudes of the input signals, and thus provide signals that are strong enough to deflect the electron beam in the crt.
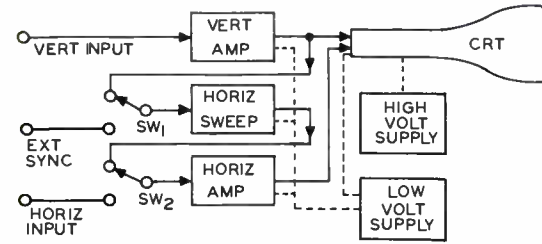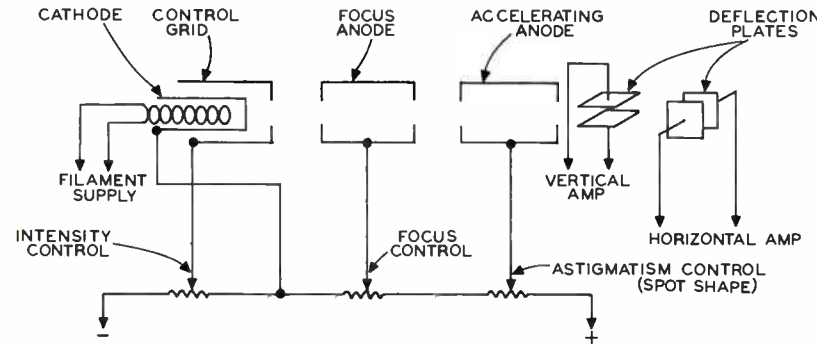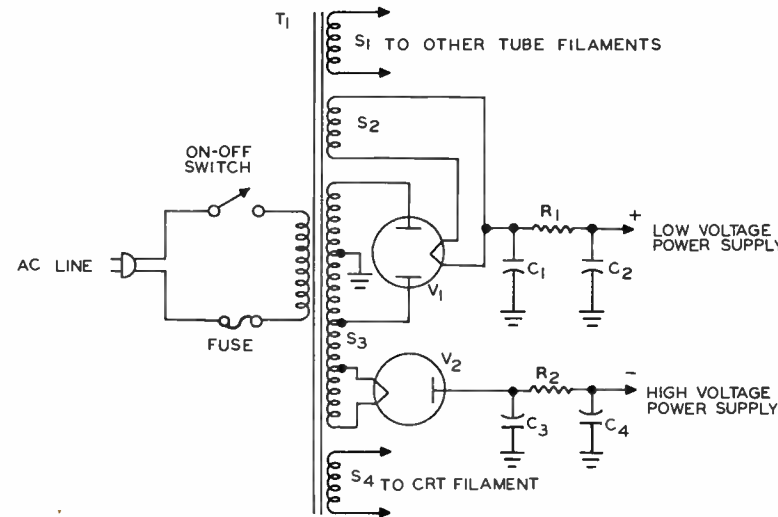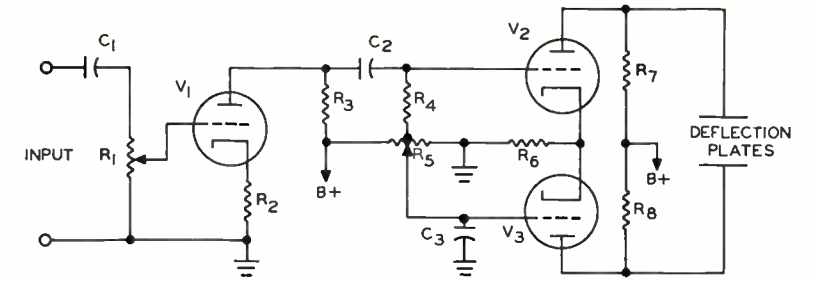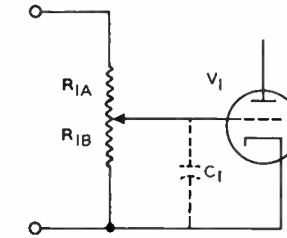
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FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

FIGURE 5

FIGURE 6

FIGURE 7

FIGURE 8

FIGURE 9

FIGURE 10

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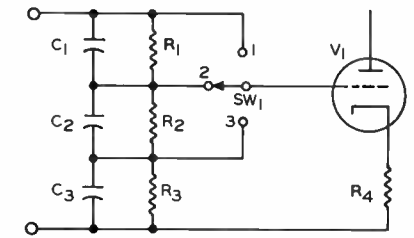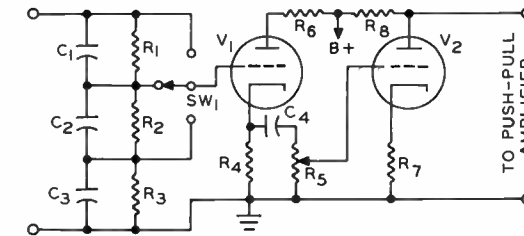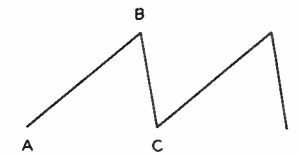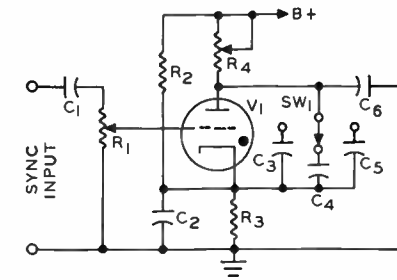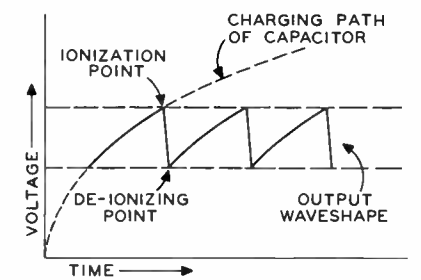
PRACTICE EXERCISE SOLUTIONS (Continued)

15. True

16. A wide frequency response allows the vertical amplifier to reproduce waveforms with minimum distortion.

17. True -- This avoids loading the test circuit and reduces distortion.

18. (b) 180° out of phase -- V_2 and V_3 of Figure 4 form a push-pull stage, so the signal voltages on the plates are 180° out of phase.

19. positioning control

20. horizontal amplitude or horizontal gain control.

21. (b) less -- Because the signal applied to this circuit is usually larger than that applied to the vertical input circuit, less gain is required to sweep the beam horizontally across the screen.

22. To overcome frequency discrimination due to the input capacitance of the amplifier.

23. (a) in phase -- A cathode follower stage does not invert a signal. In Figure 7, the signal at the cathode of V_1, coupled through C_4 to R_5, is in phase with the signal applied to the grid of V_1.

24. False -- A cathode follower does not provide a voltage gain. The purpose of V_1 is to prevent loading of the test circuit, and also to reduce the effects of shunt capacitance.

25. True

26. (b) sawtooth.

27. True

28. (b) cut off.

29. The frequency would decrease. If R_4 is set to a higher value,

PRACTICE EXERCISE SOLUTIONS (Continued)

the sawtooth forming capacitor must charge through a higher resistance. This means it will take longer to charge to the ionizing potential, and there will be fewer sawtooth waveforms per second (lower frequency.)

30. (a) conducting. -- When V_2 conducts, it forms a low resistance in the discharge path of the sawtooth forming capacitor. This produces the retrace interval of the sawtooth.

31. True -- Capacitor C_6 charges to produce the rising portion of the sawtooth during the time that V_2 is cut off.

32. proper frequency and phase relationships

33. (c) horizontal sweep generator

34. False -- The horizontal sweep generator provides the sawtooth for the horizontal deflection plates. The sync signal merely keeps the generated sawtooth from drifting in frequency and phase.

35. (1) the vertical amplifier of the scope, (2) the ac line, (3) an external source such as an accurate signal generator.

36. To control the amount of sync voltage applied to the sweep generator. -- The sync amplitude control should be advanced just far enough to hold the pattern stationary on the screen. Too strong a sync signal can trip the generator erratically and cause a highly distorted pattern on the screen.

37. vertical amplifier (V_1, V_2, V_3 and V_4), horizontal amplifier (V_7, V_8 and V_9), horizontal sweep generator (V_5 and V_6), low voltage power supply (V_{11}), high voltage power supply (V_{12}), and cathode ray tube (V_{10}).

38. (b) decrease. -- At the setting shown in Figure 12 the full input signal is applied to V_1. At the other two settings, some fraction of the input signal amplitude is applied to V_1.

True

W_4 serves as the coarse frequency switch. R_{19} is the fine
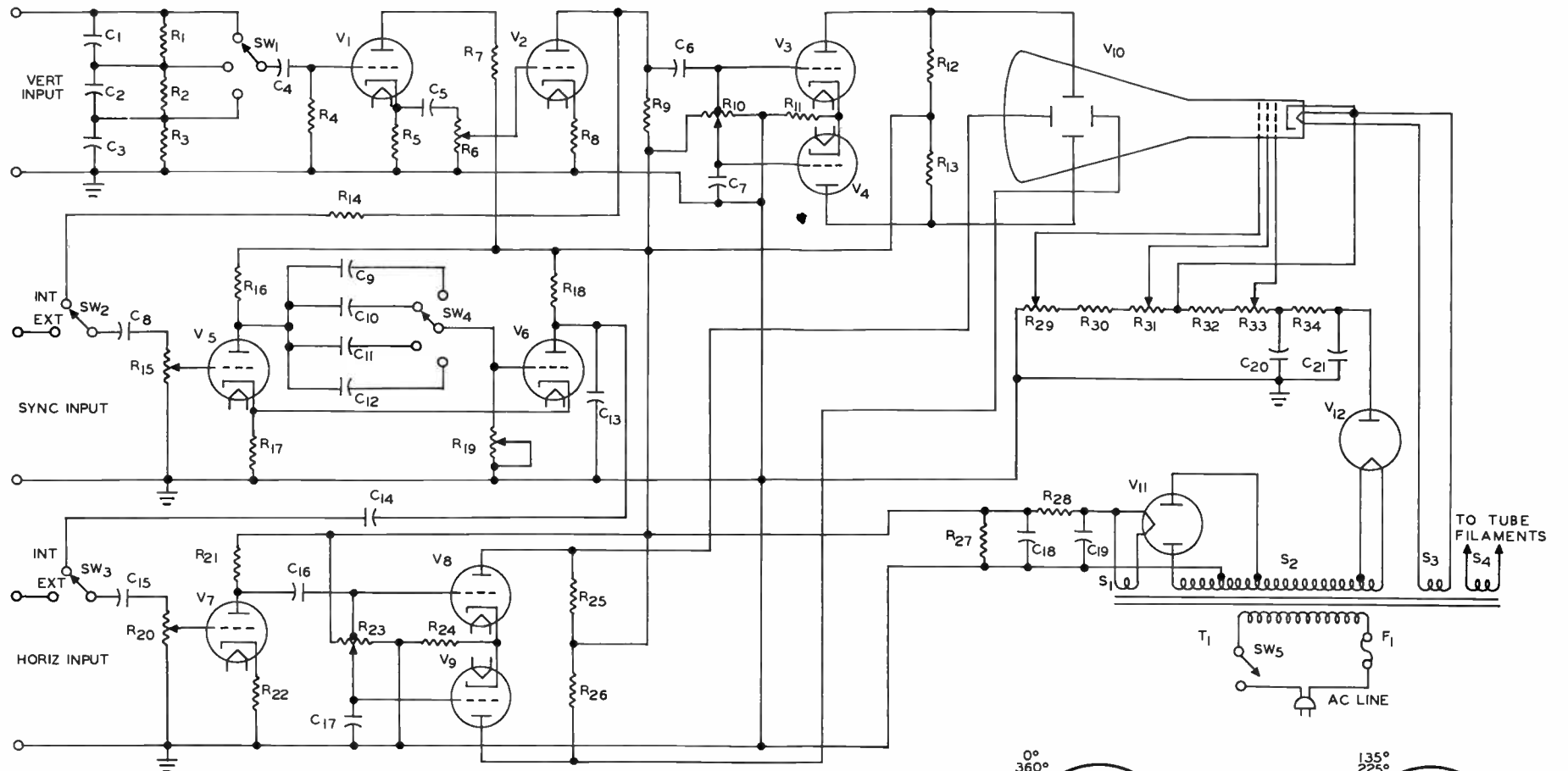
FIGURE 12
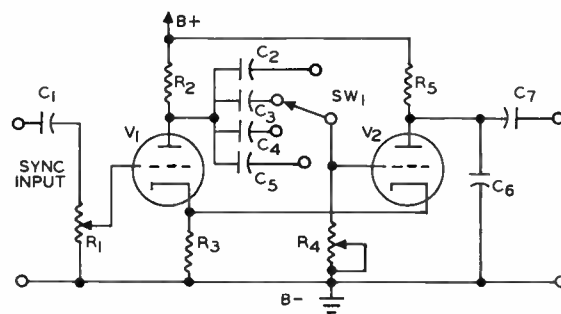
FIGURE 11

FIGURE 13

FIGURE 14

FIGURE 15

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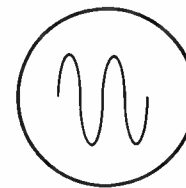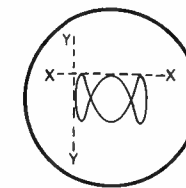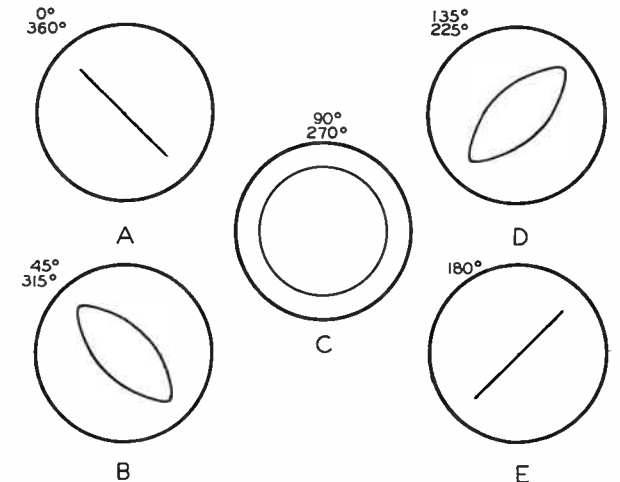
frequency control.

41. R_{20} -- This potentiometer serves as a horizontal amplitude control, and thus determines the amplitude of the sweep signal applied to the horizontal deflection plates.

42. R_{23} -- This potentiometer varies the average plate current of V_9, and thus varies the dc plate voltage on V_9. As a result, there is a change in dc voltage on the deflection plate connected to V_9, and the pattern shifts in the horizontal direction.

43. (b) focus control.

44. negative -- V_{12} is connected to provide a negative output voltage as explained for Figure 3. The slider of R_{33} is more negative than the junction of R_{31} and R_{32}, making the grid negative with respect to the cathode.

45. A known voltage is applied to the vertical input terminals, and the vertical gain controls are adjusted to produce a pattern of some convenient amplitude. Once the scope is calibrated, unknown voltages can be determined by measuring the amplitudes of the patterns they produce on the screen.

46. False -- The unknown frequency is normally applied to one input and the known frequency is applied to the other input.

47. 9000 Hz -- There are three loops touching the X-X line, and two loops touching the Y-Y line. The vertical frequency is

$$f_v = 6000 \times \frac{3}{2} = 9000 \text{ Hz}$$

48. A – 135° or 225°
    B –   0° or 360° (in phase)

49. An oscilloscope shows the waveform of the signal under test. Any distortion in the wave is readily seen on an oscilloscope.

QUESTIONS

LESSON CODE

2209 A

Example: A large river in South America is the
(A) Amazon. (B) Nile. (C) St. Lawrence. (D) Mississippi.

1. The horizontal sweep section of Figure 1 generates
(A) an external sync signal. (B) a sine wave voltage. (C) the vertical deflection voltage. (D) a sawtooth voltage.

2. In an oscilloscope, the signal to be observed is usually applied to the
(A) vertical amplifier section. (B) crt heater element. (C) horizontal sweep section. (D) crt cathode.

3. Most oscilloscopes use crt's designed for
(A) electrostatic focus and magnetic deflection. (B) magnetic focus and magnetic deflection. (C) magnetic focus and electrostatic deflection. (D) electrostatic focus and electrostatic deflection.

4. The voltage developed by the horizontal sweep section is applied to the
(A) horizontal amplifier section. (B) vertical amplifier section. (C) crt electron gun. (D) power supply section.

5. In most oscilloscopes, the brightness of the image on the screen is varied by varying the dc voltage between the
(A) focus anode and accelerating anode. (B) vertical deflection plates. (C) control grid and focus anode. (D) cathode and control grid.

6. In Figure 12, the internal sync signal is obtained from the
(A) vertical amplifier section. (B) crt filament. (C) horizontal amplifier section. (D) high voltage power supply.

7. Two sine waves of equal frequency and amplitude are applied to the vertical and horizontal input terminals of an oscilloscope. If the pattern on the screen is a circle, what is the phase angle between the two sine waves?
(A) 90°, (B) 60°, (C) 0°, (D) 120°.

8. An oscilloscope is calibrated by applying 2 volts peak-to-peak to the vertical input and adjusting the controls to produce a deflection of 4 centimeters. What is the peak-to-peak value of a test signal applied to the vertical input that causes a trace to appear 10 centimeters high?
(A) 2 volts, (B) 1 volt, (C) 5 volts, (D) 25 volts.

9. The controls of an oscilloscope are set so the horizontal sweep generator is operating at 1000 Hz. A test signal is applied to the vertical input, and 4 cycles of this signal appear on the screen. What is the frequency of the test signal?
(A) 1000 Hz. (B) 250 Hz. (C) 4000 Hz. (D) 4 Hz.

10. The deflection amplifier of Figure 4 produces signals at the vertical deflection plates that differ in phase by
(A) 180°. (B) 90°. (C) 60°. (D) 360°.
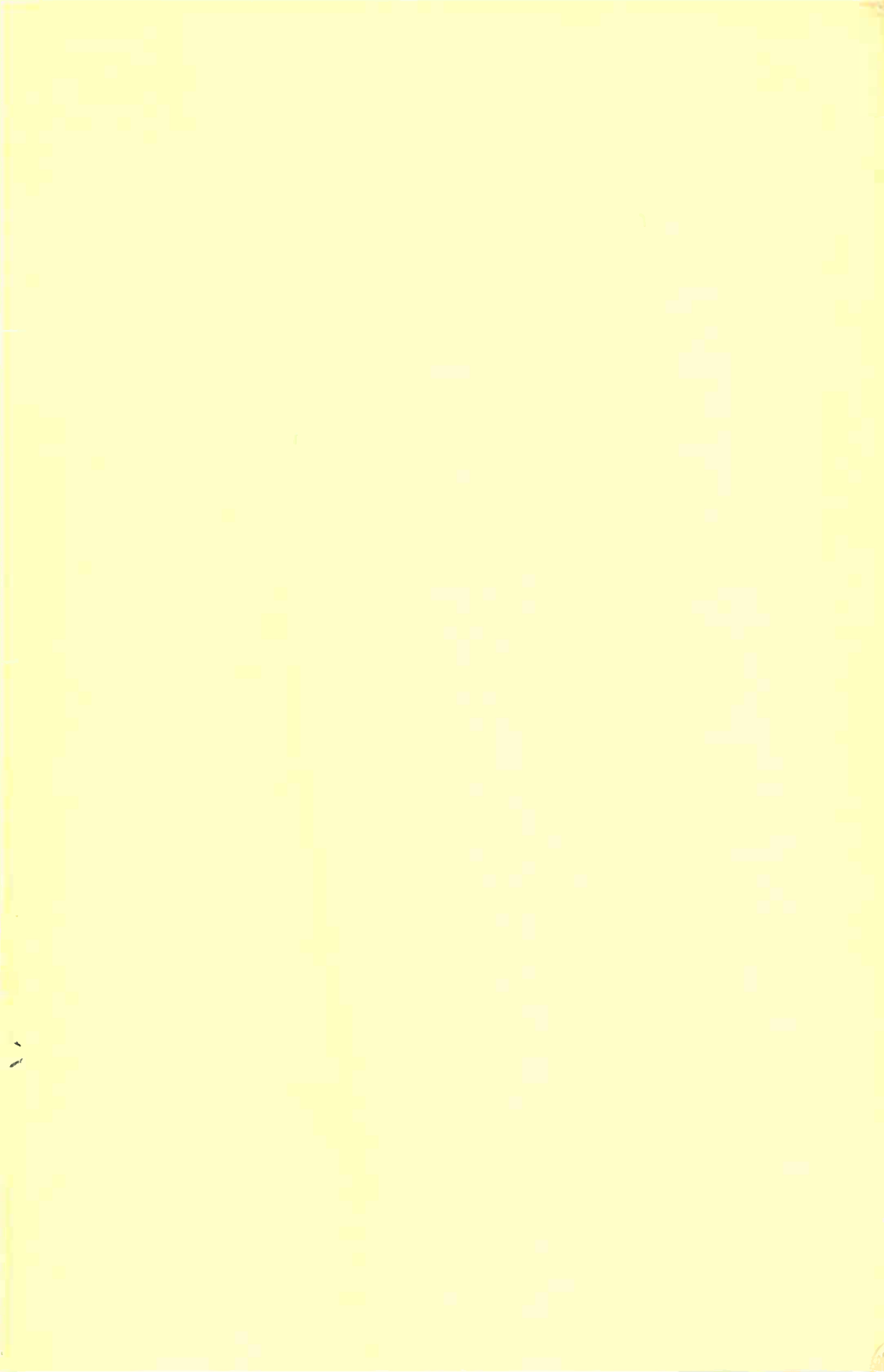
DEDICATED TO PROGRESS THROUGH EDUCATION

COMMUNICATIONS SYSTEMS

Lesson 2300A

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COMMUNICATIONS SYSTEMS

Revised 1966

OPPORTUNITY
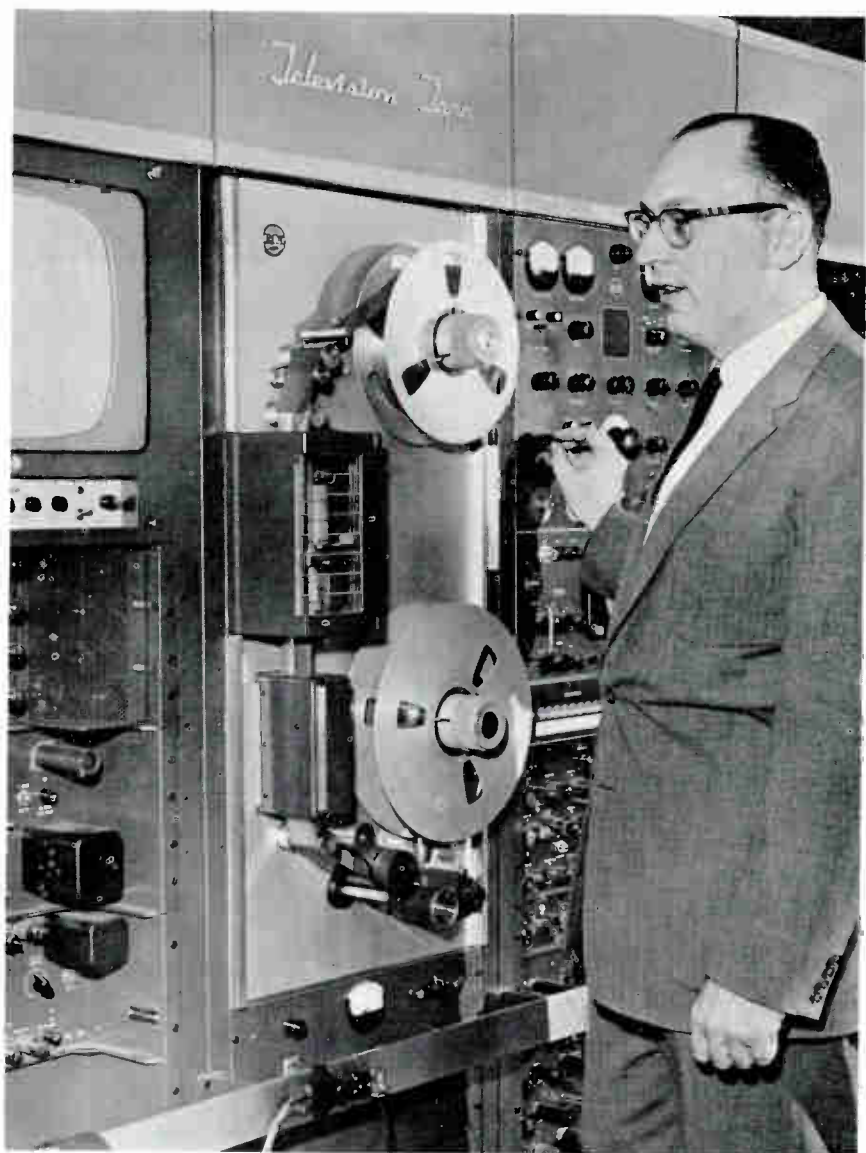
An engineer is shown operating a TV tape recorder. This recorder ollows live TV programs to be taped and rebroadcast at a later date.

COMMUNICATIONS SYSTEMS

CONTENTS

***

The easiest way to get to the top
is to get to the bottom of things.
       -The Youngstown Bulletin

COMMUNICATIONS SYSTEMS

The primary purpose of a communications system is to convey information from one point to another. At short distances, speech can be conveyed between two people by sound waves or direct audible sound. These two persons may continue to talk to each other as long as they are close enough to clearly hear each other.

As the distance between the person talking and the listener is increased, a point is reached where voice communication is impossible. Communications can be resumed by using a public address system. This system increases the sound level to cover a greater distance. But this, too, has a limited range. Communication by telephone is our next choice. This method, however, requires the use of wires which limits its use. This limitation is overcome by RADIO COMMUNICATION, which provides greater flexibility because it is wireless. Radio enables us to communicate with remote ships, aircraft, satellites, and other mobile stations.

*   *   *

1. What is a communication system?

2. What is a disadvantage of a direct voice communication system?

3. A limitation of telephone communications is that it requires the use of _____ .

*   *   *

Basically, there are two types of communications systems. These are referred to as one-way and two-way systems. In a one-way communications system information is conveyed from a sending point to a receiving point, but not in the opposite direction. Radio and television broadcasts are ex-

amples of one-way communications. We can receive the radio
or TV programs, but we cannot communicate directly back to
the station.   With a two-way communications system, we
are able to convey information back and forth between two
points. Each station has a sending and receiving unit.

Radio communications systems convey information through
space by means of radio waves. The information being con-
veyed by the radio waves is referred to as INTELLIGENCE.

Many types of intelligence can be transmitted.   Some radio
waves may contain code or speech. Others may contain music
or picture intelligence. The device used to transmit this in-
telligence is called a TRANSMITTER. The device used to
receive the transmitted intelligence is called a RECEIVER.

                    *   *   *

4.   Name several types of intelligence transmitted by radio
      waves.

                    *   *   *

BROADCAST SYSTEMS

For the most part, broadcast systems refer to one-way
communications systems.   Each system consists of a radio
transmitter, called the station, and one or more radio re-
ceivers.   The purpose of these systems is to broadcast
programs to the general public. However, the listener is
not able to broadcast or send messages back to the station.

To better understand this form of communication, let us
consider the block diagram of Figure 1. As shown, the radio
system consists of two main parts. One part is the transmit-
ter. At the transmitter, a microphone converts sound to elec-
tric signals. We refer to these signals as AUDIO SIGNALS.
In the transmitter the audio signal is combined with a radio
wave commonly referred to as a CARRIER WAVE. This
combined signal is radiated into space by an antenna.

*   *   *

5.   A radio broadcast station radiates audio signals directly into
      space.   True or False?

*   *   *

The second part of this radio system is the radio receiver.
Here the combined carrier wave and audio signal is inter-
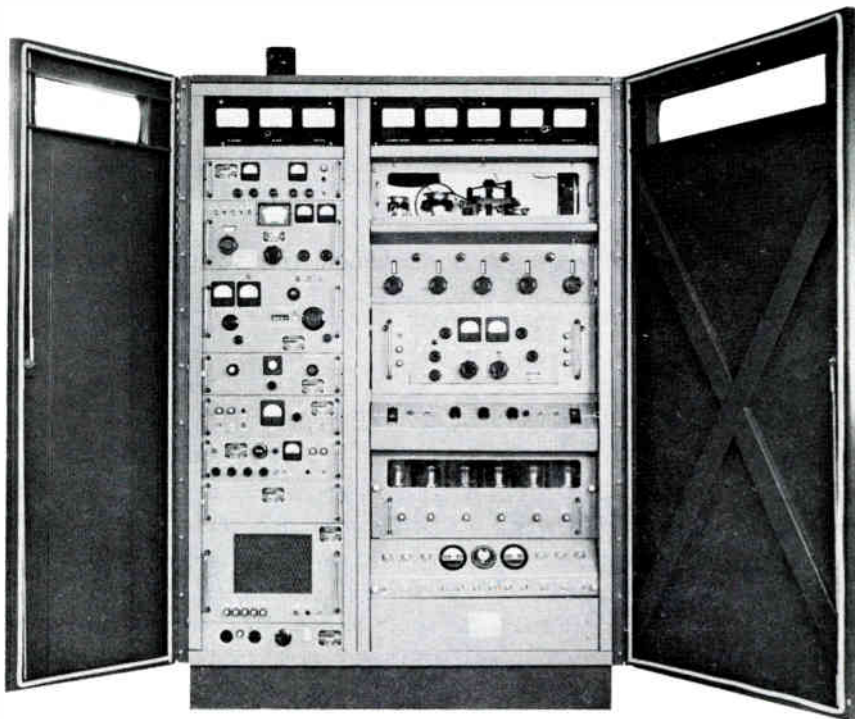
A general purpose transmitter conservatively rated at 5 KW average and 10 KW peak power output.
This unit operates in a frequency range fram 2 to 28 MHz.

Caurtesy Technical Materiel Corp.

cepted by the receiving antenna. The signal is fed into the
radio receiver where the audio signal is removed from the
combined wave. The audio signal is then amplified and

converted to sound by the radio speaker.

You may have wondered how signals can pass from a trans-
mitting antenna to a receiving antenna with no connecting
wires between them.   The answer is that the signal leaving
the transmitting antenna is in the form of varying electric
and magnetic fields. You will recall that an ordinary trans-
former transfers energy from its primary to its secondary
in much the same way -- the magnetic field around the pri-
mary cuts the secondary to induce a voltage.

You will also recall that one primary winding of a trans-
former may supply energy to more than one secondary wind-
ing.   This holds true for radio transmitters and receivers
as well.   That is, one transmitting antenna often supplies
energy to many receiving antennas.

To prevent radio interference between the different stations,
definite carrier frequencies are assigned or "allocated" to
every commercial broadcast transmitting station by the
Federal Communications Commission (FCC).   The FCC is
an agency of the United States government which regulates
all wire and radio communications between the states, ter-
ritories, and possessions.   It does not include communica-
tions facilities operated by the federal government, such as
military facilities.

             *   *   *

6.   What purpose does the FCC serve?

             *   *   *

THE RADIO SPECTRUM

The carrier frequencies allocated to the different radio sys-
tems are covered by a range of frequencies between 10 kilo-
hertz (kilocycles) and 30,000 megahertz (megacycles). This
range of frequencies is referred to as the RADIO SPECTRUM.

Basically there are seven frequency groups that make up the radio spectrum. These are shown in the chart of Figure 2. The first group covers a range of frequencies from 10 to 30 kHz. These are referred to as the Very Low Frequencies (VLF). They include the upper limit of the audio frequency range and the lower limit of the ultrasonic range.

The next group is the Low Frequency range (LF), from 30 to 300 kHz. These frequencies are for sea and air navigational aids. Medium Frequencies (MF), from 300 to 3000 kHz, include sea and air radio navigation, amateur radio, fixed and mobile communications, and government radio, to name a few. Also included in this band of frequencies is the standard radio broadcast band (535 to 1605 kHz).

*   *   *

7.   Standard broadcast stations in the United States operate in the Low Frequency range (30 to 300 kHz). True or False?

*   *   *

The range of frequencies from 3 to 30 MHz are referred to as High Frequencies (HF). This range of frequencies is used for therapeutic oscillators, commercial and amateur short wave communications and broadcasting, and electronic heating. The next range is the Very High Frequencies (VHF), from 30 to 300 MHz. These frequencies are used for television stations, FM broadcast stations, facsimile systems, and for aeronautical and amateur radio systems.

Ultra High Frequencies (UHF) are next. They cover a range of frequencies from 300 to 3000 MHz. Some radio systems which use these frequencies are government, amateur, aeronautical, fixed and mobile radio. Also included is the UHF television band. From here we move into Super High Frequencies (SHF). These frequencies cover a range from 3000 to 30,000 MHz. Some users of this range are government, amateur, fixed and mobile broadcast, and radio navigation, to name a few.

Frequencies above 30,000 MHz are used for experimental, government, and amateur use. Eventually the radio spectrum will include the range of light energy. Devices such as the laser and optical maser have been used for controlled transmission of light energy. These devices will be used to extend satellite and space communications. They may also provide coast-to-coast and continent-to-continent communication links.

STANDARD BROADCAST STATIONS

Standard broadcast stations are licensed by the FCC for the transmission of intelligence primarily intended to be received by the general public. These stations operate in the band of frequencies from 535 kHz to 1605 kHz. Within this band of frequencies there are 107 carrier frequencies. These carrier frequencies are assigned to the various radio stations to convey intelligence from the transmitters to the radio receivers. The carrier frequencies are spaced at least 10 kilohertz apart to prevent interference between one station and another.

            *   *   *

8.   The carrier frequencies in the standard broadcast band are
      spread at least (a) 10 kHz, (b) 100 kHz apart.

            *   *   *

More than one station may be assigned to the same carrier frequency. This is done only when the FCC inspectors are certain that the two stations will not interfere with each other. For example, a station on the east coast may be assigned the same carrier frequency as a station on the west coast.

Also, two stations in the same area can broadcast on the same frequency by sharing time. For example, one station may go on the air at sunrise and broadcast until sunset. The other station may broadcast at the same frequency from

sunset until sunrise the next day.

Because several broadcast stations may operate at the same frequency it becomes necessary to control the distribution of their radiated energy. One way to control the radiation is to use a DIRECTIONAL ANTENNA.

Directional antennas are used to direct the radio waves toward the center of highly populated areas. At the same time, they may be used to reduce the station energy in other locations to prevent interference with other broadcast stations.

The amount of radio frequency power radiated by a broadcast station is also regulated by the FCC. Standard broadcast stations normally radiate between 100 watts and 50 kilowatts. The exact power depends on the type of license granted to the station by the FCC.

A front panel view of a complete 1 kilowatt standard AM broadcast transmitter.
Courtesy Collins Radio

In standard broadcast systems, the energy radiated by the transmitting antenna is AMPLITUDE MODULATED (AM). By this we mean the amplitude of the carrier wave is changed in accordance with the amplitude of the audio signal, or MODULATING SIGNAL. For example, Figure 3 illustrates a carrier wave modulated by an audio signal. There are three waves to consider. They are the carrier wave, the audio wave or modulating signal, and the resulting modulated wave.

The high frequency carrier wave, shown in Figure 3A, is produced by an oscillator in the transmitter. The audio wave or signal, shown in Figure 3B, is the low frequency energy produced by the microphone. It is assumed to be within the audible range (about 16 to 16,000 hertz). This energy is used to modulate the carrier wave. When the audio wave and carrier wave are combined, the amplitude of the r-f carrier is varied in accordance with the audio wave as shown in Figure 3C.

*   *   *

9.   What is meant by the term amplitude modulation?

*   *   *

Basic AM Transmitter

The block diagram of a basic AM transmitter is shown in Figure 4. The first step is to convert the sound energy to an audio frequency electric signal. This is accomplished by the microphone. The signal developed by the micro-phone, however, is very weak. Therefore, the audio signal is increased in magnitude by an audio amplifier to a level required to operate another amplifier called the MODULA-TOR. The modulator is the final audio amplifier and sup-plies the necessary audio power for modulation.

At the lower left of Figure 4, the radio frequency oscillator produces a high frequency ac output. The output of the r-f oscillator is applied to the MODULATED STAGE. In this stage, the signal from the output of the modulator stage pro-duces amplitude changes in the carrier wave. The modu-lated wave is then fed to the antenna.

The energy radiated by a transmitting antenna consists of magnetic and electric fields. These fields are at right angles to each other. The relationship of the electric field with respect to the earth as the radio waves pass through space is referred to as polarization of the electric field.

For example, if the electric field is vertical with respect to the earth, the radio wave is said to be VERTICALLY POLARIZED. The type of polarization is determined by the construction of the transmitting antenna. Vertical polarization is the most common arrangement used in the standard AM broadcast band.

*   *   *

10. The radio frequency energy radiated by stations in the standard AM broadcast band is _____ polarized.

*   *   *

Basic AM Receiver

One of the most popular types of radio receivers in use today is the SUPERHETERODYNE RECEIVER. This is shown in the block diagram of Figure 5. As the magnetic field produced by the transmitter antenna cuts across the receiving antenna, a signal voltage appears between the ends of the receiving antenna. A modulated carrier waveform signal is shown at the antenna in Figure 5.

The energy of the antenna signal is very low, so the received signal voltages are fed into the r-f amplifier of the receiver. This stage increases the amplitude of the incoming modulated signal for further action by the receiver.

Many AM broadcast receivers do not use an r-f stage. They rely on amplification in the following stages to raise the signal to a usable level. However, receivers designed for long-range reception usually include one or more r-f amplifiers.

The input circuits of a receiver have the important job of picking out the one signal we want from the signals of all the other stations. This is the process of tuning. The input circuit can be tuned to resonance at a desired carrier fre-

quency by varying the inductance or capacitance of an LC circuit. Signals at this resonant frequency are then passed on to the rest of the receiver. The unwanted frequencies are blocked by the resonant circuit and do not appear in the output.

*   *   *

11. What is the most popular type of AM radio receiver in use today?

12. In a radio receiver, when you tune from one station to another what change occurs in the tuning circuits?

*   *   *

The next stage is the MIXER or FREQUENCY CONVERTER. It is used to combine the incoming r-f signal with an r-f signal from the LOCAL OSCILLATOR shown directly below it in Figure 5. The process of combining or mixing two different frequencies to produce a new frequency is called "beating" or "heterodyning". This is where the superheterodyne receiver gets its name.

When the incoming r-f signal and the local oscillator signal are combined in the mixer, a new frequency called the INTER-MEDIATE FREQUENCY (I-F) is produced. The intermediate frequency is the difference be-
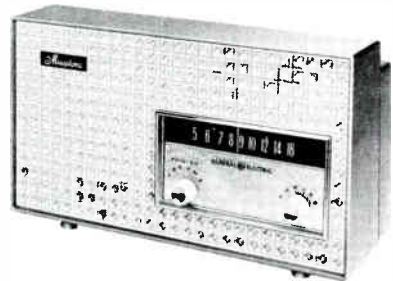
A standard AM broadcast receiver. It has a tuning range of 540 to 1600 kHz to cover the AM broadcast band.

Courtesy General Electric Co.

tween the incoming carrier frequency and the local oscilllator frequency. The i-f signal waveform is shown at the output of the mixer and i-f amplifier. Notice that the amplitude of this waveform varies according to the audio signal developed by the microphone at the transmitter. Thus, the i-f signal is a modulated signal.

*   *   *

13. The purpose of the converter or mixer stage of a super-
    heterodyne receiver is to convert the incoming r-f signal to
    the desired (a) audio signal, (b) i-f signal.

*   *   *

In the process of heterodyning we actually have four fre-
quencies to consider. These are the carrier frequency, the
local oscillator frequency, and the sum and difference of the
two. The sum and difference frequencies result from the
heterodyne action. In most receivers the difference fre-
quency signal is used. The others then have no further use
and are removed by tuned circuits.

The local oscillator is adjusted so that its frequency always
differs from the incoming r-f frequency by the same amount.
Thus, the intermediate frequency is always the same, re-
gardless of the setting of the tuning control. In most broad-
cast AM receivers, the i-f is 455 kHz. The oscillator is ad-
justed so that its frequency is 455 kHz above the incoming r-f
carrier. This frequency difference is maintained by using
a multiple-section tuning capacitor which changes the oscil-
lator frequency at the same time it changes the resonant
frequency of the input circuits.

To illustrate this principle, suppose you want to pick up a
station with a carrier frequency of 1000 kHz. As you tune
the input circuit to 1000 kHz, the oscillator section of the
tuning capacitor tunes the oscillator to 1455 kHz (455 kHz
above the incoming signal). If you tune your receiver to
pick up a station at 700 kHz, the oscillator is simultaneously
tuned to 1155 kHz, which again is 455 kHz above the incom-
ing carrier. The oscillator is always operating 455 kHz
above the incoming carrier, so the output of the mixer or
frequency converter is always 455 kHz.

You may think that this is a complicated way to design a
radio. Actually, it would be possible to feed the r-f signal

directly from the r-f amplifier to the demodulator stage.
However, there are advantages to the superheterodyne sys-
tem which make the added frequency conversion worthwhile.
The most important advantage is that the i-f amplifier sec-
tion can be designed to operate at a single frequency. It is
easier to design and adjust an amplifier to work at a single
frequency than to work over a wide range of frequencies.

The i-f signal is fed to the i-f amplifier. Here the i-f sig-
nal is increased in amplitude before it is fed into the DE-
MODULATOR. In the demodulator stage the i-f carrier is
separated from the audio signal and discarded. As shown in
Figure 5, the output of the demodulator is an audio signal
equivalent to that of the original sound produced by the micro-
phone at the transmitter. The audio signal is fed from the
demodulator to an audio amplifier. Here the audio signal is
increased in amplitude to operate the speaker.

*   *   *

14. The purpose of the demodulator of a superheterodyne receiver
     is to change the i-f signal to a radio frequency signal.   True
     or False?

*   *   *

FM BROADCAST SYSTEMS

Noise in AM reception results from electrical disturbances
due to storms, automotive ignition systems, and many other
energy sources. These disturbances amplitude modulate the
carrier. Since an AM receiver is designed to detect ampli-
tude modulation, the unwanted noise signals are detected and
reproduced along with the desired signals.   To overcome
this noise problem, a system other than amplitude modu-
lation can be used.   For reasons that we shall explain,
FREQUENCY MODULATION (FM) is one type of system that
reduces the noise problem.

Frequency modulation is used to broadcast radio programs

like that of AM broadcast stations. It is also used for the transmission of the sound portion of television programs and is widely used in government and civilian communications. In the United States, FM broadcast stations are located in the frequency spectrum from 88 to 108 megahertz. There are a total of 100 channels set aside in this band.

*   *   *

15. Name one advantage of a frequency modulation system.

16. What range of frequencies is allocated for FM broadcast stations in the United States?

*   *   *

In frequency modulation the frequency of the carrier is varied by the modulating signal. Thus, the intelligence is transmitted in the form of frequency variations, compared to the amplitude variations in an AM system.

Figure 6 illustrates the frequency modulation principle. Figure 6A shows the unmodulated carrier of an FM transmitter. The frequency of this carrier is referred to as the CENTER FREQUENCY or RESTING FREQUENCY. This corresponds to the assigned frequency of the transmitter.

Figure 6B shows an audio or low frequency modulating signal. When this signal modulates the carrier, we obtain the resulting waveform shown in Figure 6C. Notice that the frequency of the modulated wave varies according to the audio modulating signal. The amplitude of the carrier does not change.

A modulated FM wave is continually varying in frequency. The amount of variation above and below the center frequency is called DEVIATION. The maximum deviation allowed for commercial FM broadcast is ±75 kHz. That is, the strongest signal that can be used to modulate a transmitter is

limited to the value which will cause a maximum deviation of 75 kHz on either side of the center frequency. This is called the **FREQUENCY SWING**. Thus, a total of 150 kHz is
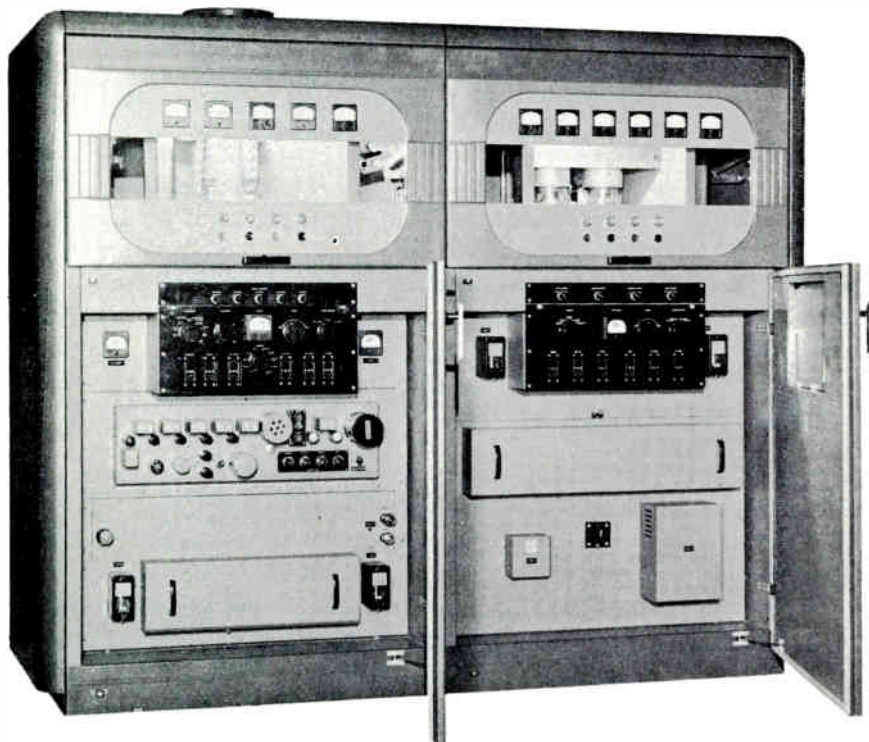
A front panel view of a 5 kilowatt FM transmitter which operates on any selected frequency between 88 to 108 megahertz.

Courtesy Collins Radio Co.

available over which the frequency of any one station may vary.

A band of 25 kHz at each end of the channel is also provided for separation purposes between channels. This 25 kHz band is called the **GUARD BAND**. Thus, a standard FM broadcast channel consists of a center frequency with a maximum frequency deviation of ±75 kHz, plus a 25 kHz guard band on either side, for a total of 200 kHz per channel.

*   *   *

17. What is the maximum frequency deviation of the carrier of an
     FM broadcast system?

*   *   *

Basic FM Transmitter

The basic elements of a simple FM transmitter are shown
in Figure 7.   The microphone converts the sound into an
audio signal.   The audio signal is strengthened by the audio
amplifiers.   This signal is then applied to the oscillator
stage where it varies the frequency of the oscillator.   The
last block in Figure 7 is the high frequency power amplifier.
It increases the power of the modulated wave to the level
required for transmission.   The output of the power ampli-
fier is fed to the antenna.

Antennas used by FM broadcast transmitters are normally
HORIZONTALLY POLARIZED.   The electric fields of the
radio waves are horizontal with respect to earth. For maxi-
mum signal pickup the receiving antenna elements should also
be horizontally polarized. This occurs when the elements of
the receiving antenna are horizontal with respect to earth.

It should be mentioned here that the method of modulation
does not determine the polarization of the signal.   It is the
physical construction of the transmitting antenna that deter-
mines the polarization of the radio wave.

*   *   *

18. The radio frequency energy transmitted by a station in the
     FM broadcast band is _____ polarized.

19. The polarization of the transmitted r-f signal is determined
     by (a) the method of modulation, (b) the physical construction
     of the transmitting antenna.

*   *   *

Basic FM Receiver

The basic stages of an FM superheterodyne receiver are
shown in the block diagram of
Figure 8. The first three
stages are similar to those of
an AM superheterodyne re-
ceiver. That is, signal volt-
ages are fed into the r-f am-
plifier from the antenna. The
output signal of this stage is fed
into the mixer. The mixer,
along with the local oscillator,
produces the required inter-
mediate frequency. In the case
of an FM broadcast receiver
the i-f frequency is usually

This FM receiver operates in the frequency
spectrum between 88 and 108 megahertz.
Courtesy Admiral Corporation

10.7 MHz. This signal is increased in amplitude by the i-f
amplifier. More than one i-f amplifier may be used.

The circuit of Figure 8 includes a **LIMITER**. The limiter is
used to clip off or remove any amplitude variations in the FM
signal. Since the intelligence is in the form of frequency
variations, any amplitude variations that may be present must
be unwanted amplitude modulation due to electrical interfer-
ence. By removing such variations we remove noise from the
speaker output and also help provide a more constant level
of output. As explained earlier, this noise limiting ability
is an important advantage of FM over AM.

The limiter output is fed to the **DISCRIMINATOR**. The dis-
criminator recovers the audio signal produced by the micro-
phone at the transmitter. The discriminator is, therefore,
an FM detector or demodulator. Following the discrimina-
tor is an audio amplifier which increases the audio signal to
a level sufficient to operate the speaker.

*   *   *

20. Why is an FM system normally less susceptible to noise than
    an AM system?

*   *   *

TV BROADCASTING SYSTEMS

Television broadcasting requires the transmission of both sound and picture intelligence by means of radio waves traveling through space. The FCC has assigned parts of the VHF and UHF spectrums to be used for television broadcasting.

There are a total of 82 television channels. These channel assignments are broken down in the following manner. Channels 2 through 6 cover a range of frequencies from 54 to 88 MHz. These are referred to as the "low band" VHF stations. Channels 7 through 13 cover a range of frequencies from 174 to 216 MHz. These are referred to as the "high band" VHF stations. Channels 14 through 83 cover a range of frequencies from 470 to 890 MHz and are called UHF stations.

*   *   *

21. Television broadcasting is limited to the VHF band. True or False?

22. The high band VHF TV channels are in the frequency range from (a) 54 to 88 MHz, (b) 174 to 216 MHz, (c) 470 to 890 MHz.

*   *   *

The effective radiated powers assigned to the various TV broadcast stations are 100 kw for channels 2 through 6, 316 kw for channels 7 through 13, and 5000 kw for channels 14 through 83. Channel 1 is not used for television broadcasting as it has been reallocated to other services.

The bandwidth of each channel is 6 MHz. Within this band of frequencies there is a picture carrier, sound carrier, and for color transmissions, a color subcarrier.

*   *   *

23. What is the bandwidth assigned for each TV channel?

*   *   *

The FCC specifies that the video carrier (picture carrier) be located 1.25 MHz higher in frequency than the lower limit of the channel. The FCC also specifies that the video carrier be amplitude modulated as in AM transmission. The sound carrier, however, is frequency modulated and is 4.5 MHz higher in frequency than the video carrier. The color subcarrier is used for the transmission of the color intelligence. The color subcarrier is 3.58 MHz from the video carrier and is amplitude modulated.

*   *   *

24. The FCC standards state that the video r-f carrier in a TV broadcast shall be (a) amplitude modulated, (b) frequency modulated.

25. The sound carrier of a TV broadcast is (a) amplitude modulated, (b) frequency modulated.

26. What is the frequency separation between the picture carrier and sound carrier in a TV broadcast signal?

*   *   *

The basic elements that make up a typical television system are shown in Figure 9. The television station is different from the radio station in that television stations use two transmitters. One transmitter is used for transmitting the picture intelligence and the other for the sound intelligence. However, at the receiver location, both transmitted signals are picked up by a single antenna and fed to a single receiver.

As shown in Figure 9, light reflected by the object or scene being televised is picked up by a camera tube. The camera tube, in turn, changes the light variations into voltage variations. We refer to these voltage changes as the VIDEO SIGNAL.

Because the video signal at the output of the camera tube is very weak, it must be amplified before it can be of any use.

This is accomplished by the video amplifier. The output from the video amplifier is fed into another amplifier called the LINE-AND-CONTROL AMPLIFIER. Here the video signal is combined with two other signals necessary in the transmission of the television signal. These signals are called the SYNCHRONIZING PULSES and BLANKING PULSES.

Synchronizing and blanking pulses are produced in the SYNC GENERATOR. The purpose of these pulses is to synchronize, or keep in step, the entire television system. In the camera circuits they control the scanning action of the camera tube. At the receiver, they control the scanning action of the picture tube, thus keeping it in step with the camera tube.

*   *   *

27. What is the purpose of the sync and blanking pulses generated in a TV transmitter?

*   *   *

The output of the control amplifier is fed into the modulated stage. Here the video signal amplitude modulates an r-f carrier. This modulated signal is then fed to the power amplifier and then to the antenna for radiation into space.

The sound transmitter is a frequency modulated system much like the FM transmitter described for FM broadcasting. Figure 9 shows two separate antennas -- one for the video section (AM) and the other for the audio section (FM). Although this system is in use, many stations use a single antenna to radiate both the video and audio signals. A special section called a DIPLEXER then feeds the outputs of the two transmitters to the single antenna.

*   *   *

28. The video and audio sections of a TV transmitting station can be compared to an AM and FM broadcast station, respectively. True or False?

*   *   *

Figure 10 illustrates a typical television receiver in block diagram form. This is a superheterodyne circuit and has an r-f amplifier, mixer, and oscillator similar to those found in AM and FM broadcast receivers. The i-f amplifier

This color television receiver is capable of reproducing pictures in either color or black-and-white.
Courtesy Sylvania Inc.

usually consists of several stages of amplification. The video detector is similar to an AM broadcast detector but it has several outputs. These include a picture signal, blanking pulses, sync signals and often the 4.5 MHz sound carrier which is frequency modulated. In some receivers the sound carrier is removed at some other point.

The picture information and blanking pulses pass through the video amplifier to either the control grid or cathode of the

picture tube. The sync pulses are fed to sync and sweep circuits. The signals fed to these circuits determine the movement of the electron beam across the screen of the picture tube. The picture tube screen fluoresces or forms light images according to the intensity of the electron beam striking it.

The 4.5 MHz i-f output produced by the video detector carries the sound or audio signal as frequency modulation. This output is fed to a 4.5 MHz i-f amplifier and then to an FM detector similar to that used in an FM broadcast receiver. The detector output is an audio frequency signal which is amplified and fed to a speaker.

RADIO TELEMETRY SYSTEMS

We usually think of communications as the transmission of voice or music, or in the case of television, as the transmission of pictures. However, another important type of communication is the transmission of information on measurements from the point of measurement to some other point. This type of communication is called TELEMETRY.

*   *   *

29. What is a telemetry system?

*   *   *

A radio telemetry system is one that uses an r-f carrier to transmit measurements from a remote location to a more convenient location. For example, a weather balloon carrying a miniature transmitter sends out signals which depend on variations of pressure, humidity, or temperature. These variations are relayed to a ground receiver by means of an r-f carrier generated in the transmitter. The receiver, in turn, converts the information back to a form to be recorded.

Radio telemetry is also used in recording data of a missile, rocket, or airplane under test. For example, it allows the

technician on the ground to see how the structural members
of the craft are holding up under flight. It also may tell him
the temperature of the metal on the outside of the craft. Or
it may tell him the amount of fuel left, or at what angle the
craft is with respect to earth.

*   *   *

30. A radio telemetry system is one which uses an r-f carrier to
    transmit information.   True or False?

*   *   *

Three frequencies are allocated for radio telemetry use.
These are 216 to 260 MHz, 1435 to 1535 MHz, and 2200 to
2300 MHz.   The maximum r-f carrier deviation in these
bands is ±125 kHz for a total swing of 250 kHz.   For fre-
quencies between 216 to 260 MHz the maximum power used
is 100 watts. For frequencies between 1435 to 1535 MHz and
2200 to 2300 MHz, the maximum power depends on the trans-
mission distance and any propagation problems that may
exist.   No more power should be used than necessary for
reliable transmission.

*   *   *

31. What portions of the frequency spectrum are allocated to radio
    telemetry systems?

32. In radio telemetry, the maximum permissible deviation of the
    r-f carrier is ±250 kHz.   True or False?

*   *   *

In the field of radio telemetry it is often necessary to trans-
mit more than one channel of information.   This can be ac-
complished by MULTIPLEXING. Multiplexing is the trans-
mission of more than one type of information using a single
transmitter.   There are two general methods of multiplex-
ing.   One is FREQUENCY DIVISION and the other TIME
DIVISION.

*   *   *

33. What is the purpose of multiplexing in telemetry systems?

*   *   *

In a frequency division multiplexing system, a number of low
frequency subcarriers are modulated -- each with a different
type of information.   These subcarriers are then combined
into one electric signal that modulates the main r-f carrier.

Figure 11 illustrates the method used in frequency division
multiplexing.   Subcarrier oscillators 1 and 2 generate sub-
carriers at different frequencies. Signal 1 modulates the
output of subcarrier oscillator 1, and signal 2 modulates the
output of subcarrier 2.   The modulated subcarriers are
combined in a linear mixer.   The mixing process here is
simply a matter of combining the two modulated subcarriers
so that the output of the mixer contains both signals.

The mixer output is fed to the modulated stage, where it
modulates the carrier generated by the r-f carrier oscillator.
The r-f wave radiated by the antenna is a carrier modulated
by the two distinct signals applied to inputs 1 and 2.   To il-
lustrate an application, signal 1 might be information on
temperature, and signal 2 might be information on pressure.
Both signals could be demodulated and separated by a prop-
erly designed receiver, and used to operate temperature and
pressure indicators at a receiving station.   The number of
signals can be increased by adding more subcarrier channels.

In time division multiplexing, the signals to be transmitted
are impressed on a single carrier at different times.   Fig-
ure 12 shows a simple diagram of how this can be done.
The multiplexing element here is a mechanically driven
switch called a **COMMUTATOR**.   As the arm rotates, it
alternately makes contact with the shaded contact and the
unshaded contact.   Depending on which contact the arm is
touching at a given time, either signal 1 or signal 2 is ap-
plied to the modulator.

The r-f oscillator generates a carrier which is modulated by signal 1 for half of the time, and by signal 2 for the other
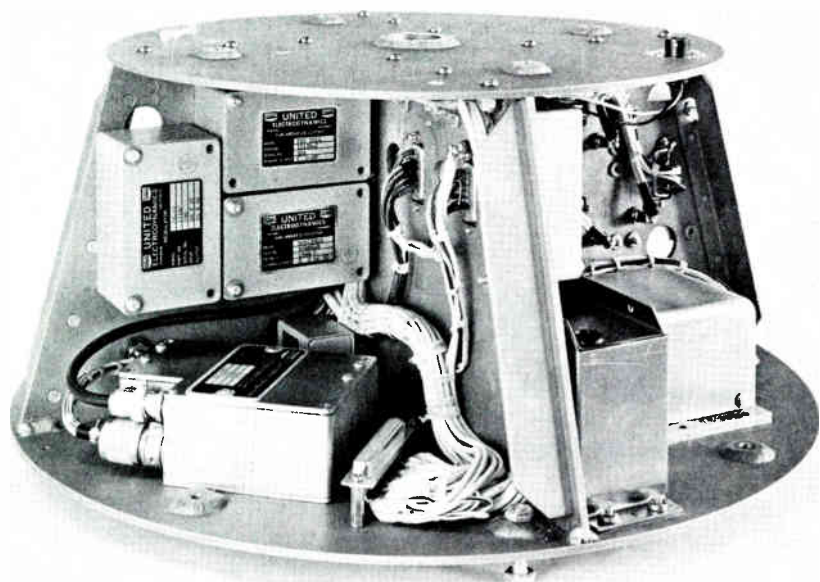
A 9-channel telemetry transmitter for airborne installation.   This unit uses frequency division mul-
tiplexing for the 9 subcarriers and frequency modulation of the main carrier.
                                                    Courtesy United Electrodynamics, Inc.

half of the time.   The switching time depends on the speed of the motor that drives the commutator arm.   To handle a greater number of signals, we simply break the commutator up into more sections.

When a multiplexed signal is demodulated at the receiver, the different signals must be separated before they can be fed to the various indicators or recording devices.   A DE-MULTIPLEXER is used for this purpose.   In a frequency division system the demultiplexer consists of band-pass filters tuned to the various subcarrier frequencies.   After the

modulated subcarriers are separated by the filter action, they are demodulated to restore the original signals.

In a time division system, the demultiplexer is a commutator in reverse, or what is called a DECOMMUTATOR. The demodulated signal is fed to the rotating arm, and the indicators or recorders are connected to fixed contacts identical to the shaded and unshaded contacts of Figure 12. The commutator and decommutator must be synchronized so that the arm is on the signal 1 contact of the decommutator at exactly the same time it is on the signal 1 contact of the commutator.

*   *   *

34. One method of multiplexing uses subcarrier signals at different frequencies. This multiplexing method is called (a) frequency division multiplexing, (b) time division multiplexing.

35. Another method of multiplexing modulates the carrier with different signals at different times. This multiplexing method is called (a) frequency division multiplexing, (b) time division multiplexing.

*   *   *

Amplitude or frequency modulation can be used in radio telemetry systems. In a time division system, such as that of Figure 12, the carrier may be either amplitude modulated or frequency modulated by the signals from the commutator. In a frequency division system such as that of Figure 11, we also have a choice of how to modulate the subcarriers.

A special type of notation is used to indicate the method of multiplexing and modulation in a frequency division system. The subcarrier modulation is listed first, and the main carrier modulation is listed second. For example, AM-FM means the subcarriers are amplitude modulated by the in-

put signals, and the subcarriers are then used to frequency modulate the r-f carrier of the transmitter.

TWO-WAY
COMMUNICATION SYSTEMS

The communications systems so far discussed in this lesson have all been of the one-way type. Two-way systems are also very widely used. A two-way system provides communication back and forth between two locations. A telephone conversation between two people is an example of two-way communication. Wireless or radio two-way systems are used to increase the effectiveness of many businesses and organizations.

For example, two-way radio is used to communicate from one aircraft to another. It is also used to communicate from an aircraft to the control tower and from the control tower to the aircraft. It may also be used between a mobile unit such as a taxi cab and a dispatcher. In addition, two-way radio provides communication between ships at sea and between ships and shore stations.

This 350 watt transmitter is built for operation in the 2 to 32 MHz range in shipboard, land and mobile installations.
Courtesy Technical Materiel Corp.

Two-way communication can be divided into seven general classes of service. These are

Marine, Aeronautical, Public Safety, Industrial, Land Transportation, Personal, and Disaster communications.

Marine or Maritime services cover communications between ship to ship and ship to shore, as well as navigational aids. All stations on board ships of U.S. registry (except for government stations) are required to be licensed by the FCC and to comply with all FCC rules and regulations.

Aeronautical services cover both traffic control and navigational aids. These services offer the necessary communications facilities to provide protection of life and property in the air. Aircraft stations are those stations installed aboard aircraft. Aeronautical stations are those listed as ground stations.

There are several different types of stations which aid Public Safety. These stations are assigned to agencies concerned with the public welfare. Such stations include police, fire, forestry conservation, highway maintenance, state guard, and special emergency operations.

Industrial services provide two-way communications for such groups as gas and electrical utilities companies, petroleum companies maintaining pipe lines, and groups working in the production of forestry products.

Land Transportation services involve companies that operate taxi cabs, railroads, highway trucks and automobile emergency services. A trucking company, for example, may use two-way radio to communicate with a truck driver on the highway to inform him of an unscheduled pickup or delivery. The truck driver in turn can use his radio to notify his company of a breakdown or accident.

Personal service covers the Amateur Radio Service which gives interested persons opportunities to engage in radio communications and experimentation as a hobby. Also covered is the Citizens Radio Service. This is a radio communication service of fixed, land and mobile stations intended for use by

citizens of the United States for private or personal radio communications. This also includes radio control equipment such as radio controlled gates, garage doors, airplanes and boats, to name a few.

Disaster service provides the necessary communications in time of disaster or other incidents which involve disruption of regular communications facilities. When there is no disaster, or threat of one, these stations may communicate only with respect to drills and practice sessions and to conduct equipment tests. In time of emergency or disaster. they carry any communications necessary to relief work including personal matters.

*   *   *

36. What are the seven general classes of services that use two-way communications?

*   *   *

FREQUENCY ALLOCATIONS

The services so far discussed use various frequencies in the radio frequency spectrum. Public Safety, Industrial, and Land Transportation services are located in the band of frequencies from 25 to 50 MHz and 152 to 174 MHz. Marine and Aeronautical services are allocated at different points along the spectrum also. Some of the bands allocated to their services are from 3.15 to 3.20 MHz, 0.2 to .285 MHz, or from .325 to .415 MHz depending upon their use.

Citizen radio services are allocated from 26.9 to 27.2 MHz and 462.5 to 466.4 MHz. Amateur radio services on the other hand, occupy a number of points along the frequency spectrum. Some of the amateur bands are 3500 to 4000 kHz, 7000 to 7300 kHz, 52 to 54 MHz, and 220 to 225 MHz. Disaster communications operate from 1750 to 1800 kHz.

The bandwidth assigned to two-way systems may be as little as 6 kHz or as much as 50 kHz. Two-way communications sys-

tems can be either amplitude modulated or frequency modulated. Frequency modulation is the most popular type at present.

*   *   *

37. Two bands in the frequency spectrum that are widely used for land, public, and industrial two-way systems are 25-50 MHz and 152 to 174 MHz. True or False?

38. The bandwidth of a two-way communication transmitter is usually between (a) 6 to 50 kHz, (b) 60 to 500 kHz.

39. In two-way communication (a) amplitude, (b) frequency modulation is most popular.

*   *   *

TWO-WAY COMMUNICATION EQUIPMENT

A complete two-way communication system generally must have at least two transmitters and two receivers. These may operate on the same or different frequencies. If they are on the same frequency, the transmissions must alternate. That is, one transmitter must be off while the other is on to avoid interference. Some systems use TRANS-CEIVERS, which have a transmitter and receiver built into the same unit. Some of the circuits may be shared by the transmitter and receiver sections. This is done by switches which change from "transmit" to "receive" operation.

Most communications receivers use a superhetrodyne circuit. In general, a communications receiver has more stages than the average broadcast receiver. This provides greater SENSITIVITY (the ability to receive weaker signals), and SELECTIVITY (the ability to distinguish between signals separated by only a small frequency difference). They may have more than one r-f amplifier stage and several i-f amplifier stages. The circuits are also built to be very stable. By this we mean that they will remain tuned to a station re-

gardless of supply voltage changes, mechanical vibrations, temperature changes, or other factors which could influence tuning.

There are also some special circuits which appear in communications receivers. One of the signals a communications

A two-way transceiver designed for use in the Industrial, Public Safety and Land Transportation services.

Courtesy E.F. Johnson Company

receiver may have to receive is a continuous wave (CW) signal used to transmit Morse Code. The CW signal is an r-f carrier without any modulation. The r-f carrier is simply turned on and off by a telegraph key to produce a series of dots and dashes. Since the carrier is unmodulated, the detector in a broadcast receiver produces no output when a CW signal is received.

The AM receiver of Figure 13 includes a circuit to produce an output tone when an unmodulated or CW carrier is received. A special oscillator, called a BEAT FREQUENCY OSCILLATOR (BFO) is added to this circuit. This oscilla-

tor is tuned to a frequency about 1 kHz less than the i-f frequency. When an unmodulated carrier is received it is mixed in the second detector with the signal from the BFO. Because the i-f amplifier output is 1 kHz from the BFO output, a 1 kHz difference frequency is produced. This frequency is audible when applied to a speaker.

Thus, in the receiver of Figure 13, a 1 kHz audio note is produced whenever a dot or dash arrives. Since the BFO would produce a disturbing 1 kHz note for voice or music broadcast, a special switch on the front panel enables us to turn the BFO on and off as desired.

The receiver of Figure 13 also has an automatic noise limiter as a part of the second detector. This system automatically limits the detector output if static causes a sudden burst of energy. While such limiters produce some distortion, they are used quite often for voice reception.

*   *   *

40. Why is a BFO required for reception of CW signals?

41. Noise due to static can be reduced in a communications receiver by (a) a BFO, (b) an automatic noise limiter.

*   *   *

FACSIMILE SYSTEMS

Perhaps one of the least known communications systems, yet one of the most useful, is the FACSIMILE SYSTEM. Facsimile is a communication system for the transmission of fixed images for reception in permanent form. With facsimile we are able to transmit and receive fixed images over electric wires or by r-f carrier between distant points. These fixed images may be pictures, weather maps, or typewritten or printed texts, to name just a few.

*   *   *

42. A facsimile system is one which permits the transmission of fixed images so they can be received and reproduced in permanent form.   True or False?

*   *   *

Figure 14 shows a basic facsimile transmitter. The picture, or other information to be transmitted, is wrapped around a cylinder.   The cylinder is then rotated at a constant speed.

A facsimile transmitter for sending maps, sketches, written or printed matter from one city to another via microwave, telephone, or private lines.

Courtesy Air Associates Inc.

As it rotates, it is moved back and forth along the shaft on which it is mounted.   A strong light source is directed to-

ward the revolving drum through a condenser lens and aper-
ture. This beam is concentrated by the focus lens to illu-
minate a very small scanning area of the copy. Through a
suitable pickup lens, the reflected light is then directed to
the cathode of a photoelectric cell.

As the drum turns, the scanning spot reflects light in pro-
portion to the density (darkness or lightness) of the illumin-
ated area of the copy. These variations of reflected light
cause the photoelectric cell to generate corresponding elec-
tric pulses. These pulses are applied to the input of a pre-
amplifier, which feeds a transmitter.

At the receiver, a recorder converts the signal variations
to a reproduction of the picture being transmitted. This re-
production can be made in any one of several ways.

One method of recording facsimile information is shown in
Figure 15. A sheet of light-sensitive paper is wrapped
around a drum. This paper is scanned by a small spot of
light. The brilliance of this light depends on the received
signal. This light exposes the film. The recorder drum
rotates and moves in step with the transmitter drum. After
exposure, the light sensitive paper is developed by the usual
photographic methods.

Like other radio communications systems, facsimile is also
governed by a set of standards. These are set forth by the
FCC. The frequency spectrum used for FM broadcasting
(88 to 108 MHz) is also used for facsimile.

*   *   *

43. What part of the frequency spectrum is used for facsimile?

44. In a facsimile receiver, the permanent reproduction is formed
    by a photocell. True or False?

*   *   *

FM broadcast stations may transmit facsimile in one of two ways. First, facsimile may be transmitted during periods not devoted to regular FM broadcasting. For example, when the station is not broadcasting regular program material, it can transmit facsimile information. The second method is to transmit by the multiplex method, using amplitude or frequency modulated subcarriers. With this method, the facsimile information is broadcast simultaneously with the regular FM broadcast. This can be done providing that the transmission of the facsimile does not reduce the audio quality of the normal program.

In a facsimile system that amplitude modulates a subcarrier, the maximum density or blackness of the subject copy corresponds to the maximum subcarrier amplitude and maximum radio frequency swing. In a facsimile system that frequency modulates a subcarrier, the highest transmitted frequency corresponds to the maximum blackness of the subject copy. These systems, known as negative modulation, are illustrated in Figure 16.

It should be pointed out that FM broadcast stations are not the only ones permitted to transmit facsimile. For example, facsimile may be found in newspaper offices, police stations, weather bureaus, and telegraph offices, to name a few. However, these offices usually do not send and receive their information by an r-f carrier wave. They use direct wire much like the telephone.

RADAR SYSTEMS

The word RADAR is derived from the phrase RAdio Detection And Ranging. Radar systems enable us to determine the direction and distance of an object from a transmitting station.

In a radar system, high power r-f energy in the frequency range from 100 to 30,000 MHz is transmitted from a directional antenna in a narrow beam. When the r-f energy strikes an object in the beam path a small amount of the energy is re-

flected back to the same antenna or to a separate receiving antenna. Thus, the principle is somewhat the same as an echo returning to the source of sound.

A receiver detects the reflected energy and compares it
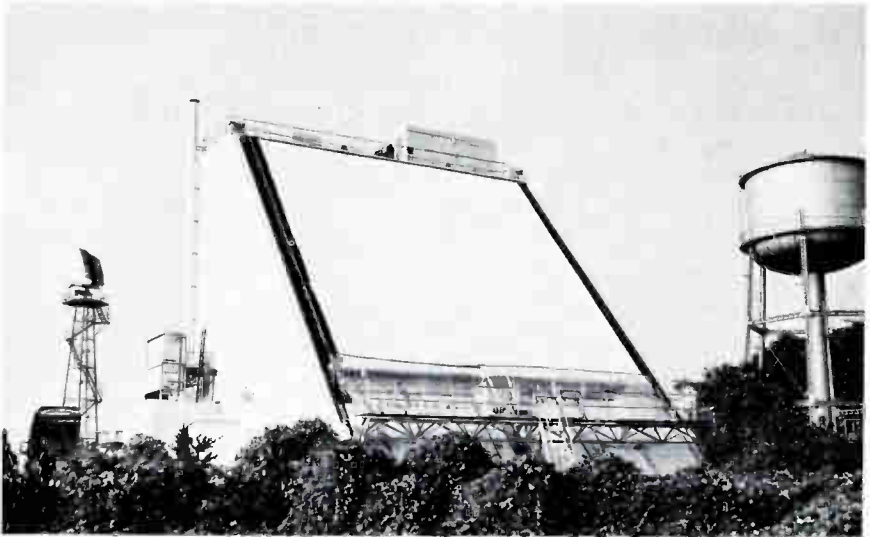
This unusual radar building contains many small antennas. This enables the radar system within the building to scan a large area at one time.

Courtesy Bendix Corporation

with a sample of the original transmission to determine certain facts about the object such as its direction and distance.

*   *   *

45. The purpose of a radar system is to determine the direction and distance of an object.   True or False?

46. What range of frequencies are used for radar systems?

*   *   *

To better understand the basic radar system, it is impor-
tant to study the various stages which make up the system
as shown in Figure 17. This system is divided into six
blocks; the pulse timer, the pulse modulator, the transmit-
ter, transmit-receive (T-R) switch, receiver, and crt indi-
cator.

The pulse timer produces pulses at a fixed rate. These
pulses are applied to both the pulse modulator and crt indi-
cator. This synchronizes both ends of the system. The
pulse modulator accepts the timing pulses and shapes and
amplifies the pulses. These pulses are then used to key the
transmitter oscillator at the desired rate and for the proper
time duration.

Thus, the transmitter produces short bursts of r-f carrier
energy at regularly spaced intervals. This particular sys-
tem uses the same antenna for transmitting and receiving.
The energy bursts are applied to the antenna, through the
T-R switch, for radiation into space. When the radar trans-
mitter is sending out a pulse of r-f energy, the T-R switch
connects the transmitter to the antenna. To pick up the echo,
the T-R switch connects the receiver to the antenna. The
antenna is highly directive and concentrates the transmitted
r-f energy into a narrow beam.

The same antenna receives the minute energy or echo re-
flected from any object in the path of the transmitted beam.
This received signal reaches the receiver through the T-R
switch. In the receiver, the r-f signal is converted to an
i-f signal, demodulated, and amplified. The output of the
receiver is then applied to the cathode ray tube for a visual
presentation.

In the simplest radar system, the time between transmission
and reception is shown by two peaks or pips rising up from
a straight horizontal line. One pip is produced at the instant
the signal is transmitted. The other pip is produced when
the echo returns. The distance between the two pips depends
on the time between transmission and reception, which in

turn depends on the distance to the reflecting object.   If a
scale calibrated in miles or feet is attached to the crt, the
distance can be read directly from the screen.   Since the
energy is transmitted in a highly directional beam, the direc-
tion of the object is determined by the direction in which the
antenna faces at the time of the transmission.

         *   *   *

47. In a radar system, the distance of an object can be determined
    from the direction in which the antenna faces at the time the
    energy is transmitted.   True or False?

         *   *   *

SUMMARY

One-way and two-way communications systems convey in-
formation over long distances. Standard AM broadcast radio
is one method used to convey information by one-way trans-
mission. The AM broadcast band includes frequencies from
535 to 1605 kHz. This type of communication is used to con-
vey news and entertainment to the general public.

FM broadcasting provides another means of one-way com-
munications.   This system operates in the radio frequency
spectrum from 88 to 108 MHz, and the carrier is frequency
modulated. This type of modulation eliminates many inter-
ference problems encountered in AM radio.

Television broadcasting, also a one-way system, is the
transmission and reception of sound and picture intelligence
by means of radio waves traveling through space. Television
operates in a range of frequencies from 54 to 88 MHz, 174
to 216 MHz, and from 470 to 890 MHz. The picture intelli-
gence amplitude modulates the picture carrier, whereas the
sound intelligence frequency modulates the sound carrier.

Radio telemetry systems enable us to make measurements

at remote locations. These measurements are then repro-
duced at a more convenient location. An r-f carrier wave
is used to transmit the information from a remote location
to a more convenient location where it is reproduced. Radio
telemetry also uses multiplexing which allows us to transmit
more bits of information using a single transmitter. Two
types of multiplexing used in telemetry are time division and
frequency division.

Two-way communications differ from broadcast communi-
cations in that we are able to communicate back and forth
between two points. Two-way systems use a number of
frequencies depending on the use of the system. Some uses
are found in aeronautical, public safety, industrial radio,
land transportation, personal and disaster services.

Another useful communication device is the facsimile sys-
tem. This system allows us to transmit and receive fixed
images by means of wires or an r-f carrier wave. Fac-
simile is transmitted through the air using frequencies be-
tween 88 and 108 MHz. This is possible by transmitting fac-
simile during the time that the regular FM broadcasting is
signed off the air. Another method is the transmission of
facsimile along with the regular FM broadcast by multi-
plexing.

Radar systems are used to detect and determine the direc-
tion and distance of objects from a radar transmitter. A
radar station consisting of a transmitter and receiver may
be located on land, aboard ship or aboard an airplane.
Radar systems operate in a range of frequencies from 100
to 30,000 MHz.

Basically, the radar transmitter sends out a strong burst,
or pulse, of r-f carrier energy using a highly directional
antenna. Any object in the path of this r-f energy will re-
flect a small amount of the energy back to the radar station.
This small amount of energy is detected by the same antenna
or by a separate receiving antenna, and is then fed into a
receiver. At the receiver the returned pulse is compared
with that of a transmitted pulse to determine the distance of
the object from the radar station.

IMPORTANT DEFINITIONS

AMPLITUDE MODULATION (AM) - A type of modulation in
    which the amplitude of the carrier varies in accord-
    ance with the modulating signal.

BLANKING PULSE - A pulse used to cut off the electron
    beam in television camera and picture tubes during the
    time when no picture is being formed.

DEMODULATOR - A circuit or a stage of a radio receiver
    used to recover the modulating signal from a modu-
    lated carrier. Also called a DETECTOR.

DETECTOR - See DEMODULATOR.

DEVIATION - In an FM system, the amount an r-f carrier
    is varied above and below its center frequency. Also
    called FREQUENCY DEVIATION.

DISCRIMINATOR - The circuit or stage of an FM receiver
    that converts frequency modulated signals into audio
    signals.

FACSIMILE - [fak SIM i li] - A system used to transmit
    and receive fixed images such as photographs, weather
    maps, and typewritten matter by use of r-f carrier
    waves or electric wires between widely separated
    points.

FREQUENCY MODULATION (FM) - A type of modulation in
    which the frequency of the carrier varies in accord-
    ance with the modulating signal.

GUARD BAND - A narrow band of frequencies provided be-
    tween adjacent carriers in certain portions of the
    spectrum to prevent interference between stations.

IMPORTANT DEFINITIONS (Continued)

HORIZONTALLY POLARIZED - Transmission of radio waves in such a way that the electric field of the wave is horizontal (parallel to the earth's surface).

INTELLIGENCE - [in TEL i jens] - The information conveyed by radio waves in communications systems.

INTERMEDIATE FREQUENCY (I-F) - The difference frequency obtained by heterodyning the local oscillator signal and incoming r-f signal in a superheterodyne receiver.

LIMITER - An FM receiver stage which removes amplitude variations from the FM signal by cutting off all peaks exceeding a certain amplitude.

MODULATED STAGE - The r-f amplifier stage of a transmitter in which the intelligence signal modulates the radio frequency carrier wave.

MODULATOR - [MAH joo lay tor] - The final audio amplifier of a transmitter, which supplies the necessary audio power for modulation.

MULTIPLEXING - [MUHL ti pleks ing] - The transmission of two or more signals using a common carrier wave or transmission link.

RADAR - [RAY dahr] - A contraction of the term RAdio Detecting And Ranging. The use of radio to determine the direction and range or distance of an object.

RADIO SPECTRUM - [SPEK truhm] - A range of frequencies from 10 kilohertz to 30,000 megahertz, used for various types of radio transmissions.

IMPORTANT DEFINITIONS(Continued)

SYNCHRONIZING PULSE - [SING kruh nighz ing] - A pulse
added to the video output signal of a television camera
for the purpose of synchronizing television receivers
with the transmitter.

TELEMETRY - [ti LEM i tree] - Taking measurements at
a remote location and reproducing the measurements
at a more convenient location to be displayed or re-
corded.

TRANSCEIVER - [tran SEE vuhr] - A two-way communica-
tion radio combining both a transmitter and receiver
in a single housing.

VERTICALLY POLARIZED - Transmission of radio waves
in such a way that the electric field of the wave is
vertical or at right angles to the earth's surface.

VIDEO SIGNAL - [VIH dee oh] - That portion of a television
signal which consists of the picture intelligence.

STUDENT NOTES

STUDENT NOTES

PRACTICE EXERCISE SOLUTIONS

1. A system which permits an exchange of information between two points.

2. The maximum distance between the person speaking and the person listening is relatively short.

3. wires

4. Speech, music and picture intelligence are three of the most common types of intelligence transmitted by radio waves. Morse code, control signals and signals related to measured data are other examples.

5. False -- The audio signals are combined with a radio frequency carrier, and the combined signal is then radiated.

6. The FCC regulates all wire and radio communications in the United States, its possessions and territories. This does not include communications facilities operated by the federal government.

7. False -- The standard broadcast band is from 535 to 1605 kHz which is in the Medium Frequency range.

8. (a) 10 kHz

9. Amplitude modulation is a method of impressing low frequency signals on a high frequency carrier so that the amplitude of the carrier varies according to the changes in amplitude of the low frequency signal.

10. vertically

11. the superheterodyne receiver

12. You change the resonant frequency of those circuits. This, in turn, determines which carrier frequency is passed on to the rest of the receiver.

13. (b) i-f signal.

14. False -- The demodulator changes the i-f signal to an audio frequency signal.
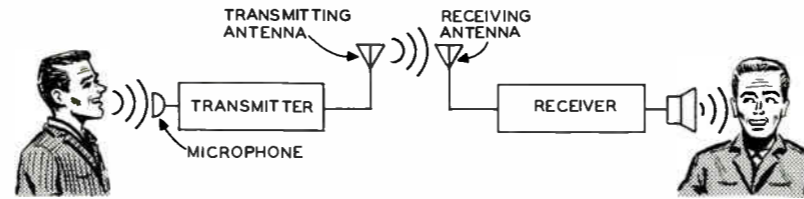
FIGURE 1

DESIGNATION	ABBR	FREQUENCY
VERY LOW FREQUENCY	VLF	10 TO 30kHz
LOW FREQUENCY	LF	30 TO 300kHz
MEDIUM FREQUENCY	MF	300 TO 3000MHz
HIGH FREQUENCY	HF	3 TO 30MHz
VERY HIGH FREQUENCY	VHF	30 TO 300MHz
ULTRA HIGH FREQUENCY	UHF	300 TO 3000MHz
SUPER HIGH FREQUENCY	SHF	3000 TO 30,000MHz

FIGURE 2
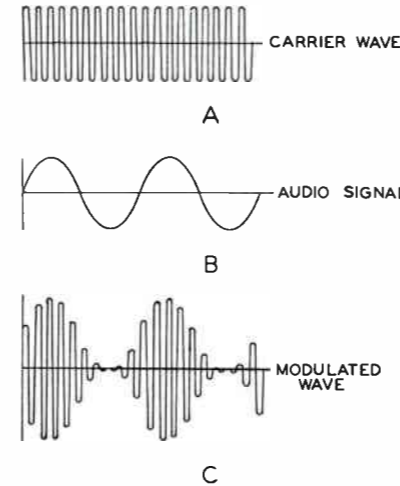
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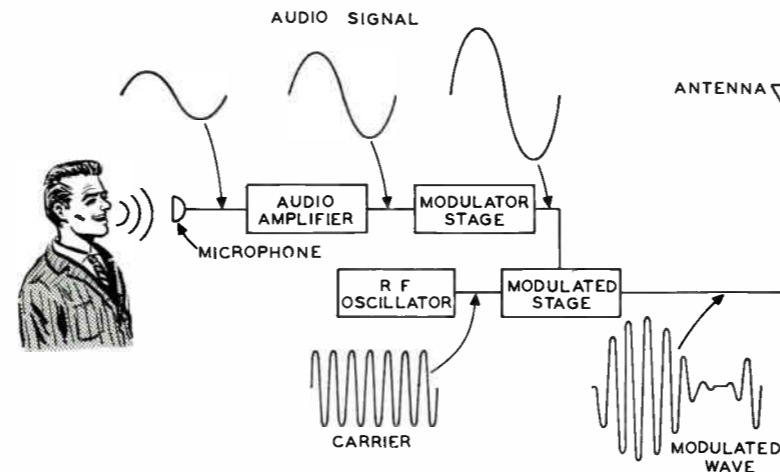
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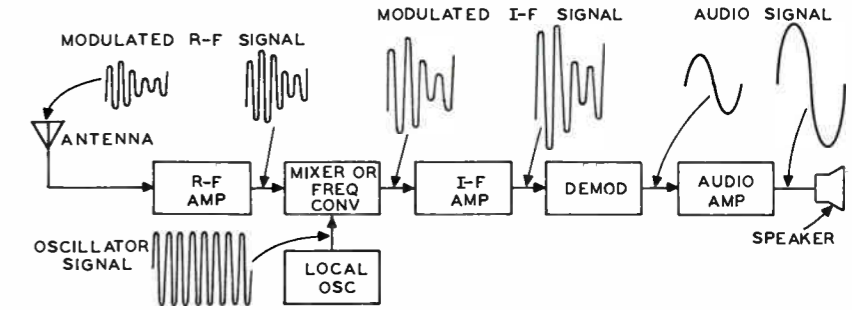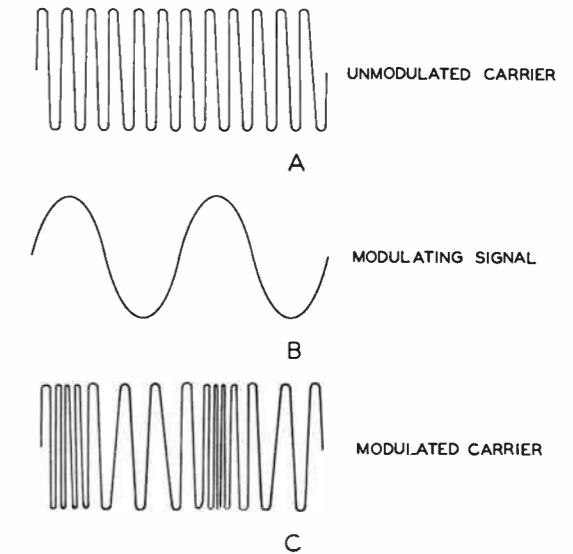
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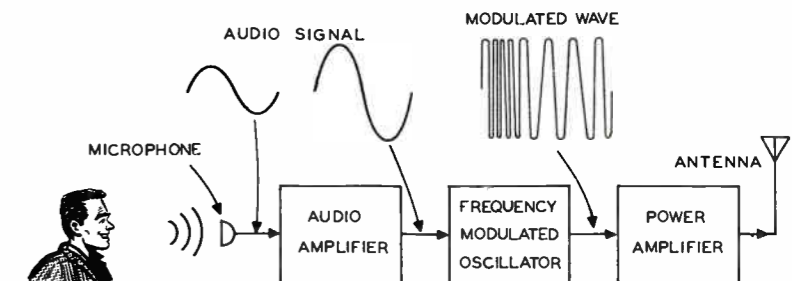
FIGURE 6

FIGURE 7

2300

2300

FIGURE 8

FIGURE 9

FIGURE 10

2300
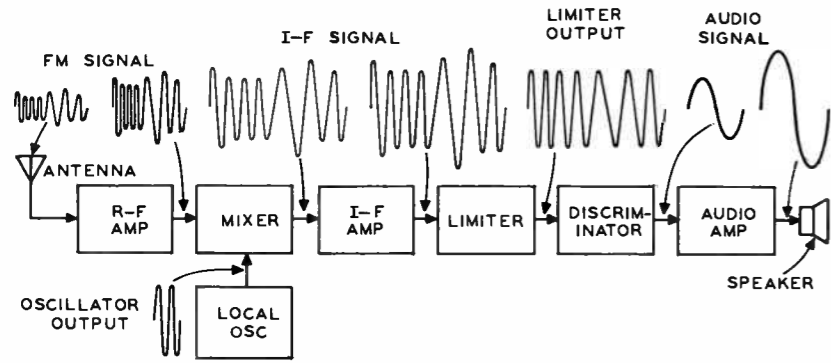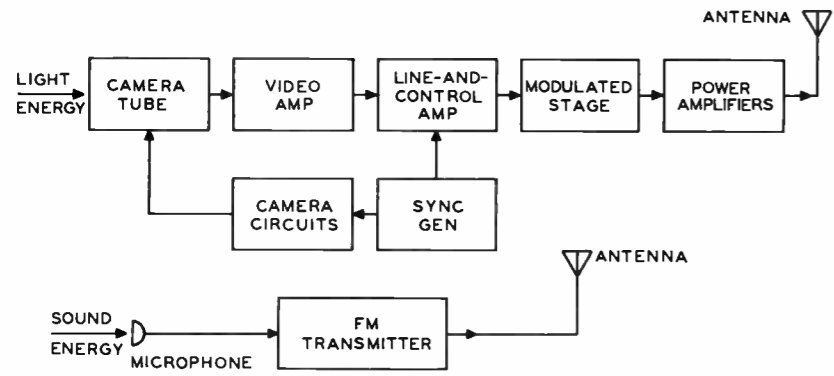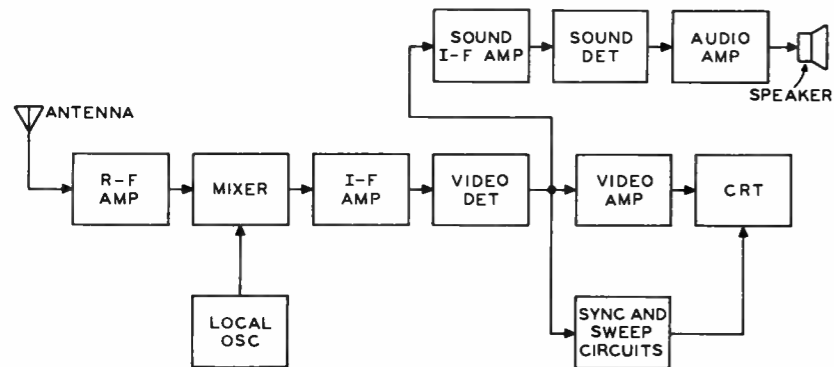
PRACTICE EXERCISE SOLUTIONS (Continued)

15. Noise interference can be greatly reduced with this system.

16. 88 MHz - 180 MHz

17. ±75 kHz for a total swing of 150 kHz

18. horizontally

19. (b) the physical construction of the transmitting antenna.

20. Most noise signals cause amplitude modulation of a transmit-ted wave, and thus are detected right along with the desired signals in an AM system. In FM, the intelligence is in the form of frequency variations, and any amplitude variations can be removed by a limiter to reduce interference.

21. False -- The FCC allocates TV broadcast channels in both the VHF and UHF bands.

22. (b) 174 to 216 MHz

23. 6 MHz

24. (a) amplitude modulated.

25. (b) frequency modulated.

26. 4.5 MHz

27. The sync and blanking pulses make it possible to lock the pic-ture formed on the TV receiver screen in step with the pic-ture produced in the camera tube.

28. True -- The picture or video section compares to an AM broadcast station. The sound section compares to an FM broadcast station.

29. A system of making measurements from a distance.

30. True

31. 216 to 260 MHz, 1435 to 1535 MHz, and 2200 to 2300 MHz.
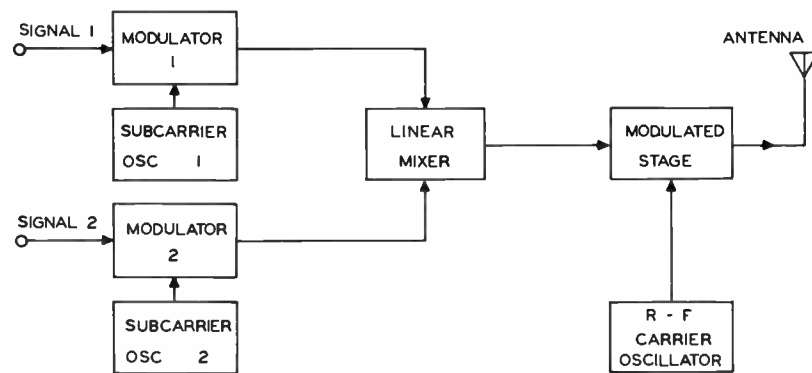
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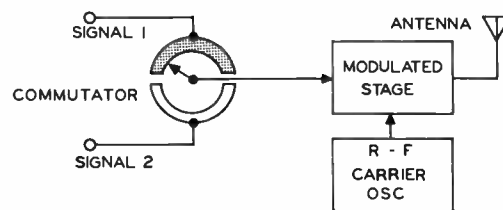
FIGURE 12

FIGURE 13

FIGURE 14

FIGURE 15

FIGURE 16

FIGURE 17

2300

2300
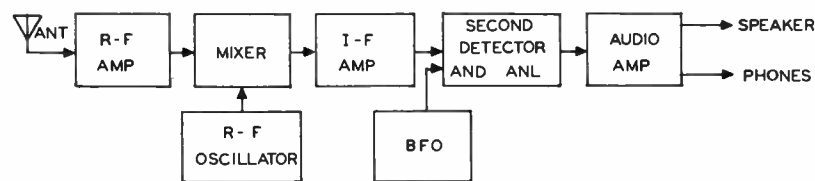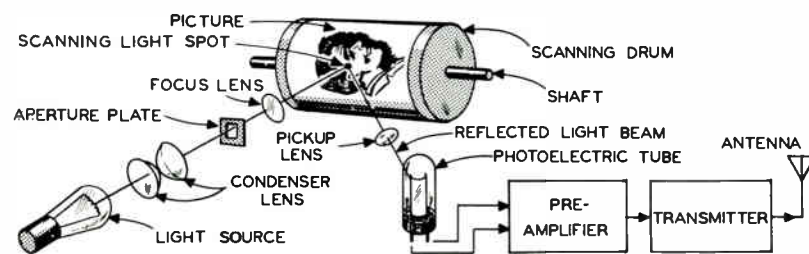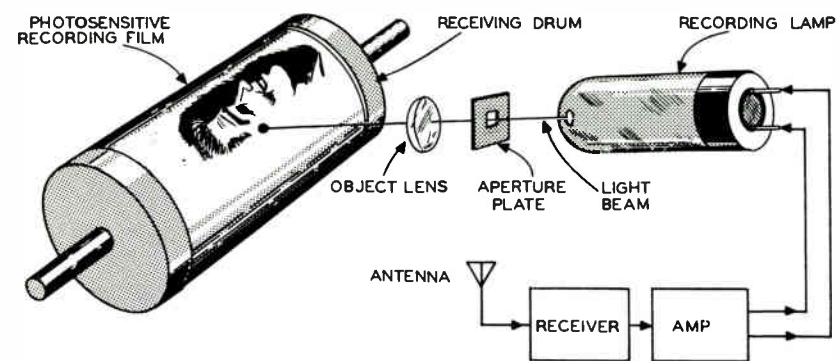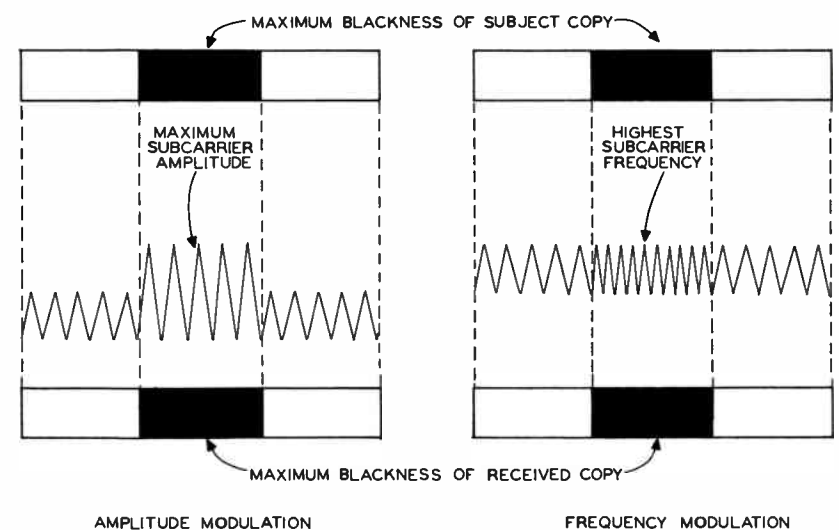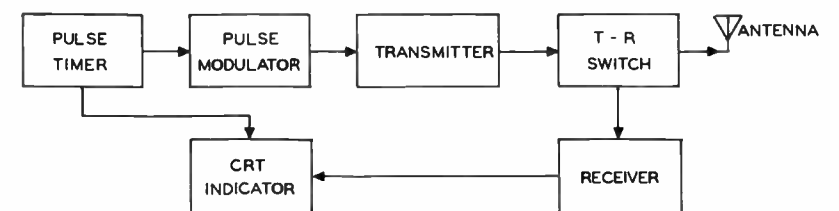
PRACTICE EXERCISE SOLUTIONS (Continued)

32. False -- The maximum deviation is ±125 kHz for a total swing of 250 kHz.

33. The purpose of multiplexing is to transmit more than one type of information with one transmitter.

34. (a) frequency division multiplexing.

35. (b) time division multiplexing.

36. Marine, Aeronautical, Public Safety, Industrial, Land Transportation, Personal and Disaster communications.

37. True

38. (a) 6 to 50 kHz.

39. (b) frequency

40. To make the signal audible. -- CW is an unmodulated carrier, and thus produces no sound from the speaker or headphones. A BFO produces a signal that beats with the i-f signal to produce an audible signal.

41. (b) an automatic noise limiter.

42. True

43. The FM broadcast band -- 88 to 108 MHz.

44. False -- The image is formed on a light-sensitive paper by the variations of light from a recording lamp.

45. True

46. approximately 100 to 30,000 megahertz

47. False -- The distance is determined from the interval between the time the pulse is transmitted and the time the echo returns.

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question, as illustrated in the example below.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

LESSON CODE

2300 A

Example: A foot is equal to

A ■
B ☐
C ☐
D ☐

(A) 12 inches. (B) 36 inches. (C) 6 inches. (D) 24 inches.

1.
A ☐
B ☐
C ☐
D ☐

The most common i-f frequency used in broadcast AM superheterodyne receivers is
(A) 455 kHz. (B) 535 kHz. (C) 10 kHz. (D) 1605 kHz.

2.
A ☐
B ☐
C ☐
D ☐

The I-F FREQUENCY of an FM BROADCAST RECEIVER is usually
(A) 200 kHz (B) 108 MHz. (C) 88 MHz. (D) 10.7 MHz.

3.
A ☐
B ☐
C ☐
D ☐

Noise due to electrical interference is greatly reduced in an FM receiver by
(A) a limiter. (B) a discriminator. (C) an audio amplifier. (D) an r-f amplifier.

4.
A ☐
B ☐
C ☐
D ☐

In television, channels 2 through 6 are classed as
(A) UHF stations. (B) VHF stations. (C) MF stations. (D) SHF stations.

5.
A ☐
B ☐
C ☐
D ☐

The maximum power established for radio TELEMETRY SYSTEMS in the frequency band of 216 to 260 MHz. is
(A) 100 w. (B) 100 kw. (C) 50 kw. (D) 5000 kw.

6.
A ☐
B ☐
C ☐
D ☐

In radio telemetry, more than one channel of information can be transmitted using a common carrier frequency by using a process called
(A) modulation. (B) heterodyning. (C) multiplexing. (D) beating.

7.
A ☐
B ☐
C ☐
D ☐

Two-way police communications is classified as
(A) Aeronautical service. (B) Public Safety service. (C) Industrial Radio service. (D) Land Transportation service.

8.
A ☐
B ☐
C ☐
D ☐

A two-way communications unit which consists of both a radio transmitter and receiver is called a
(A) modulator. (B) television receiver. (C) local oscillator. (D) transceiver.

9.
A ☐
B ☐
C ☐
D ☐

The light reflected from the revolving drum of a facsimile transmitter is picked up by a
(A) photoelectric cell. (B) preamplifier. (C) transmitter. (D) cathode ray tube.

10.
A ☐
B ☐
C ☐
D ☐

When a radar transmitter is SENDING OUT a pulse of r-f energy, the T-R switch connects the transmitter to the
(A) receiver. (B) cathode ray tube. (C) antenna. (D) pulse timer.
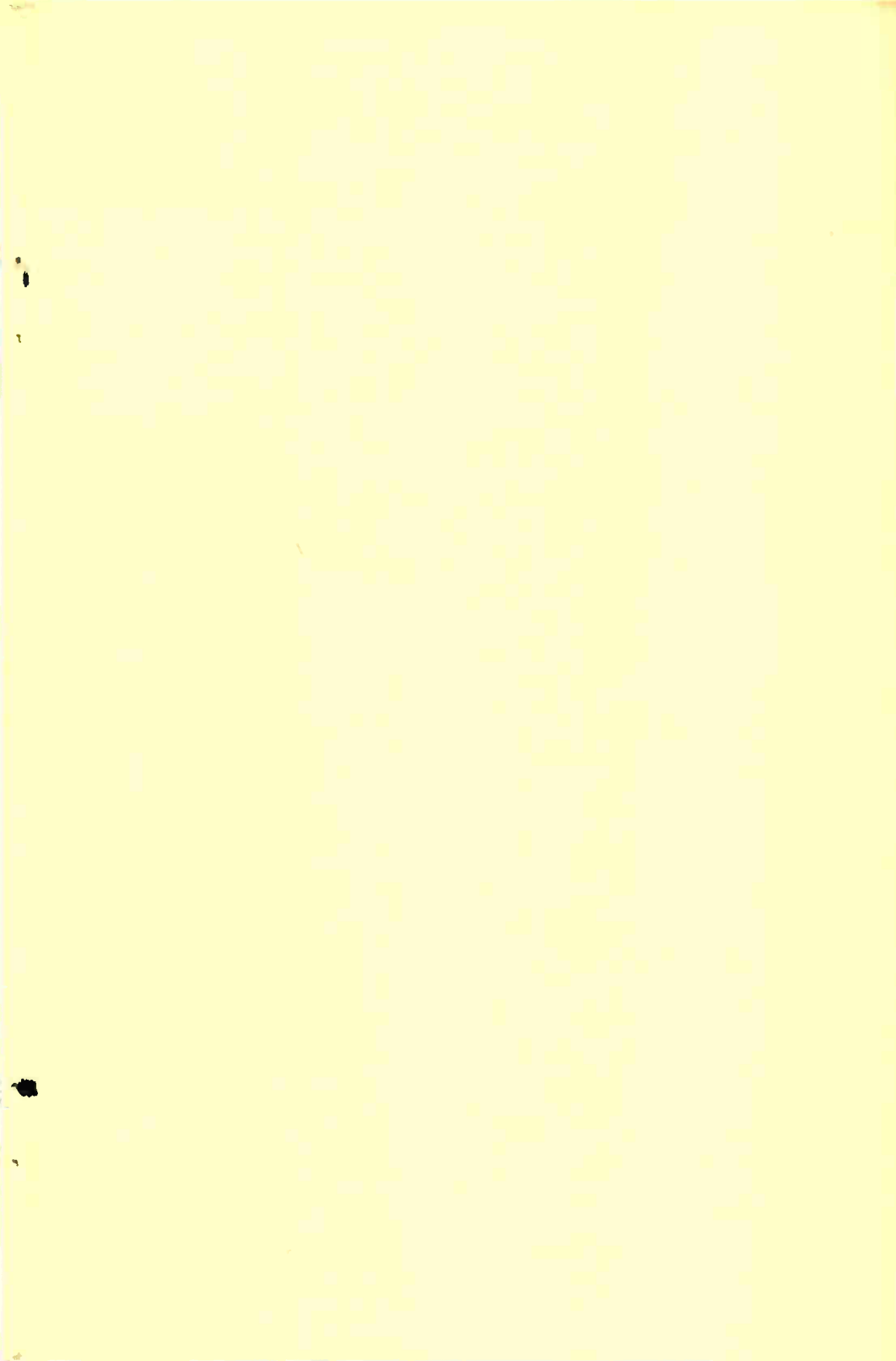
MAGNETIC AMPLIFIERS
PART 1
Lesson 2400B

DeVRY INSTITUTE OF TECHNOLOGY

MAGNETIC AMPLIFIERS

PART 1

Revised 1968

OPPORTUNITY

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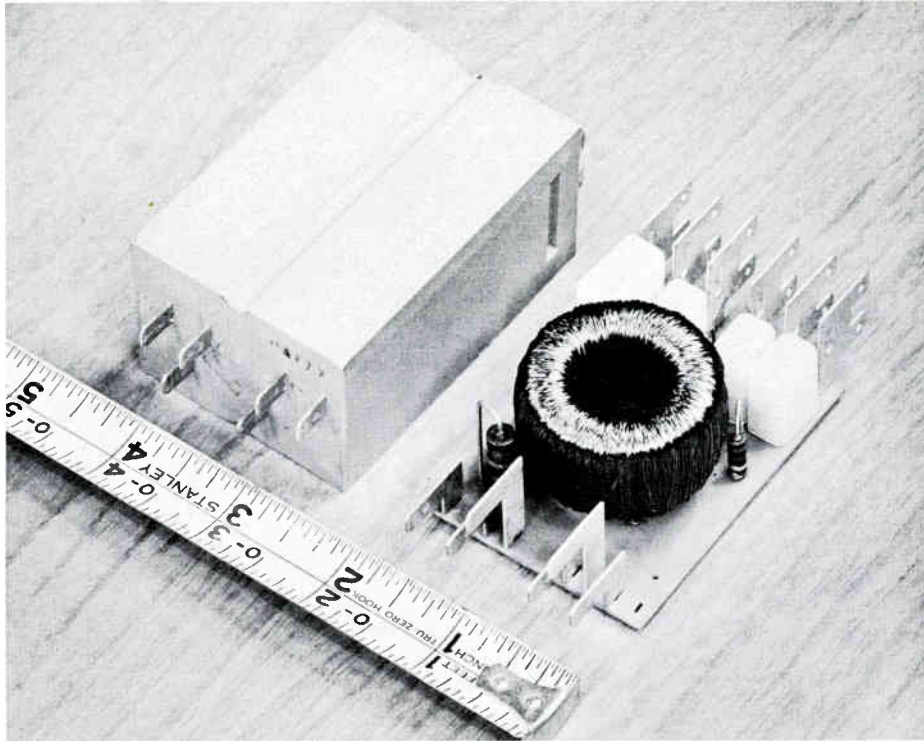
A magnetic amplifier designed for use in the memory circuit of a computer.
Courtesy Westinghouse Electric Co.

MAGNETIC AMPLIFIERS

PART 1

CONTENTS

*****

The man who does things makes
many mistakes but he never
makes the biggest mistake of all
--doing nothing.

                    -Poor Richard

MAGNETIC AMPLIFIERS

In recent years the magnetic amplifier has become widely used as an amplifier and control device. The sudden increase in its use is largely due to the improved types of magnetic materials and diode rectifiers that are now available. These improvements have increased the efficiency of the magnetic amplifier to a practical level.

A magnetic amplifier is made up of combinations of saturable reactors, rectifier diodes, variable and fixed resistors, and transformers. Like a tube or transistor amplifier, the magnetic amplifier is a device that uses a small signal to control a large signal. Although all amplifiers have this function in common, each of them has special characteristics which makes it better for a certain job than the others. For this reason, each of these amplifiers is finding its own field of usefulness in electronics.

Magnetic amplifiers are rugged and free from drift. They operate at high efficiency, require a minimum of maintenance and are capable of operating at high temperatures. Also, they do not require the warm-up time that is characteristic of tube amplifiers. These characteristics make magnetic amplifiers ideal for applications in such systems as missile and rocket autopilots, range controls for large guns, and safety and control systems for nuclear reactors. Magnetic amplifiers are also used to control motor speed, to regulate the output of generators, to provide amplification in servomechanism systems, and as flip flops and memory devices in computer systems.

To illustrate the operation of a magnetic amplifier, let's examine the simple voltage divider circuit of Figure 1. Inductor L_1 and resistor R_1 are in series with an ac source. The source voltage divides between L_1 and R_1 in proportion to the opposition each offers to the source current. Suppose we adjust L_1 to offer much more opposition to current than R_1

does. Then a larger amount of the source voltage is developed across L_1 than across R_1. The opposition of L_1 to current is known as inductive reactance (X_L). By varying the reactance of L_1 we can control the current through and the voltage across R_1.

As simple as this may seem, it is the basic principle on which all magnetic amplifiers work. Consider resistor R_1 of Figure 1 to be the load of a magnetic amplifier. Inductor L_1 represents a variable inductor called a SATURABLE REACTOR. The saturable reactor is the heart of a magnetic amplifier, and the first requirement for an understanding of magnetic amplifiers is a knowledge of saturable reactor operation.

                    *   *   *

1. In Figure 1 the voltage across L_1 is directly proportional to the opposition L_1 offers to current. True or False?

2. By varying the inductance of L_1 in Figure 1, we can vary (a) the voltage of the ac source, (b) the resistance of R_1, (c) the voltage across R_1.

                    *   *   *

SATURABLE REACTORS

One common type of saturable reactor is shown in Figure 2. This saturable reactor has a circular iron core with two windings, L_1 and L_2. L_1 is known as the LOAD WINDING since it is usually connected in series with the load. L_2 is known as the CONTROL WINDING since it is used to control the current in the load winding. Notice the similarity between the circuits of Figures 1 and 2. Inductor L_1 in Figure 2 serves the same function as L_1 in Figure 1. Resistor R_1 represents the load which is connected in series with the ac source and the load winding L_1. The current through the load is varied by changing the inductive reactance of L_1.

The inductive reactance of load winding L_1 can be varied by controlling the current through control winding L_2. So by controlling the current through L_2 of Figure 2, we can control the load current.

To see how the reactance of the load winding can be controlled, let's take a closer look at the saturable reactor itself. Referring to the saturable reactor of Figure 2, suppose a direct current is applied to control winding L_2. This condition is shown schematically in Figure 3A, where the load winding and its circuit are omitted for simplicity. Current through L_2 causes magnetic lines of force to be set up in the core. As the resistance R_2 in series with L_2 is decreased, the dc current in L_2 increases and the number of lines of force in the core increases as shown in Figure 3B.

Figure 4 shows graphically how the number of flux lines in the core varies with the current through the control winding. The solid curve of Figure 4 is called a B-H curve. The vertical scale at the left represents the flux density (B) in the core. This is an indication of the number of magnetic lines of force per square inch in the core. The horizontal scale at the bottom represents the magnetizing force (H) which produces the flux in the core. This is the product of the current through the coil and the number of turns per inch, expressed as ampere-turns/inch. Since the windings of the coil are fixed, the magnetizing force is proportional to the current in the coil.

From Figure 4 we see that the flux in the core increases rather slowly at first as the magnetizing force H is increased. As the magnetizing force is increased past 3 ampere-turns/inch, the flux in the core increases rapidly. As the magnetizing force nears 10 ampere-turns/inch the increase in flux in the core slows down. Point A designates this point on the curve. Beyond point A a large change in magnetizing force produces only a small change in flux density. Point A is called the SATURATION POINT. This is the point above which an increase of magnetizing force does not produce much of an increase in flux density within the core. The region to the right of the saturation point is the SATURATION REGION.

The saturation point does not mean that the core is so full of lines of flux that no more can be added. It means that beyond point A it takes a large increase in magnetizing force to produce a small increase in flux density. A reactor used in this way is called a saturable reactor.

*   *   *

3. With a magnetizing force of 5 amp-turns/inch, the core represented by Figure 4 is saturated. True or False?

4. When a core is saturated, the number of lines of force through it (a) can still be increased greatly, (b) can be increased only slightly.

*   *   *

A core can be saturated in a positive direction or in a negative direction. To illustrate this, suppose the core in Figure 3 is in positive saturation. The circular arrows represent the direction of flux. If we reverse the polarity of battery B_1 so current flows in the opposite direction through L_2, the direction of flux lines also reverses. If the current in L_2 is increased in this direction until the core can hold no more lines of force, the core is said to be negatively saturated. Negative saturation is shown at the lower left of Figure 5. If an alternating current is applied to a saturable reactor, the core flux increases in one direction on one alternation

A saturable reactor in various stages of assembly, with the completed unit in its case at the lower right.
Courtesy EMP Electronics
Research Laboratories, Inc.

of the supply voltage. On the opposite alternation, core flux increases in the other direction. If the amplitude of

the alternating current is large enough, the core alternately becomes positively saturated and then negatively saturated.

The ability of a material to pass magnetic lines of force is called **PERMEABILITY**. The permeability of a material is a ratio of the ease with which magnetic lines of force can be set up in the material to the ease with which they can be set up in air. Suppose coil L_2 of Figure 3A has air as its core and not the core shown. Air has a permeability of 1. Let's assume 100 lines of force are set up in this air core coil. If a metallic core with a permeability of 3 is inserted in L_2, the same coil would develop 300 lines of force.

Let's see how the permeability of a core can be varied. The current through L_2 is small in Figure 3A. Thus, the magnetizing force applied to the core is small and the number of lines of force in the core is also small. At this time an increase in magnetizing force can easily increase the number of flux lines in the core. The permeability of the core is high since the core can be magnetized easily.

The greater the number of lines of force in a core, the harder it is to magnetize it further. To illustrate this let's consider the magnetizing force applied to L_2 in Figure 3B to be large enough to saturate the core. At this time a large increase in magnetizing force is required to change the number of lines of force in the core a small amount. Since it is hard to magnetize the core under this condition, the permeability of the core is low. By varying the amount of magnetizing force applied to a winding on a core, we can vary the permeability of the core from a high value to a low value.

The dashed curve in Figure 4 represents the permeability of the core material. THE INDUCTANCE AND THE IN-DUCTIVE REACTANCE OF A COIL VARY DIRECTLY WITH THE PERMEABILITY OF THE CORE. Therefore, the dashed permeability curve also shows how inductance and inductive reactance vary in the reactor with changes in the magnetizing force.

The opposite of permeability is **RELUCTANCE**. This is the ability of a material to oppose magnetic lines of force. It is the reciprocal of permeability. Thus, a core whose permeability is 3 has a reluctance of 1/3 or .333.

*   *   *

5. The ability of a material to pass lines of force is called (a) reluctance, (b) permeability.

6. If the permeability of a core increases, the inductance of the coil on the core (a) increases, (b) decreases.

*   *   *

Now let us consider a saturable reactor with two windings. This is shown in Figure 6. Control winding L_2 has a dc source. Load winding L_1 is connected in series with the load represented by R_1 and an ac source. With the dc control current set at point B of Figure 4, any small increase of dc through the control winding causes the core flux to approach the saturation point. This reduces the permeability of the core. With lower permeability the inductance and inductive reactance of L_1 decrease. A decrease of inductive reactance lowers the impedance of the load circuit, causing an increase in load current. THUS, INCREASING CONTROL CURRENT DECREASES THE IMPEDANCE OF THE LOAD CIRCUIT. If the control current is decreased, the permeability of the core increases, causing an increase in inductance and inductive reactance, and resulting in a decrease in load current.

Load winding L_1 has comparatively few turns of heavy wire because of the large load current it must carry. Control winding L_2 has many turns of fine wire. Because of this a small current in the control winding can control a large current in the load winding. This is why a circuit such as Figure 6 provides gain or amplification. A direct current of a few milliamperes in the control winding can control an alternating current of many amperes in the load winding.

*   *   *

7. In Figure 6, L_1 is the load winding and L_2 is the control wind-
   ing. True or False?

8. In Figure 6, L_1 has many more turns than L_2. True or False?

*   *   *

SATURABLE REACTOR CHARACTERISTICS

The saturable reactor of Figure 6 has operating character-
istics similar to those of a thyratron grid controlled recti-
fier.   The dc load current in Figure 6 is determined by the
length of time the core of the reactor is saturated during a
cycle of the ac source.   As mentioned earlier, when the
core is saturated the reactance of L_1 is very low, and when
the core of L_2 is not saturated the reactance of L_1 is high.
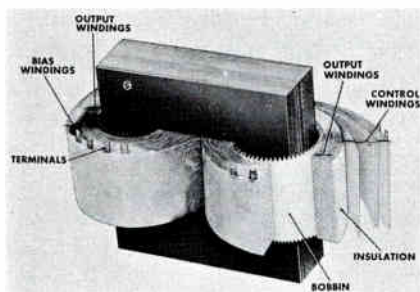
A magnetic amplifier built on a two-
legged core. The cutaway section shows
how the windings are assembled on the
core.

Courtesy Vickers, Inc.

To illustrate how this action
controls the dc load current,
let's assume the reactor of
Figure 6 has the ideal B-H
curve of Figure 7. This "per-
fect" response curve would be
impossible to achieve in prac-
tice, but we can use it for pur-
poses of illustration.

Assume the dc control cur-
rent in Figure 6 is zero.
Under these conditions, the
ac source produces a magne-
tizing force as shown by the
sine curve on the H axis in Figure 7. Neither the positive alter-
nation nor the negative alternation of the ac source develops
enough magnetizing force (H) to drive the core of the reactor
into saturation. Thus, the reactance of L_1 remains high dur-
ing the entire cycle of the ac supply. As a result, load current
is very low as shown by the load current waveform of Figure 8.

Now suppose R_2 in Figure 6 is adjusted to provide a dc cur-
rent in L_2 which provides a dc magnetizing force as shown
in Figure 9.   The magnetizing force developed by the ac
source varies around this dc level as shown in Figure 9.
The total flux in the core is equal to the sum of the flux
developed by the ac source and the flux developed by the
control winding.   Notice in Figure 9 that the positive alter-
nation of the ac source develops enough magnetizing force
to saturate the core.   The point at which the core is driven
into saturation is called the FIRING POINT.

During the time that the core is saturated, the reactance of
L_1 is very low, thus permitting a high load current.   The
reactance of L_1 remains low for the length of time that the
core is saturated.   The load current under these conditions
is as shown in Figure 10.   Notice that the load current is
dc.   In addition to controlling load current, the reactor
rectifies the ac source voltage.

The width of the load current pulses is determined by the
point at which the core saturates or fires during the input
cycle.   In turn, the average dc load current is proportional
to the width of the load current pulses.   If the dc control
winding current is increased further, the core will saturate
even earlier in the cycle.   This develops a higher average
dc in the load.   In summary, a low dc control winding cur-
rent causes the core to fire later in the input cycle, thus
developing narrow load current pulses and a low average
dc in the load.   Increasing the dc control winding current
causes the core to fire earlier during the input cycle, thus
developing wide load current pulses and a high average dc
in the load.

*   *   *

9.   While the core is driven into saturation as shown in the B-H
      curve of Figure 9, the reactance of the load winding is
      (a) very large, (b) very small.

*   *   *

BASIC SATURABLE REACTOR CIRCUITS

The basic circuit of Figure 6 has certain disadvantages. For one thing, efficiency is reduced by a transformer action between the control and load windings. The varying flux produced by the load winding L_1 induces a large varying voltage in control winding L_2. Since the control winding has a low impedance it permits a large current which dissipates a large amount of power. The large induced ac in the control winding sets up a varying core flux. This, in turn, causes unwanted variations in the inductive reactance of the load winding, thus changing the output of the circuit.

One way to prevent ac in the control winding is to place an iron-core choke in series with the control winding. This choke offers low resistance to direct current, but presents high impedance to alternating current. With less current there is less power dissipated by the control winding. This method is used mostly in low frequency control circuits with a large turns ratio between control and load windings.

This 400 cycle magnetic amplifier raises the level of an error signal so it will drive a control unit. Notice the compact design and the plug-in base.
Courtesy Airpax Electronics, Inc.

Another way to reduce these undesired effects is shown in Figure 11. Here, two saturable reactors are used, with the load windings connected series-aiding and the control windings connected series-opposing. The dc circuit operates correctly because the degree of saturation does not depend upon the direction of the control windings. However, because the control windings are series-opposing, any voltage induced in one control winding by ac voltage in the load winding is cancelled by an equal and opposite voltage induced in the other control winding. Thus, the un-

wanted induced alternating currents do not appear in the control circuit in Figure 11. The same results can be obtained by connecting the control windings series-aiding and the load windings series-opposing.

*   *   *

10. Windings L_2 and L_4 in Figure 11 are series-aiding. True or False?

*   *   *

In two-core arrangements, the problem of insulation between adjacent cores becomes important when the turns ratio of load windings and control windings is high. Much insulation is needed because of the large voltages encountered. Thus, two-core reactors are normally used in magnetic amplifier circuits where the turns ratio is low.

A very common saturable reactor uses a three-legged core. The load windings are wound on the outer legs and the control winding is wound on the inner leg. A reactor of this type is shown in the diagrams of Figure 12.

To understand how the core functions, assume a dc voltage (E_{DC}) of the polarity indicated in Figure 12A is applied to control winding L_1. For this example, assume there is no ac voltage applied to load windings L_2 and L_3. Notice that the magnetic flux passes downward through the two outer legs, and upward through the center leg of the core. The flux through one outer leg is equal in density to the flux through the other outer leg. If we change the polarity of the dc, the direction of flux is reversed, but nothing else changes. By increasing the amount of direct current, each leg of the core can be saturated.

Suppose now that no dc is applied to the control winding, but that an ac voltage (E_{AC}) is applied to the load windings. Consider the alternation of this ac voltage in which the polarity is as indicated in Figure 12B. The direction of

magnetic flux is downward through the left leg, and upward through the right leg of the core. These lines of force are equal in density but opposite in direction. The magnetic circuit for the flux produced by L_2 is through the left leg and the center leg and the circuit for the flux of L_3 is through the right leg and the center leg. Thus, the center leg carries the lines of force produced by both load coils.

In the center leg of the core, the flux direction produced by L_2 is upward. The flux direction produced by L_3 through the center leg is downward. These fluxes are equal and opposite and thus cancel each other. That is, the net flux produced in the center core by the ac in the load coils is zero. The flux lines of the two outer coils may be considered as joining in a common path through the outer core legs.

Now let's consider the action of the saturable reactor when ac is applied to the load windings and dc is applied to the control winding. As shown in Figure 12C, the flux through the CENTER LEG is produced by the dc control current. The flux through the OUTER LEGS is the resultant of that produced by both the control and load windings. Consider the half cycle of ac when the polarity is as shown in Figure 12C and the ac is at its peak value. The flux is large in the left leg of the core because the fluxes developed by L_1 and L_2 add. The flux is small in the right leg because the fluxes developed by L_1 and L_3 are opposing and tend to cancel each other. Since the flux in the left leg is very large, this part of the core is saturated and the reactance of L_2 is very small. The flux in the right leg is small. This part of the

The unit at the right is the magnetic amplifier at the left with its protective case removed. Note the saturable reactor mounted at the rear of the unit.
Courtesy Sangamo Electric Company

core is far from saturation and therefore the reactance of L_3 is large. The total load winding reactance is the sum of the L_2 and L_3 reactances since L_2 and L_3 are connected in series.

On the next half cycle, the polarity of E_{AC} reverses but the total inductive reactance remains constant. As the reactance of L_3 decreases, the reactance of L_2 increases. In order to change the inductive reactance of the coils, the dc in the control winding must be changed. As core saturation is approached, the rate of change in magnetic flux decreases and the total inductive reactance of the load coils decreases.

*   *   *

11. The load winding current in Figure 12C causes a large flux in the center leg of the reactor. True or False?

*   *   *

SATURABLE REACTOR SYMBOLS

Many different saturable reactor symbols are in use today. Figure 13 shows several of the more common ones. Figures 13A and 13B represent the circuit of Figure 11. Standard transformer symbols are used to represent the saturable reactors.

Figures 13C and 13D represent the circuit of Figure 12. Again standard transformer symbols are used except for the indication of the core. The line through the core represents a magnetizing curve such as that of Figure 7. This line is used to show that the core material of a saturable reactor is not the same as that of a common transformer. In schematic diagrams it is also common to abbreviate the term saturable reactor as SX. If more than one reactor is used, they are abbreviated SX_1, SX_2, SX_3, and so on.

DC MAGNETIC AMPLIFIERS

Reactance exists only in ac (or pulsating dc) circuits. There-

fore, the load circuit has an ac voltage source to provide
the changes in reactance required in the load circuit of a
saturable reactor. The previous circuits show methods of
controlling alternating current with direct current. Sup-
pose, however, a controlled direct current is desired.
This action is accomplished by the addition of a rectifier in
the ac loop to change ac to dc. The circuit of Figure 14 is
an example of how a half wave rectifier is used to rectify
the load current.

The rectifier in Figure 14 is a semiconductor diode, desig-
nated D_1. Common types of semiconductor diodes used in
magnetic amplifier circuits are germanium diodes and sili-
con diodes. In the symbol for a semiconductor diode, the
bar represents the cathode and the triangle represents the
anode. Normal conduction is from cathode to anode, or in
terms of the symbol, from bar to triangle. The diode pre-
sents a relatively low resistance in the "forward" direction,
and presents a much higher resistance to current in the "re-
verse" direction, from anode to cathode. The load current
therefore is half wave dc. Both the forward and reverse
resistances have an important bearing on the operating
characteristics of a magnetic amplifier.

In Figure 14, B_1 provides control current for the ampli-
fier. R_1 varies the direct current through control winding
L_1 of the reactor. If the resistance of R_1 is decreased, the
current through L_1 increases and the reactances of load
windings L_2 and L_3 decrease. During ac supply alterna-
tions of the indicated polarity there is load current through
L_2 and L_3, rectifier D_1, and R_2. On opposite alternations
of the ac supply voltage, the load current is blocked by the
rectifier. Thus, the load current is half wave dc, with an
amplitude that depends on the supply voltage and the react-
ances of L_2 and L_3.

Suppose resistance R_1 is increased. This reduces the dc
control current through L_1. With a lower value of control
current, the reactances of L_2 and L_3 increase. The pulses
of load current are reduced in amplitude by this increase in

the reactances of L_2 and L_3.

A decrease in the resistance of R_1 permits a larger dc control current through L_1, and the reactances of L_2 and L_3 decrease. This causes an increase in the amplitude of the pulsating dc load current.

Note that the control current, the reactances of L_2 and L_3, and the load current are related. The reactances are inversely proportional to the control current, and the load current is directly proportional to the control current.

This rugged magnetic amplifier unit is designed for industrial control service.
Courtesy Control Division of
Magnetics, Inc.

In half wave rectification there is load current during only half of the supply cycle. This results in a large amount of

ripple, and calls for elaborate filter systems. To reduce
the ripple a full wave rectifier can be used. The type of full
wave rectifier most commonly used in magnetic amplifiers
is the bridge rectifier. This arrangement is shown in Fig-
ure 15. L_1 is the control winding, and L_2 and L_3 are the
load windings.

When the polarity of the ac supply is as shown, the load cur-
rent path is shown by the solid arrows.   This current is
through D_1, through load resistance R_2, through D_2 to L_2,
through L_2 and L_3 to the positive terminal of the ac source.
On the other alternation the load current path is through L_3,
L_2, D_3, R_2, D_4 and back to the supply.   This current path
is shown by the broken arrows. On both alternations of the
ac supply, current passes in the same direction through the
load.   Thus, there is a voltage of the indicated polarity
across the load during each alternation of the ac source.
As in the half wave rectifier of Figure 14, the amplitude of
the rectified load current in Figure 15 depends upon the set-
ting of R_1 in the control circuit.

*   *   *

12. The outputs of the magnetic amplifiers shown in Figures 14
     and 15 are (a) alternating current, (b) direct current.

13. The rectifier circuit of Figure 15 produces a full wave dc
     output.   True or False?

*   *   *

MULTISTAGE MAGNETIC AMPLIFIERS

An amplifier with a dc output can be used to control another
amplifier. The second amplifier, by use of a bridge rectifier
in its ac output circuit, can be used to control a third ampli-
fier.   The third amplifier can control a fourth, and so on.
Amplifiers connected in this way are said to be CASCADED.

Figure 16 shows three magnetic amplifier stages in cascade.

In the SX_1 stage the dc current in L_1 controls the ac through L_2 and L_3, which is converted to dc by the bridge circuit made up of diodes D_1 through D_4. The controlled dc output of the bridge circuit is applied to L_4, the control winding of SX_2. This controls the second stage, and the amplified and rectified output of this stage is applied to L_7, the control winding of SX_3. The amplified and rectified output of the third stage is then applied to a load, (R_1) or it may be used to control a fourth stage.

AC voltages are applied to the load windings of all three stages and these ac voltages are converted to dc in all three stages. The current gain of each stage may be anywhere from 10 to 100. Thus, the output of these three stages is anywhere from 1000 to 1,000,000 times the input. Current gain is the ratio of output to input current. A further explanation of this gain is given in Appendix A at the back of this lesson.

There is a limit to the number of stages and the overall sensitivity in circuits of this type. This limit depends on how much current there is in the output circuit or ac loop when there is zero current in the control circuit or control loop. There is some current in the ac loop at all times because the reactance of the load coils can never be infinite. This current is called **QUIESCENT LOAD CURRENT**. Suppose the total reactance of L_2 and L_3 in Figure 16 is 2,512,000 ohms, and that the opposition of the $D_1D_2D_3D_4$ bridge and L_4 brings the total opposition up to 2,513,200 ohms. By Ohm's Law, the current in the ac loop is 110 volts divided by 2,513,200 ohms, or .043 ma.

Suppose all three reactors of Figure 16 are identical, having a gain of 10, and that a control current of 4 ma will saturate any reactor. With three stages of amplification and with no input current applied, the output current of SX_3 is .043 $\times$ 10 $\times$ 10, or 4.3 ma. If you added a fourth stage, the output from SX_3 is large enough to saturate SX_4. This occurs with no input signal applied to SX_1. The whole amplifier is now useless because the input cannot control the

output. Even without the fourth stage, the 4.3 ma output of SX_3 is not a true indication of the input current, which is zero.

<center>*   *   *</center>

14. In Figure 16, the output of the first stages is the current through winding L_4. True or False?

15. In Figure 16, L_4 is the (a) control winding of SX_2, (b) load winding of SX_1.

<center>*   *   *</center>

COMPENSATED MAGNETIC AMPLIFIERS

To overcome the undesirable effects of quiescent load current, compensated magnetic amplifiers are used. A compensated magnetic amplifier is an amplifier in which the quiescent load current is zero when its control current is zero. An example of a compensated magnetic amplifier is shown in Figure 17. The ac loop consists of the secondary of T_1 in series with L_2, L_3 and L_4. A bridge circuit is connected between the junction of L_3 and L_4, and the center tap of the T_1 secondary. L_4 is used to balance the amplifier in such a way that the output current is zero when no control current is applied. A reactor used for this purpose is called a COUNTERPOISE REACTOR.

This magnetic amplifier relay consists of a high-gain magnetic amplifier loaded by a rugged relay. This arrangement results in a very high sensitivity.

Courtesy Ad Yu
Electronics Lab., Inc.

Counterpoise reactor L_4 is so designed that its reactance is equal to the total reactance of L_2 and L_3 when no current is applied to control winding L_1. The total voltage from the secondary of T_1 is impressed across L_2, L_3 and L_4. Half

of the voltage is across L_2 and L_3. The other half is across L_4. Thus, voltage E_1 is equal to voltage E_2. Assuming the tap is at the exact electrical center of T_1, E_1 is equal to E_3, and E_2 is equal to E_4.   Therefore, no voltage appears across points A and B, and there is no conduction in the bridge circuit.

With current in the control loop, the inductive reactance of L_2 and L_3 decreases, so that this reactance is less than that of L_4. As a result, E_1 decreases and E_2 increases. The bridge circuit is now unbalanced and begins to conduct. When the top of T_1 is positive, conduction takes place from B through D_4, R_1 and D_2 to A. When the top of T_1 is negative, electron flow is from A through D_3, R_1 and D_1 to B. Thus, the counterpoise reactor L_4 eliminates ac load current when the control current is zero, but allows ac load current when the control current is applied.

*   *   *

16. Winding L_4 in Figure 17 is (a) a saturable reactor winding, (b) a counterpoise reactor.

17. The purpose of L_4 in Figure 17 is to reduce the output current to zero when no control current is applied to the circuit. True or False?

*   *   *

HYSTERESIS

Suppose you place a demagnetized material within a coil. If you increase the magnetizing force from zero in a positive direction, the flux density in the material increases as shown by the curve from 0 to a in Figure 18. But when you decrease the magnetizing force to zero, the flux density in the core material does not return to zero.   Instead, the flux density follows curve ab of Figure 18 stopping at point b. Thus, the B-H curve for the decreasing value of magnetizing force is not the same as the original rising curve.

The flux that remains in the material after the magnetizing force is returned to zero is called RESIDUAL FLUX. Point b represents the residual flux in Figure 18. The amount of residual flux depends on the RETENTIVITY of the material. Retentivity is the ability of a material to retain magnetism after the external magnetizing force is removed. To re-move this residual magnetism you must apply a magnetizing force in the opposite direction. This opposite magnetizing force results in curve bc of Figure 18.

If you increase the magnetizing force further in the negative direction, the flux density follows curve cd. If you return the magnetizing force to zero and then increase it in a posi-tive direction, the flux density follows the curve from d to e, from e to f, and then from f to a, to complete the loop. At this point the material is said to have been taken through a complete cycle. Note that the original B-H curve from 0 to a is not retraced. This can only be done if the magnetiz-ing force is applied to the material in its demagnetized state.

The curve of Figure 18 is called the HYSTERESIS LOOP of the material. Each time a cycle is completed, an amount of energy which is proportional to the area of the hysteresis loop is lost. The term hysteresis means to lag. It refers to the fact that the flux density B lags behind the applied magnetizing force H, as shown by the curve. That is, the change in the magnetic state of the material lags behind the change in magnetizing force. A hysteresis curve formed by a magnetizing force that changes slowly is called a static hysteresis loop. A hysteresis curve formed by a rapidly changing magnetizing force is called a dynamic hysteresis loop.

The shape of the hysteresis loop depends on the core mate-rial (the higher the permeability, the narrower the loop), the thickness of the sheets that make up the core (the thicker the sheets, the wider the loop), the temperature of the core (the higher the temperature, the narrower the loop), the frequency of the applied magnetizing force (the higher the frequency, the wider the loop), and the amplitude of the

applied magnetizing force (the greater the amplitude, the wider the loop).

REDUCTION OF HYSTERESIS LOSSES

Hysteresis losses can be reduced by careful selection of core materials.   To illustrate this, look at Figure 19A.
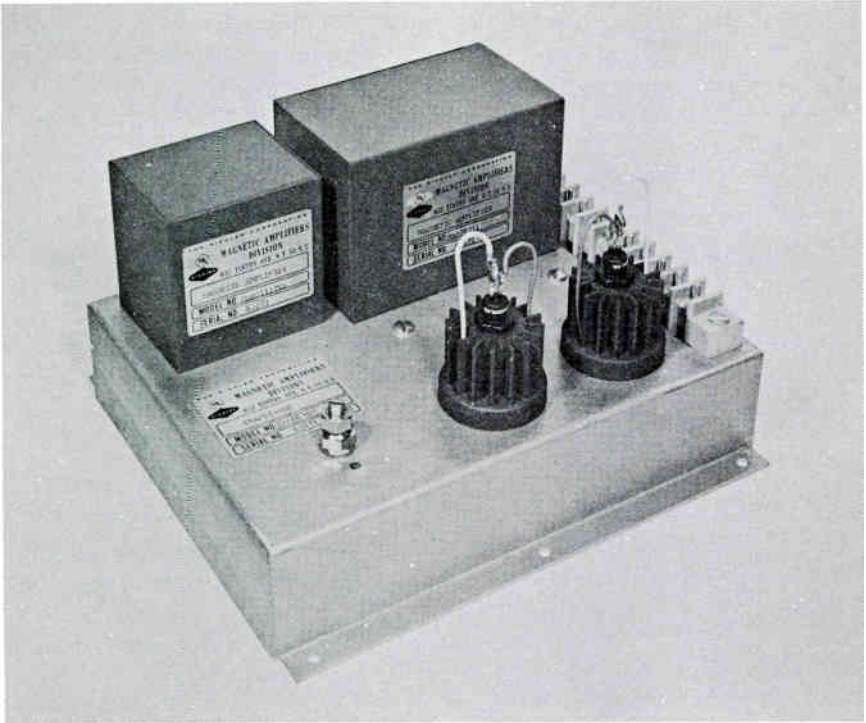
This high power servo amplifier uses a transistor-magnetic pre-amp.   The unit has a silicon controlled rectifier power stage.

Courtesy The Siegler Corporation
Magnetic Amplifiers Division

This is the hysteresis curve for a hard steel core.   Notice that the area within the curve is larger than that for the soft steel core of Figure 19B.   The soft steel core has smaller hysteresis losses than the hard steel core.   Industry has done much to decrease hysteresis losses by devel-

oping new core materials.

Hysteresis losses are reduced in another way which we have already studied. In Figure 14 a diode is used in the load circuit to produce a pulsating direct current. In effect, this reduces hysteresis losses. Let's examine this more closely by looking at the hysteresis loop shown in Figure 20. If a large ac magnetizing force is applied to a core, the flux density in the core varies as shown in Figure 20. The flux density follows the curve a,b,c,d,e,f,g, and back to a again. This was explained for Figure 18.

If a rectifier is inserted in the load circuit, as shown in Figure 14, the current in the load is no longer ac. Load current is pulsating dc. The magnetizing force applied to the core is then a pulsating dc. This pulsating magnetizing force is shown in Figure 20. The flux density no longer follows the path shown before. Flux density now varies from point a to point b, from point b along the broken line to point g, and from point g back to point a. This cycle repeats for each pulse.

The area enclosed by a, b and g is much smaller than that enclosed by a,b,c,d,e,f and g. Since hysteresis losses are directly proportional to the area within a hysteresis loop, the pulsating dc current in the load reduces the hysteresis losses of the reactor in Figure 14.

*   *   *

18. A saturable reactor core should have (a) high permeability, (b) low permeability to minimize losses due to hysteresis.

*   *   *

SUMMARY

The use of magnetic amplifiers has become widespread, because of certain advantages they have over tube and transistor amplifiers. The magnetic amplifier is an extremely

rugged device which is able to withstand excessive shock
and vibration.   Because of this, it is used in applications
where reliability must be maintained and where the require-
ments for continuous service are severe.

The heart of a magnetic amplifier is the saturable reactor.
The saturable reactor is simply a variable inductance. The
inductance of the reactor is varied by changing the flux
density in the reactor core. The characteristics of a satur-
able reactor are represented by the B-H curve for the re-
actor.

With magnetic amplifiers, it is possible to obtain either ac
or dc outputs.   If dc is desired, rectifiers are used in the
ac circuit.   Rectifiers are devices used in magnetic ampli-
fiers to convert ac to pulsating dc.   When this is done, the
dc output can be used to control a second amplifier.   If the
second amplifier uses rectifiers, its output can be used to
control a third stage, and so on.   Amplifiers connected in
this way are said to be cascaded. The number of amplifiers
that can be cascaded is limited due to the ac quiescent cur-
rent when the control current is zero.   For this reason,
compensated magnetic amplifiers with counterpoise reactors
are used to keep the quiescent current at zero when the con-
trol current is zero.

Hysteresis is the lag of flux change in a material as com-
pared to the change in magnetizing force.   Hysteresis also
is thought of as a power loss. Circuit losses due to hyster-
esis can be made smaller by using low loss materials for
the cores of saturable reactors.   Hysteresis losses can
also be reduced by rectifying the load current.

IMPORTANT DEFINITIONS

COMPENSATED MAGNETIC AMPLIFIER - A magnetic amplifier in which the quiescent load current is zero when its control current is zero.

COUNTERPOISE REACTOR - [KOWN ter poyz ri AK ter]- In a compensated magnetic amplifier, the inductor that balances the amplifier in such a way that its quiescent output current is zero.

HYSTERESIS - [hiss ter EE sis] - The lag of flux change in a material as compared to the change in magnetizing force.

MAGNETIC AMPLIFIER - A saturable reactor, in which a small change of current through the control winding causes a relatively large change in current through the load winding. The output is thus an amplified form of the input.

REACTOR - A device used to provide inductive reactance in a circuit.

SATURABLE REACTOR - [SAT cher u b'l ri AK ter] - A reactor made of an iron-core inductance in which the reactance is variable over wide limits by changes of permeability due to changes of flux density.

SATURATION POINT - Applied to a magnetic core, that point on its magnetization curve above which a further increase of the magnetomotive force applied to the core will not produce much of an increase of flux density within the core.

APPENDIX A

GAIN OF MAGNETIC AMPLIFIERS
WITHOUT FEEDBACK

The gain of a magnetic amplifier without feedback is the ratio of the output current of the amplifier to its input current:

$$A_I = \frac{I_L}{I_{DC}}$$

where:

A_I = current gain
I_L = load current in amperes
I_{DC} = control current in amperes

In magnetic amplifiers, however, the ampere-turns of the ac and dc windings are equal when the amplifier is operated on the linear portion of the magnetization curve:

$$N_{DC}I_{DC} = N_{AC}I_{AC}$$

where:

N_{DC} = number of control winding turns
I_{DC} = current in control winding
N_{AC} = number of turns on the load winding
I_{AC} = current in the load winding

Rearranging the equation:

$$\frac{I_{AC}}{I_{DC}} = \frac{N_{DC}}{N_{AC}}$$

Since I_L is the same as I_{AC}, the ratio of the output to the input current (current gain) is:

$$A_I = \frac{I_L}{I_{DC}} = \frac{N_{DC}}{N_{AC}}$$

The output power of an amplifier is equal to the load current squared times the load resistance, and the input power is equal to the control current squared times the resistance of the control circuit. The power gain is the ratio of output power to input power:

$$A_P = \frac{I_L{}^2 R_L}{I_{DC}{}^2 R_C} = \frac{I_L{}^2}{I_{DC}{}^2} \times \frac{R_L}{R_C}$$

where:

     A_P = power gain in the amplifier
     R_L = load resistance in ohms
     R_C = resistance of control circuit in ohms

It was previously determined that the ratio of the output to input currents is equal to the ratio of the number of turns of the dc winding to the number of turns of the ac winding. Also, the ratio of the output to input currents is the current gain of the amplifier. Therefore, the power gain may be written as:

$$A_P = \frac{N_{DC}{}^2}{N_{AC}{}^2} \times \frac{R_L}{R_C} = \frac{N_{DC}{}^2 R_L}{N_{AC}{}^2 R_C} = (A_I)^2 \times \frac{R_L}{R_C}$$

Power gains from 10 to 100 are possible in magnetic amplifier circuits without feedback, depending on the design of the amplifier.

EXAMPLE:

Suppose a non-feedback amplifier has a control winding of 500 turns, and two series-opposing load windings of 50 turns each. The resistive load is 100 ohms and the applied control current is 500 milliamperes from a 12.5 volt source. Substituting the data into the current gain equation:

$$A_I = \frac{N_{DC}}{N_{AC}}$$

$$A_I = \frac{500}{2 \times 50} = \frac{500}{100} = 5$$

Substituting into the power gain equation:

$$A_P = (A_I)^2 \times \frac{R_L}{R_C}$$

$$R_C = \frac{E_{DC}}{I_{DC}} = \frac{12.5}{.5} = 25$$

$$A_P = 5^2 \times \frac{100}{25}$$

$$A_P = \frac{25 \times 100}{25} = 100$$

STUDENT NOTES

PRACTICE EXERCISE SOLUTIONS

1. True

2. (c) the voltage across R_1 -- By changing the inductance of L_1 the current through L_1 is varied. Since L_1 and R_1 are in series, the same current passes through L_1 and R_1. With a varying current through R_1, the voltage across R_1 changes.

3. False -- The core does not approach the saturated region until point A is reached.

4. (b) can be increased only slightly.

5. (b) permeability

6. (a) increases -- The permeability of a core is directly proportional to the inductance of the coil.

7. True

8. False -- The control winding of a saturable reactor has many more turns of wire than the load winding. This fact makes gain possible in a saturable reactor.

9. (b) very small.

10. False -- Windings L_2 and L_4 are series-opposing. This is done to effectively cancel unwanted currents induced in them by load windings L_1 and L_3.

11. False -- The flux in the center leg of the reactor of Figure 12C is caused by the control winding current. The ac fluxes in the center leg cancel.

12. (b) direct current -- The outputs of the ac supplies in the load circuits are rectified by the diodes.

13. True -- Diodes D_1, D_2, D_3 and D_4 form a bridge rectifier.

14. True

15. (a) control winding of SX_2 -- Windings L_2 and L_3 are the load windings of SX_1.
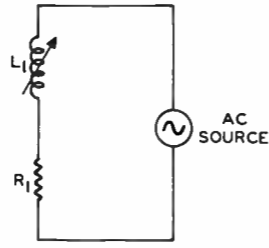
FIGURE 1
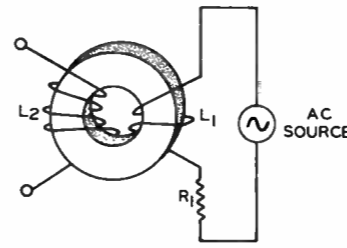
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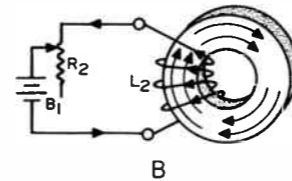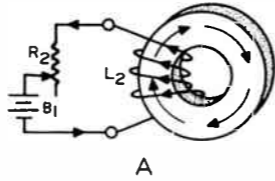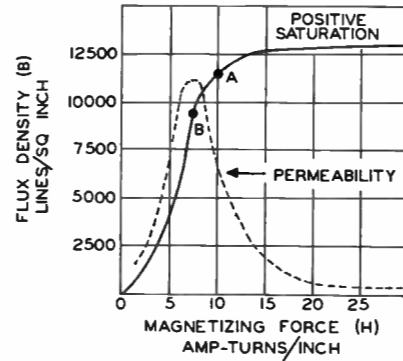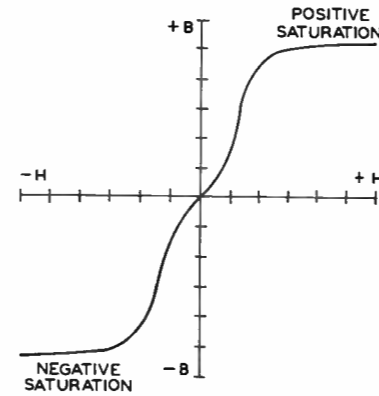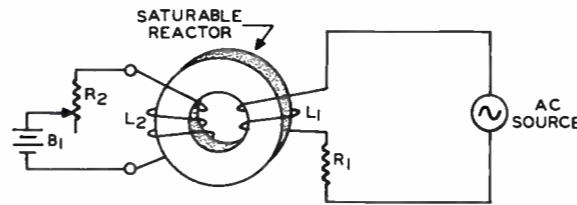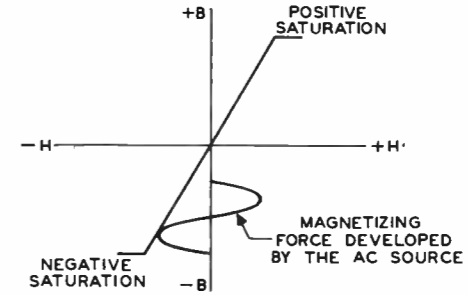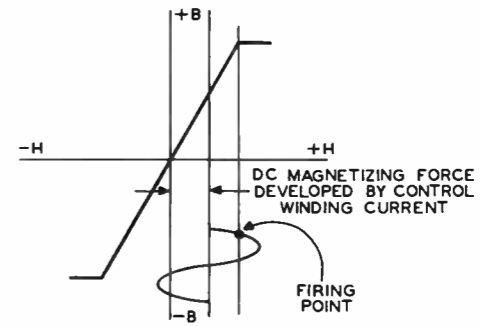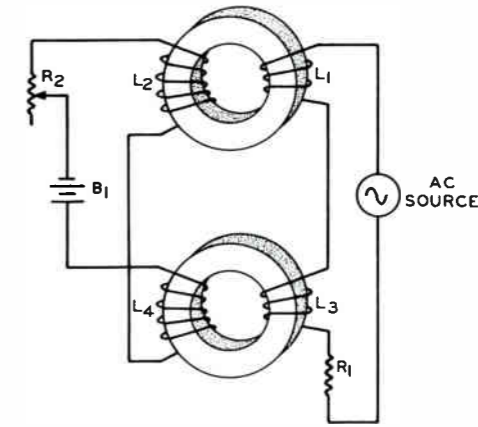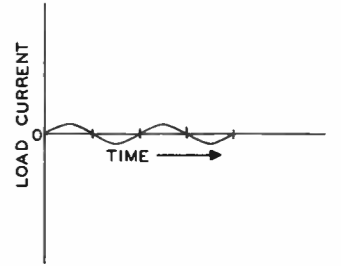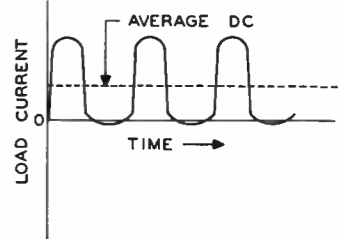
FIGURE 3

FIGURE 4

FIGURE 5

FIGURE 6

FIGURE 7

FIGURE 8

FIGURE 9

FIGURE 10

FIGURE 11

FIGURE 12

2400

2400

A

B

C

D

FIGURE 13

FIGURE 14

FIGURE 15

2400
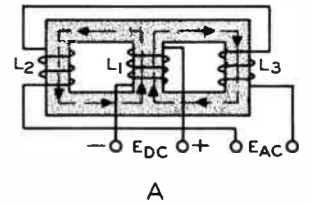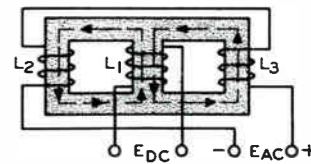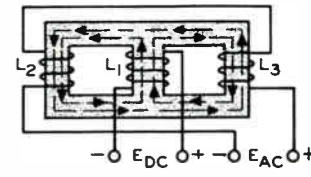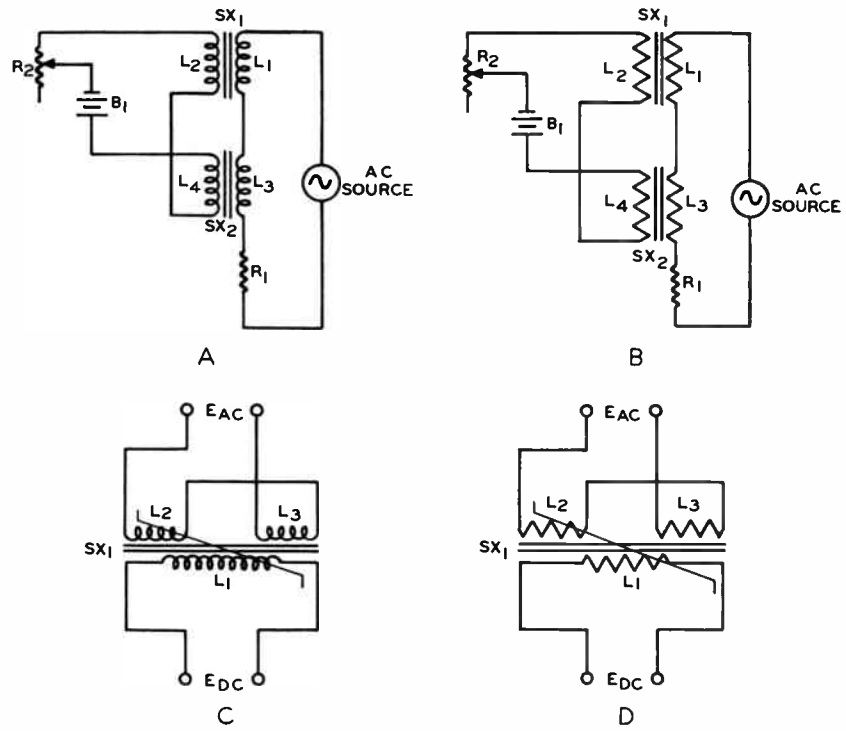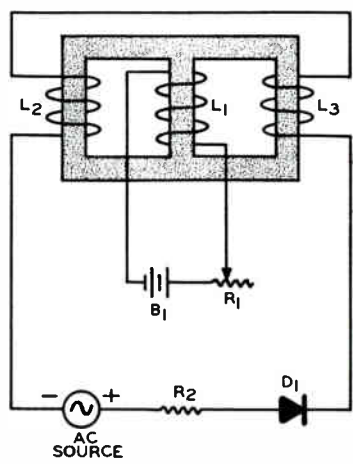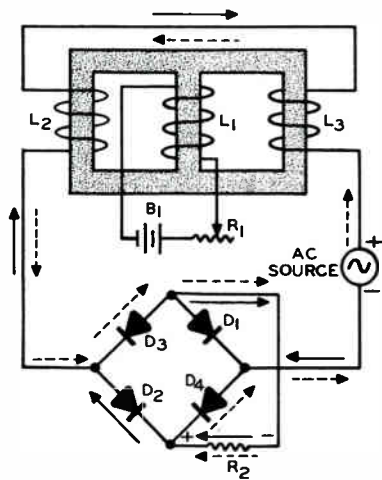
PRACTICE EXERCISE SOLUTIONS (Continued)

16. (b) a counterpoise reactor.

17. True -- L_4 is used to balance the amplifier and reduce the quiescent current to zero.

18. (a) high permeability -- In a core with a high permeability the losses due to hysteresis are low.
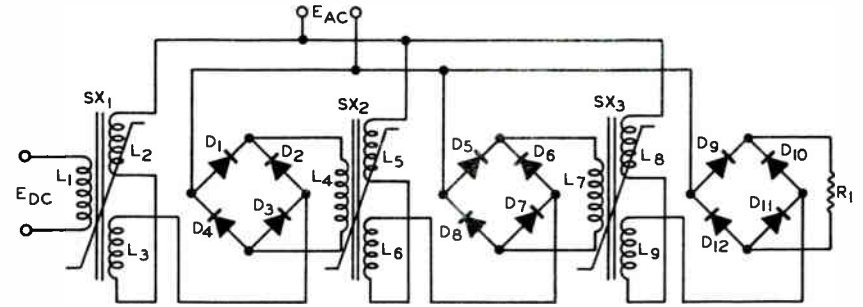
FIGURE 16
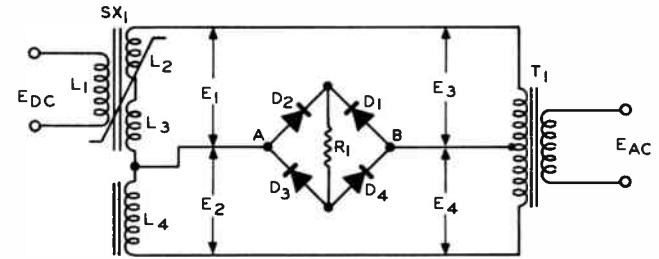
FIGURE 17

FIGURE 18

A

FIGURE 20

B

FIGURE 19

QUESTIONS

LESSON CODE

2400 B

Example: The person who invented the electric light bulb was
A
B
C ■
D
(A) Ty Cobb. (B) Joe Louis. (C) Thomas Edison. (D) Knute Rockne.

1. The ease with which magnetic lines of force pass through a material is known as
A
B
C
D
(A) permeability. (B) conductance. (C) reluctance. (D) resistance.

2. The control winding of a saturable reactor
A
B
C
D
(A) has fewer turns than the load winding. (B) always has the same number of turns as the load winding. (C) is made of heavy wire. (D) has many more turns than the load winding.

3. The inductive reactance of a coil
A
B
C
D
(A) varies directly with the permeability of the core. (B) varies the permeability of the core. (C) varies inversely with the permeability of the core. (D) is independent of the permeability of the core.

4. An increase in dc through the control winding of a saturable reactor INCREASES the current in the load winding by
A
B
C
D
(A) INCREASING the permeability of the core. (B) DECREASING the permeability of the core. (C) DECREASING the reluctance of the core. (D) INCREASING the reactance of the ac winding.

5. In the circuit of Figure 6, if the control current is increased so that the core saturates,
A
B
C
D
(A) the impedance of the load circuit decreases. (B) the impedance of the load circuit increases. (C) the permeability of the core increases. (D) current through the load decreases.

6. Losses due to hysteresis in a saturable reactor can be reduced by
A
B
C
D
(A) using a core with a larger hysteresis loop. (B) increasing the ac source voltage. (C) using a diode in the load circuit. (D) keeping the value of control current small.

7. In Figure 12C, the flux in the center leg of the core is
A
B
C
D
(A) produced by E_{AC}. (B) produced by E_{DC}. (C) produced by E_{AC} and E_{DC}. (D) a constantly reversing flux.

8. With a large control current in L_1 of Figure 14, the load current is
A
B
C
D
(A) a large alternating current. (B) very small. (C) full wave dc. (D) half wave dc.

9. In Figure 17, winding L_4
A
B
C
D
(A) is called a counterpoise reactor. (B) increases the output current of the circuit. (C) is the secondary of a step-up transformer. (D) is used to keep load current constant.

10. In the hysteresis loop of Figure 18, RESIDUAL FLUX is represented by the value of flux at
A
B
C
D
(A) point c. (B) point a. (C) point b. (D) point d.

Sweep Circuits

Lesson 2624

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CHICAGO   PHOENIX   TORONTO
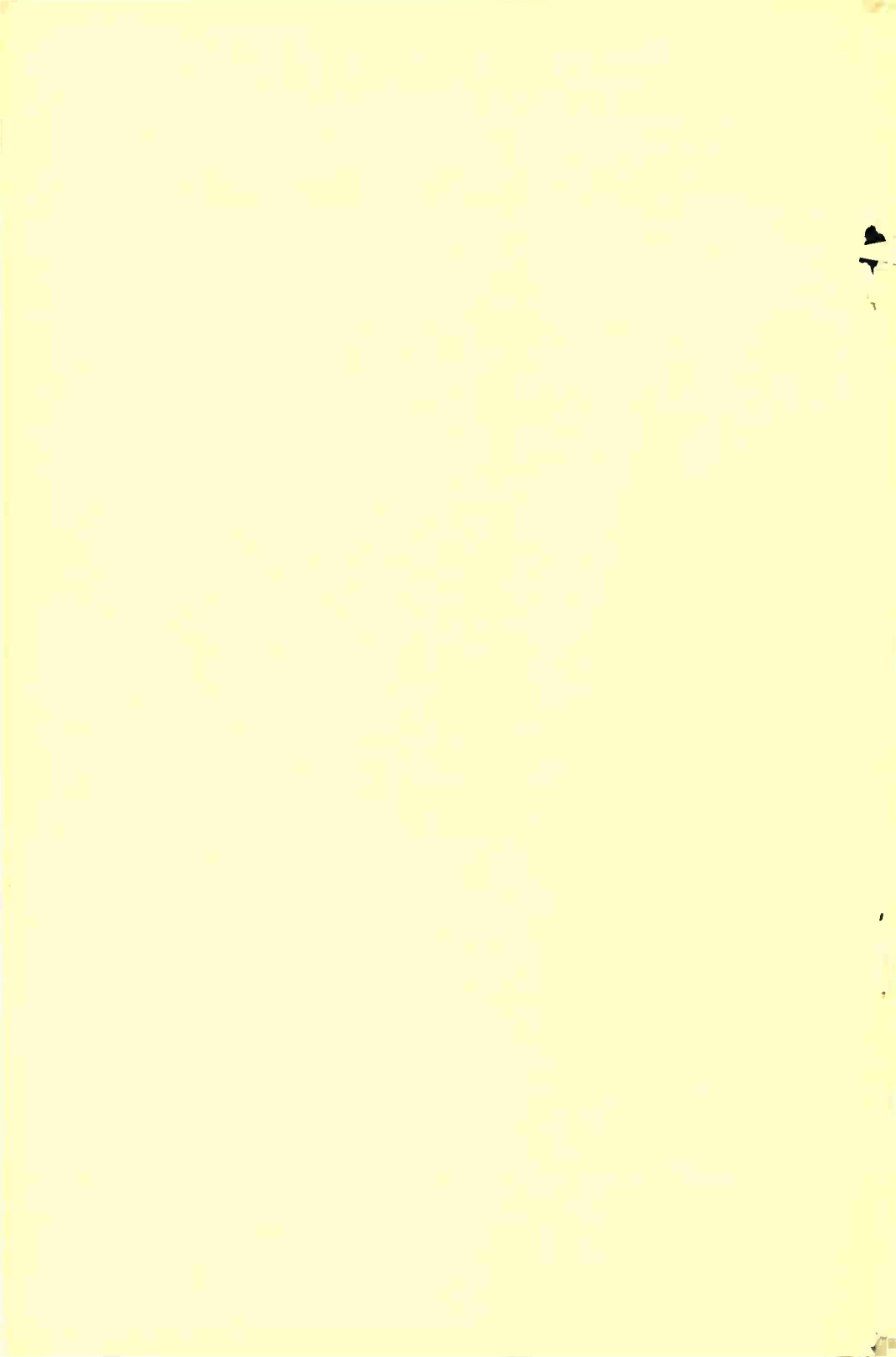
SWEEP CIRCUITS

Revised 1968

OPPORTUNITY

8
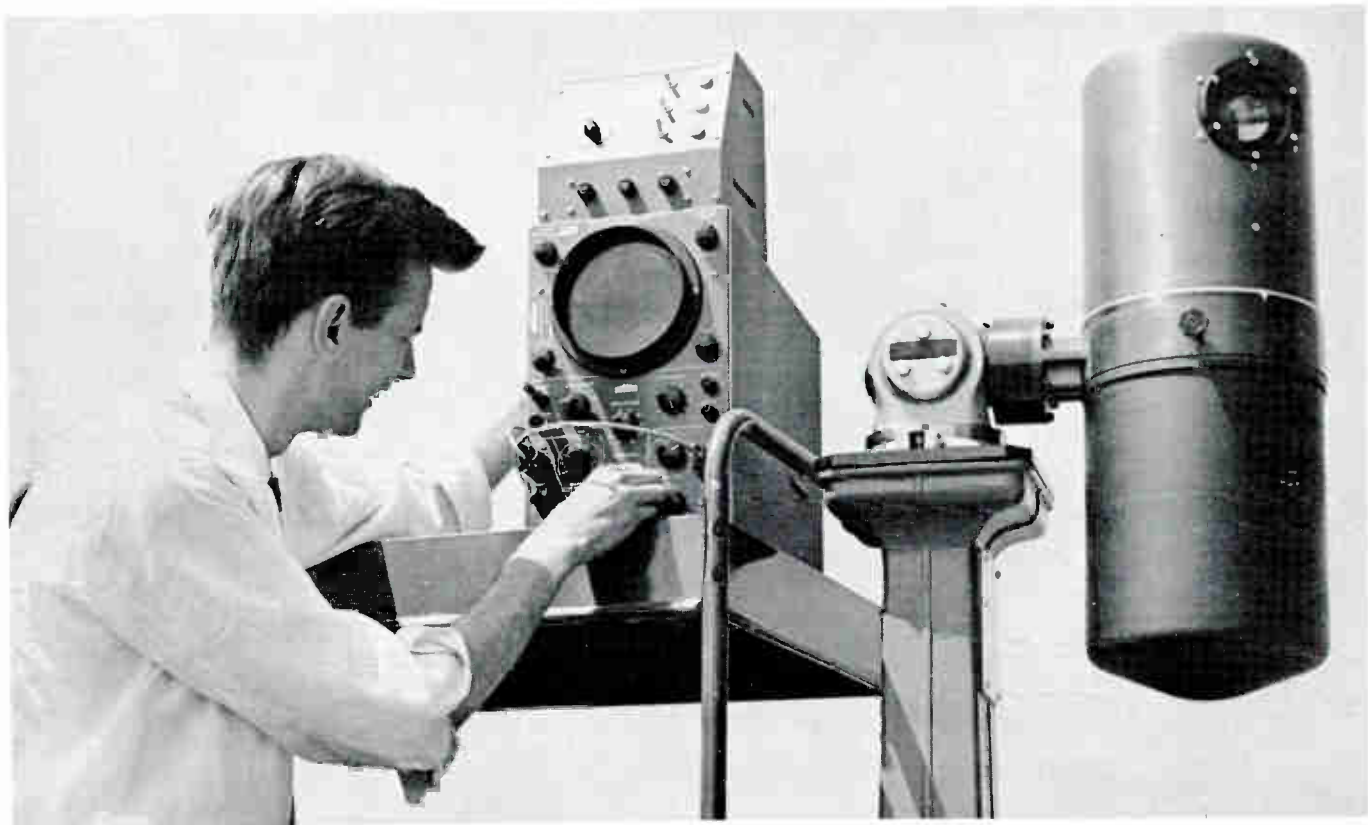
This infrared receiver was built to study the possibility of detecting objects by infrared techniques. The receiver output is displayed on the screen of the oscilloscope in the center of the picture.

SWEEP CIRCUITS

Contents

MEN ARE FOUR

He who knows not and knows not he knows not,
   is a fool—shun him;

He who knows not and knows he knows not,
   is simple—teach him;

He who knows and knows not he knows,
   is asleep—wake him;

He who knows and knows he knows,
   is wise—follow him.

                    —Ancient Proverb

SWEEP CIRCUITS

Cathode ray tubes, abbreviated crt's, are used in many types of electronic equipment. As an example, crt's are used in television cameras, receivers, and monitors; in oscilloscopes; in digital and analog readout equipment; and in radar systems. In a cathode ray tube an electron beam is directed from a cathode to a screen. Upon striking the screen the electron beam produces a spot of light.

To obtain visual indications, **SWEEP CIRCUITS,** sometimes called **DEFLECTION GENERATORS,** are needed to move the electron beam on the crt screen. In the electrostatic crt the movement of the beam depends on the voltages applied to the deflection plates. In the electromagnetic crt the movement of the beam depends on the magnetic fields developed in the deflection coils around the neck of the tube. In turn, these magnetic fields depend on the coil currents. With the proper deflection plate voltages or coil currents, the electron beam can be moved anywhere on the face of the crt.

A periodic movement of the electron beam on the face of a crt is called **SCANNING.** The scanning motions may be from one side to the other, from top to bottom, from center to outer edge, circular, or some combination of these motions.

BASIC DISPLAYS

Most oscilloscopes use electrostatic crt's. The waveform to be observed is applied to the vertical deflection plates and a linearly increasing voltage is applied to the horizontal deflection plates. Linearly increasing means that the voltage increases by the same amount during equal periods of time. A linearly increasing or sawtooth voltage is needed so that the electron beam moves at a steady rate across the crt screen.

Figure 1 shows a sine wave applied to the vertical deflection plates, and a sawtooth, below the screen, applied to the horizontal deflection

plates of a crt. These signals are adjusted so that both waveforms begin at exactly the same time.

At point 1 on the waveforms, the ungrounded horizontal plate (horizontal terminal) is negative with respect to the grounded plate. Thus, the negative electron beam starts from the left side of the screen. Since the potential of the ungrounded vertical plate (VERTICAL terminal) is zero at this time, the beam is not deflected vertically.

As the negative voltage at the HORIZONTAL terminal decreases toward zero, the electron beam moves to the right. At the same time the increasing positive voltage at the VERTICAL terminal causes the beam to move upward until time 2 is reached. At time 2 the voltage at the VERTICAL terminal begins to decrease and the electron beam moves downward, but the sawtooth continues to carry it across the screen at a steady rate. At point 3 both voltages are zero and the electron beam crosses the center of the screen. As the voltage at the HORIZONTAL terminal goes positive, the electron beam is attracted toward the ungrounded horizontal plate. The sine wave continues to move the beam downward until time 4 is reached.

After time 4 the sine wave moves the beam upward until the sawtooth reaches its maximum positive voltage at point 5. At point 5 the sawtooth quickly drops to its original negative value and the electron beam snaps back to the left side of the screen. Starting from its original negative value the sawtooth repeats, as does the sine wave, over and over again to produce the image on the crt.

The portion of the image that appears as the sawtooth goes from its maximum negative value to its maximum positive value is called the **TRACE**. The portion of the image that occurs as the sawtooth drops from its maximum positive value to its maximum negative value is called the **RETRACE** or **FLYBACK**.

Since the beam moves at a steady rate across the screen with respect to time when a sawtooth voltage is applied to the horizontal deflection plates, a crt display can be used to determine the exact time interval

between two voltage changes. For this reason the horizontal scanning motion of an electron beam is often called a **TIME BASE,** and the sweep circuits which produce sawtooth voltages are sometimes called **TIME BASE GENERATORS.**

*   *   *

1.   **In an oscilloscope a sawtooth sweep voltage is usually applied to the vertical plates of the crt. True or False?**

*   *   *

In a radar system the transmitter sends out a pulse of high-frequency energy. When this energy strikes an object, it is reflected and picked up by the radar receiver. The receiver feeds this reflected signal or "echo" to crt display units. The display units are either **DEFLEC-TION MODULATED** or **INTENSITY MODULATED.** These two terms describe how the echo pulse affects the trace on the face of the crt. With deflection modulation, the pulse changes the position of the trace. With intensity modulation the pulse changes the intensity, or brightness, of the trace.

Figure 2 shows two typical deflection-modulated radar displays. The transmitted pulse shows up as a pulse at the beginning of the sweep. The echo is detected and amplified, and then applied to the deflection system of the crt where it produces a pulse or pip on a single horizontal or circular sweep. The distance between the transmitted pulse and the echo pulse tells the distance from the radar set to the object.

The sweep on the face of the crt appears as a jagged line due to noise pulses arriving before and after the echo pulse. The type of display shown in Figure 2A is called A-scan, and the type of display shown in Figure 2B is called J-scan. The circuits which produce the **CIR-CULAR SWEEP** are described later in this lesson.

Figure 3 shows a typical intensity-modulated radar display. This type of display is called B-scan, or type B presentation. This type of radar display not only tells the distance to the reflecting object, but

also tells the direction of the reflecting object. For this type of presentation, a highly directional antenna is rotated while pulses are transmitted and received in the usual manner. However, the antenna turns very slowly, compared with the rate at which the pulses are transmitted, so that a number of pulses are reflected from each object.

Two complete sweep circuits are needed in the type B presentation. One produces a horizontal sweep which is synchronized with the rotation of the antenna so that the electron beam strikes the face of the crt at a position that corresponds to the direction of the antenna. The

other sweep circuit produces a vertical sweep much like the horizontal sweep in the type A-scan. That is, each vertical sweep begins at the same time a pulse is transmitted from the radar antenna.

Normally the crt in an intensity-modulated display unit is biased at cutoff. After detection and amplification, the input signal, or echo pulse, is applied to either the control grid or the cathode of the crt to increase the intensity of the
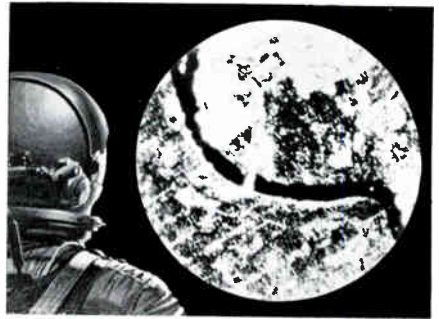
The above photo shows the indicator of a "picture" radar system which produces detailed ground maps of an area through clouds or fog.
Courtesy Philco Corp.

trace on the normally dark tube. Thus, the echo signals appear as bright patches on a normally dark background.

The horizontal placement of a bright spot indicates the direction of the reflecting object, and the vertical placement of the spot indicates the distance from the antenna to the reflecting object.

On the screen of the crt the meaning of the zero-degree marking varies with usage. On a movable base, such as a ship or aircraft, the 0° means "dead ahead", but at fixed locations, such as at airports, it may represent north or any other direction suitable for the particular application.

Intensity modulation is also used to reproduce televised images. A horizontal sawtooth deflection voltage or current causes the electron beam to move back and forth across the crt screen. At the same time a vertical sawtooth voltage causes it to move downward. As shown in Figure 4, as the beam traces out a rectangular area on the screen, the screen gets brighter and darker according to the picture it is reproducing.

In both the B-scan radar display and in the reproduction of a televised image, there may be a small space between the individual sweeps of the electron beam. However, the small spaces are usually much too small to be noticeable at normal viewing distance.

*   *   *

2.   An intensity modulated or type B presentation radar system requires two deflection or sweep circuits. True or False?

3.   Television systems incorporate intensity modulation and two deflection or sweep circuits. True or False?

*   *   *

PRODUCTION OF SAWTOOTH VOLTAGE

A sawtooth voltage is often formed by charging a capacitor slowly through a large resistance and then discharging it quickly through a small resistance. Thus, the voltage across the capacitor builds up at a slow rate due to the large resistance in the charge circuit and then falls at a fast rate due to the small resistance in the discharge circuit.

Figure 5A shows a simple RC circuit which produces a sawtooth voltage. Here, a direct voltage is applied to resistor R and capacitor C in series. Switch SW, connected across the capacitor, is alternately opened and closed, as shown in Figures 5A and 5B, respectively.

With SW open as in Figure 5A, the only current path is from the negative terminal of the voltage source to the lower plate of capacitor C, and from the upper plate through resistor R to the positive ter-

minal of the voltage source. This current charges C to the polarity shown. This charging action produces an increasing voltage across C. The voltage across C is the output voltage E_o. With SW open, E_o increases as shown between points 1 and 2 in Figure 5C.

When SW is closed, it shorts the terminals of the capacitor, as shown in Figure 5B. Under these conditions, electrons flow from the negative plate of C through SW to the positive plate, as shown by the arrows. This quickly discharges the capacitor, and E_o drops as shown between points 2 and 3 in Figure 5C. Since the resistance of SW is much smaller than that of R, the capacitor discharges in a much shorter time than it took to charge. There is also current from the negative terminal of the voltage source through SW and R to the positive terminal of the voltage source.

At point 3 of Figure 5C, SW is opened and C begins to charge again. At point 4, SW is closed to discharge the capacitor, and so on. Thus, by opening and closing SW at the right intervals a train of sawtooth voltage waveforms is produced across C and output terminals E_o.

Most sweep circuits use this charging and discharging process. The main difference is that practical sweep circuits use electron tubes or transistors to perform the switching action. The capacitor charges through a resistance, but discharges through the tube or transistor. Because its purpose is to discharge the sawtooth forming capacitor, the tube or transistor is called a discharge tube or discharge transistor. Sometimes, to provide a controlled variable resistance, a tube or transistor also provides the capacitor's charging resistance.

Figure 6 shows a circuit that uses an electron tube to discharge a sawtooth-forming capacitor. Here, tube V_1 is normally biased below cutoff by the $-E_{cc}$ supply. This corresponds to an open switch and allows capacitor C_1 to charge to the polarity shown. Electrons flow from ground to the lower plate of the capacitor and from the upper plate of the capacitor through resistor R_2 to $+E_{bb}$. However, when a

positive pulse is applied to the grid V_1 tube conducts (corresponding to a closed switch) long enough to discharge C_1 and thus form a sawtooth waveform.

The discharge path of C_1 is from its lower plate to ground and from ground up through V_1 to the upper plate of C_1. Electrons also flow from ground, up through V_1 and R_2 to E_{bb}. At the end of the positive pulse the tube is cut off and the capacitor charges again. The frequency of the positive pulses determines the frequency of the sawtooth.

●   ●   ●

4.   **Referring to the circuit of Figure 6, a sawtooth voltage is produced by slowly charging C_1 through R_2 and rapidly discharging it through (a) R_2, (b) V_1, (c) the load present at the E_0 output terminals.**

●   ●   ●

PRODUCTION OF SAWTOOTH CURRENT

If a magnetic deflection coil circuit consisted of resistance only, or if its resistance was large compared to its inductance, a sawtooth current could be produced in it by applying a sawtooth voltage. This is illustrated in Figure 7A, where sawtooth voltage E_A, applied to resistance R, results in current I_R having a sawtooth waveform. However, all magnetic deflection circuits include some inductance.

If a magnetic deflection coil circuit consisted of inductance only, with no resistance, a sawtooth current I_L could be produced in the coil by applying a rectangular voltage. This is because inductance opposes a change in current and it takes some time for the current to build up in the inductor. This action is illustrated in Figure 7B.

Since the plate current of a pentode varies according to the voltage applied to the control grid, and is almost independent of the voltage developed across the plate load impedance, the current waveform in the plate load impedance is forced to have the same shape as the

voltage waveform applied to the control grid. Thus, if a deflection coil is placed in series with the plate of a pentode, and if a sawtooth voltage waveform is applied to the pentode's control grid, the current waveform in the deflection coil is a sawtooth.

In a transistor magnetic deflection circuit, the coil inductance L and the transistor's collector resistance are sometimes effectively in series. Since the collector resistance is much greater than the inductive reactance of the coil, it is mainly the collector resistance that determines the current in the circuit. Thus, in many transistor magnetic deflection circuits a sawtooth voltage produces a sawtooth
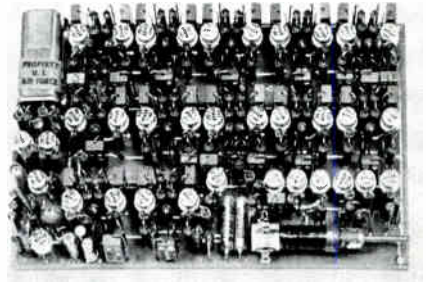
The transistor circuits of a video telemetry (Television) system for missiles. All practical Television systems use at least two sweep circuits. Courtesy Lockheed Electronics and Avionics Div.

of current. In other transistor magnetic deflection circuits the transistor's resistance is in parallel with the deflection coils. Thus, the transistor's resistance does not affect the coil current and a rectangular voltage produces a sawtooth of current.

In a triode electron tube magnetic deflection circuit, the coil inductance L and resistance R_L are effectively in series with plate resistance R_p of the tube. Therefore, since the circuit contains both resistance and inductance, and since the inductive reactance is large compared to the resistance, neither a sawtooth nor a square wave of applied voltage produces sawtooth current. To provide sawtooth current in a circuit of this type, the impressed voltage must have a **TRAPE-ZOIDAL WAVEFORM.** That is, it must have both square and sawtooth components as shown by voltage E_A of Figure 7C.

One method of producing a trapezoidal voltage is illustrated in Figure 8A. Here, V_1 represents the discharge tube of the deflection voltage generator, and R_2 is the high resistance through which sawtooth-

forming capacitor C_1 charges. Another resistor, R_3, is connected in series with capacitor C_1 so that it carries both the charge and discharge currents of C_1. Since the resistance is relatively small, it has little effect on the charge and discharge rates of the capacitor.

When V_1 is cut off and C_1 is charging, electrons flow from ground through R_3 to the negative plate of C_1, and from the positive plate through R_2 to E_{bb}. When V_1 conducts, electrons leave the negative plate of C_1, flow through R_3 to ground, and through V_1 to the positive plate of C_1. In Figure 8B the sawtooth voltage developed across C_1 is indicated by E_{c_1}.

An alternating voltage with the waveform of E_{R_3} in Figure 8B is developed across R_3 by the charge and discharge currents of C_1. Referring to Figure 8A, when C_1 charges the direction of electron flow is such that the upper end of R_3 is positive with respect to ground. When C_1 discharges the electron flow reverses to make the upper end of R_3 negative with respect to ground.

At the beginning of the cycle, the charge current is maximum and E_{R_3} has a maximum positive value as shown in Figure 8B. As C_1 charges, the current decreases slightly and E_{R_3} falls toward zero. At the beginning of the discharge interval, the discharge current has a high value and a high negative voltage drop is produced across R_3. However, as the discharge current dies down, the negative value of E_{R_3} is reduced. The instant V_1 stops conducting, C_1 again begins to charge and the polarity of E_{R_3} immediately becomes maximum positive, completing the cycle.

As indicated in Figure 8A, output voltage E_o is developed across C_1 and R_3 in series. Therefore, at every instant, E_o is the sum of E_c and E_{R_3}. In Figure 8B the addition of E_c and E_{R_3} waveforms provides the trapezoidal waveform E_o.

When used to provide the trapezoidal voltage, a resistor such as R_3 of Figure 8A is called a **PEAKING RESISTOR.** Most sweep circuits

that would otherwise produce sawtooth waveforms can be made to produce trapezoidal waveforms by simply adding a peaking resistor.

*   *   *

5.   When the deflection coil circuit contains only inductance, a (a) sawtooth, (b) trapezoidal, (c) square wave deflection voltage is needed to produce a sawtooth.

6.   When the deflection coil circuit contains both inductance and resistance, a (a) sawtooth, (b) trapezoidal, (c) square wave deflection voltage is needed to produce a sawtooth current.

*   *   *

THYRATRON SWEEP CIRCUITS

Gas triodes or thyratrons have certain characteristics that make switching take place automatically. A thyratron sweep circuit is free running, and thus continues to generate one sawtooth after another, while many vacuum tube sweep circuits must be driven by a series of pulses.

Figure 9A shows a basic thyratron sweep circuit. V_1 is in parallel with sawtooth-forming capacitor C_1. When power is first applied to the circuit there is no charge on C_1 and V_1 acts like an open circuit due to the negative cutoff voltage on its control grid. The capacitor charges along the charge curve shown in Figure 9B. As the charge on C_1 increases, the voltage across C_1 and V_1 becomes too high for the control grid to keep the tube cut off, and a small plate current is developed. This plate current ionizes the gas in the tube at point 1 in Figure 9B, and the resulting high plate current quickly discharges C_1.

Below a certain plate voltage the tube does not remain ionized. When the capacitor discharges to this voltage, at point 2, the gas in the tube deionizes and the grid regains control of plate current. At this point

the tube becomes an open circuit again and allows the capacitor to recharge.

Figure 9B shows the charge and discharge curves of C_1 for two different values of grid bias, a large grid bias and a small grid bias. If the grid is made less negative, it takes less plate voltage to ionize the tube. When ionization occurs earlier on the capacitor's charge curve, the amplitude of the sawtooth decreases, but it repeats more often. That is, its frequency increases.

Another result of a smaller grid bias is that the sawtooth is more linear since the smaller linear portion of the charge curve is used. A nonlinear sawtooth sweep voltage distorts the image on a crt. Thus, the more linear the sweep voltage is, the less the image is distorted. Although a smaller grid bias causes the tube to ionize at a lower plate voltage, it does not affect the deionizing voltage. This depends on the gas pressure within the tube.

If the grid is made more negative, a higher plate voltage causes ionization. When ionization occurs later on the capacitor's charge curve, the amplitude of the sawtooth increases, but it repeats less often, that is, its frequency decreases. Also, with a larger grid bias the sawtooth is less linear since a larger portion of the charge curve is used. Like a smaller grid bias, a larger grid bias does not affect the deionizing voltage.

<p style="text-align:center">*   *   *</p>

7.   A gas tube sweep generator must be triggered by an input pulse to produce each cycle. True or False?

<p style="text-align:center">*   *   *</p>

MULTIVIBRATOR SWEEP CIRCUITS

Figure 10 shows the circuit of a typical vacuum tube multivibrator sweep circuit. This circuit is made up of a sawtooth sweep circuit followed by a push-pull deflection amplifier.

Push-pull deflection provides a greater gain for a given supply voltage. Only half of the required voltage is applied to each deflection plate, and as one plate "pushes", the other "pulls" to provide the sweep. Since half of the required voltage is applied to each deflection plate, each amplifier tube need only supply a voltage half as great as would be needed for single-ended (one tube) deflection.

Another advantage of push-pull deflection is that it allows the deflection plate voltages to be more nearly the same as the accelerating anode voltage which is at ground potential. This prevents defocusing of the image on the crt. If the average deflection plate voltages are different than the accelerating anode voltage, a weak electrostatic field is set up between the deflection plates and the accelerating anode. This electrostatic field defocuses the image on the crt.

In the circuit of Figure 10, V_1 and V_2 function as a cathode-coupled multivibrator. The sawtooth generator, V_2, serves as the discharge tube for sawtooth-forming capacitor C_3. C_3 charges through R_7 and potentiometer R_6 when V_2 is cut off, and discharges through R_2 and V_2 when the tube conducts. The oscillator frequency is adjusted by means of variable resistor R_4.

A sync pulse input is provided in this circuit so that the multivibrators can be synchronized with some other oscillator. Negative sync pulses cause V_1 to cut off which, in turn, causes V_2 to conduct and thus discharge the sawtooth forming capacitor at the same frequency as the sync pulses. Synchronization is very important in many systems, such as TV or radar. In TV the camera tube sweep circuits must be in sync with the picture tube sweep circuits. In many radar displays the sweep must begin at exactly the same time that a pulse of microwave energy is transmitted.

It is common practice to vary the sawtooth generator output amplitude by changing the resistance through which the sawtooth-forming capacitor charges. However, an undesirable effect of this arrangement is that a slight change in oscillator frequency occurs also. To

avoid this interaction, in the circuit of Figure 10 the total series resistance, $R_6 + R_7$, remains constant at all times.

Potentiometer R_6 carries the sawtooth charging current of capacitor C_3, and the sawtooth voltage which appears at the wiper arm of R_6 is coupled through C_4 to the grid of V_3. With this arrangement, potentiometer R_6 may be adjusted to apply the desired amplitude of sawtooth voltage to V_3 without affecting the oscillator frequency. Therefore, the control is known as the amplitude control. R_4 is the frequency control.

V_3 and V_4 function as a phase inverting amplifier, with the V_3 output coupled through C_5 to one of the deflection plates. In series with $+E_{bb_2}$, R_{14} and R_{15} form a voltage divider, with the junction between them connected to the V_3 plate load resistor R_{11}. Since neither section of the voltage divider is bypassed, any variation in the V_3 plate current results in a change in the voltages developed across R_{11}, R_{14}, and R_{15}. Thus, a part of the V_3 output voltage appears across R_{15} and is coupled through C_6 to the grid of V_4, the output of which is coupled through C_8 to the other deflection plate.

You may recall that positive feedback in an amplifier increases the distortion (change in the input waveshape) in an amplifier. If a sweep circuit amplifier distorts a nonlinear sawtooth input voltage in such a way that the sawtooth becomes more linear, then some positive feedback may be desired to increase this distortion. In the circuit of Figure 10, positive feedback is obtained by coupling through C_9 and R_{12} from the V_4 plate to the V_2 plate of the oscillator. In addition, some negative feedback is introduced by supplying the C_3 charging current and the V_2 plate current through R_7 from the tap between R_{14} and R_{15}.

Figure 11 shows another typical multivibrator sweep circuit. Again a cathode-coupled multivibrator, V_1 and V_2, is used for the sawtooth generator. The oscillator frequency is controlled by variable resistor R_3. Sawtooth-forming capacitor C_3 charges through the series resis-

tors R_6 and R_7, and discharges through R_2 and V_2. The sawtooth voltage amplitude is determined by the setting of R_7.

The sawtooth voltage is coupled through C_4 to the grid of amplifier tube V_3. The V_3 sawtooth plate current is carried by the center section of autotransformer T_1, thereby inducing a sawtooth voltage across the entire winding. The center section acts as the primary and the entire winding as the secondary. Thus, a voltage stepup is obtained with the polarity at one end of the winding 180° out of phase with that at the other end.

A push-pull action is obtained by coupling the voltage across the entire winding through capacitors C_7 and C_8 to the deflection plates. The

The above equipment uses special oscilloscopes to check pulse waveforms.
Courtesy Radiation, Inc.

linearity of the output is improved by applying positive feedback through R_{10} and C_6 from the lower end of transformer T_1 to the V_3 grid.

$$* \qquad * \qquad *$$

8. Referring to the circuit of Figure 10, the V_3V_4 stages function as a (a) multivibrator, (b) push-pull amplifier.

9. Referring to the circuit of Figure 10, the C_9R_{12} circuit is used to supply positive feedback. True or False?

$$* \qquad * \qquad *$$

BLOCKING OSCILLATOR SWEEP CIRCUITS

Figure 12 shows a blocking oscillator sweep circuit. Here, the sync pulses are coupled through C_1 and applied across R_1 to the oscillator and discharge tube. The sawtooth voltage is formed across C_4, which charges through R_4 and R_5 and discharges through V_1 and the plate winding of transformer T_1. The oscillator frequency is controlled by variable resistor R_3. Variable resistor R_5 controls the amplitude of the sawtooth voltage output, which is coupled through C_5 to the grid of amplifier V_2.

Tubes V_2 and V_3 form a phase inverting amplifier of the same type explained for Figure 10. In Figure 12 the V_2 output is coupled through C_7 to one deflection plate and through C_6 to the voltage divider R_7 and R_8. From the junction of R_7 and R_8 a fraction of this voltage is applied to the grid of V_3. The V_3 output is coupled through C_8 to the opposite deflection plate. To improve the waveform, positive feedback is coupled from the V_3 plate to the oscillator by means of R_{11} and R_{12}.

The blocking oscillator sweep circuit in Figure 13 contains a single tube that performs the functions of blocking oscillator, discharge tube, and output tube. In connection with transformer T_1, tube V_1 operates as a blocking oscillator with the sync pulse input coupled through

capacitor C_1 to the grid circuit. The negative grid bias is developed across C_4. This capacitor is charged by V_1 grid current and discharges through R_3 and R_4 when V_1 is cut off. By varying the grid bias, variable resistor R_4 controls the oscillator frequency over a narrow range.

When V_1 is cut off, C_5 charges with electrons flowing from ground to the C_5 negative plate. Other electrons leave the positive plate and flow through the upper winding of T_2 and through part of R_5 to $+E_{bb}$. As in any RC circuit, C_5 charges rapidly at first, but the charging current gradually dies down. In the upper winding of T_2, this changing current produces a flux which induces a voltage in the lower winding. C_6 is across the lower winding and charges to the polarity indicated.

When V_1 conducts, both C_5 and C_6 discharge through the tube and plate winding of T_1. During discharge, electrons flow from the negative plate of C_6 to the cathode of V_1, through the tube and the plate winding of T_1 to the positive plate of C_5. From the negative plate of C_5, electrons flow to the positive plate of C_6.

As shown, the upper plate of C_5 is positive with respect to ground, and this sawtooth voltage is coupled through C_7 to one deflection plate. The upper plate of C_6 is negative with respect to ground, and this sawtooth voltage is coupled through C_8 to the other horizontal plate. Thus, push-pull output is obtained by means of the circuit arrangement of Figure 13, in which part of the sawtooth output is formed in the oscillator plate circuit and the other part in the cathode circuit. Resistors R_1 and R_2 and capacitors C_2 and C_3 connected across the T_1 winding prevent high frequency oscillations.

Figure 14 shows a PNP transistor blocking oscillator. This circuit is very much like its vacuum tube counterpart. Transformer T_1 provides feedback from the collector output circuit to the base input circuit. Sync pulses are fed to the base. The sawtooth deflection voltage is developed across C_1 from collector to ground.

Similar to vacuum tube operation, the capacitor charges when the transistor is cut off and discharges when the transistor conducts.

However, because of the differences between tubes and transistors, there are some differences between vacuum tube and transistor blocking oscillator sweep circuits. These are described as the transistor circuit is explained.

The transistor is biased beyond cutoff by the negative voltage across R_8. The value of this voltage can be varied by R_7, and thus R_7 serves as a frequency control. When Q_1 is cut off, C_1 charges through R_5 until the voltage across R_2 becomes more negative than the emitter voltage. When this happens, Q_1 conducts. The resulting collector current induces a voltage in the base winding of T_1 which increases the forward bias and, in turn, collector current. This induces an even greater voltage in the base winding of T_1 which, in turn, further increases collector current.

As a result, transistor Q_1 acts like a very low resistance and C_1 quickly discharges. The discharge path of C_1 is from its upper plate through the collector winding of T_1, Q_1, and R_8 to ground, and from ground up to its lower plate. When C_1 discharges, the voltage across R_2 and R_3 is almost zero, and Q_1 is driven into cutoff by the difference between the emitter voltage, at the ungrounded side of R_8 and the voltage induced at the base by the collapsing field of T_1. This action continues to generate one sawtooth after the other.

The sawtooth output waveform of Figure 14 is negative. If a positive-going signal is needed, an NPN transistor and a positive supply voltage would be used. Reversing polarity in this way is a special feature of transistor circuits that is not possible with tube circuits.

*   *   *

10.   The circuit of Figure 13 produces an output only when sync pulses are applied to its input. True or False?

11.   Referring to the circuit of Figure 14, capacitor C_1 charges when (a) Q_1 is conducting, (b) Q_1 is cut off.

*   *   *
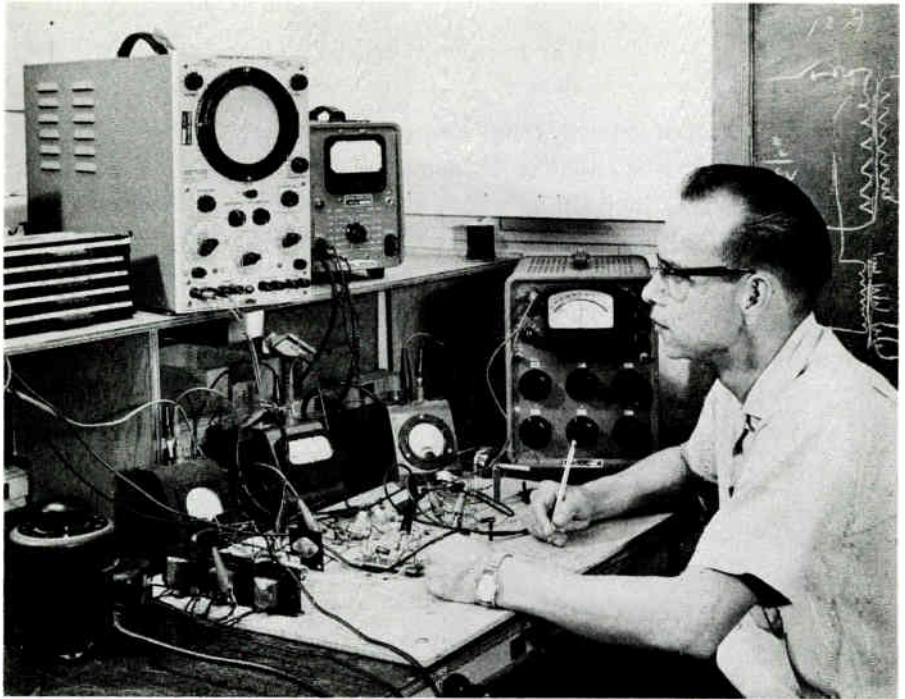
A technician checks out o new power supply circuit. One of his most useful
test instruments is the oscilloscope.

Courtesy Dressen-Barnes Corp.

GATED AND TRIGGERED SWEEP CIRCUITS

The thyratron, multivibrator, and blocking oscillator sweep circuits
described so far are all free running. They begin to generate an
output soon after their supply voltages are applied. However, some
sweep circuits are not free running. That is, they generate an output
only when a trigger or gate signal is applied to their input.

Sometimes the terms gated sweep circuit and triggered sweep circuit
are used interchangeably. However, there is some difference between
them. In a true gated sweep circuit the sweep voltage is started, main-
tained for a certain period, and then ended. In a true triggered sweep
circuit, on the other hand, the input pulse merely starts or ends the

sweep voltage. This pulse is called a trigger and is usually a peaked waveform. The sweep circuit itself ends or starts the sweep voltage; not the trigger.

Figure 15 shows a typical gated sweep circuit as used in a radar system for an A-type scan. The transmitted pulse triggers three univibrators (not shown), each of which generates a negative square wave of a different width. By setting switch S_{1A}, one of these negative square waves is applied as a gate pulse to the grid of V_1 to cut the tube off. THE TIME DURATION OF THE SWEEP is determined by the duration of the gate pulse.

When the tube is cut off, one of the capacitors (C_1 through C_3) charges to form the sawtooth sweep voltage. The proper capacitor network is selected by switch S_{1B}, which is ganged to switch S_{1A}. The univibrators are adjusted for the times required to give the radar set ranges of 5, 25, and 50 miles. As the radar set is switched to a greater range by S_{1A}, larger value sawtooth-forming capacitors are switched into the circuit by S_{1B} to maintain the same amplitude of output voltage and thus the same length of trace on the crt.

As explained for Figure 9B, when the charging time of a sawtooth-forming capacitor is changed, the amplitude of the sawtooth also changes. The variable resistors are also used to vary the amplitude of the sweep voltage since the exact capacitance values needed may not be available. The variable resistors can also be used to adjust for any small changes in the capacitor values over a period of time.

Monostable state multivibrators, also called one-shot multivibrators, etc., are used to generate triggered sweeps. These multivibrators normally remain in a stable state until they are triggered into an unstable state and go through one cycle of operation.

Figure 16 shows a typical triggered sweep circuit incorporating a monostable multivibrator. In this circuit the bias voltage developed across the common cathode resistor R_2 is applied only to the grid of V_1. The grid of V_2 is returned through R_3 to its own cathode, and not

to ground. When the supply voltages are applied to this circuit, V_2 conducts heavily and V_1 is cut off because of the large cathode bias. The multivibrator remains in this state until the positive input trigger is applied.

The positive trigger drives V_1 into conduction and causes its plate voltage to decrease. This decrease in voltage is coupled through C_2R_3 to the grid of V_2, which is driven negative. The resultant decrease in V_2 plate current decreases the current through R_2. With less current through R_2 there is a decrease in voltage across this resistor, which decreases the amount of cathode bias applied to V_1. Thus, V_1 plate current increases.

The initial increase in V_1 plate current due to the positive trigger pulse results in a smaller bias, which further increases V_1 plate current. The increase of V_1 plate current results in a decrease in V_1 plate voltage, which drives the grid of V_2 more and more negative and thus decreases the V_2 plate current. This regenerative action causes V_1 to become saturated and V_2 to become cut off.

As the plate voltage of V_1 decreases, C_2 discharges through R_3 and V_1. When the grid voltage of V_2 is no longer negative enough to hold the tube cut off, V_2 conducts. This conduction increases the cathode bias applied to V_1. Again a regenerative action occurs causing V_1 to be cut off and V_2 to become saturated. This is the state the circuit was in before the trigger was applied. The circuit remains in this state until the next trigger is applied, at which time the entire cycle begins again. For the circuit to operate, an input trigger is required. Without the trigger, the circuit remains in its stable state.

Sawtooth-forming capacitor C_3 is connected between the plate of V_2 and ground. As long as V_2 conducts, the capacitor is shunted by the tube's low plate resistance. When a trigger is applied to the multivibrator, V_2 is cut off. This allows the capacitor to charge through R_5, thereby generating the sawtooth sweep voltage. When V_2 conducts again, the capacitor discharges rapidly through the tube. In this

way, the trigger applied to the multivibrator begins the sweep. C_3 continues to charge as long as V_2 is cut off. The time constant of the C_2R_3 coupling circuit largely determines the amount of time that V_2 remains cut off. The sweep ends when V_2 conducts.

In some equipment, several sweep lengths or times are needed. A switching arrangement permits different values of resistors to be substituted for R_3 of Figure 16. If this resistance is increased, V_2 remains cut off for a longer time interval and a longer sweep duration is generated. If R_3 is reduced, the sweep duration is also reduced. The switching arrangement that changes the value of R_3 must also change the value of the sawtooth-forming capacitor C_3. This is necessary to maintain the same amplitude of sweep when the time duration is changed.

In some radar applications the sawtooth-forming capacitor is omitted from the multivibrator stage. Without this capacitor the output is a rectangular wave. This rectangular wave output is used to gate a discharge tube. The discharge tube produces a gated sweep like that described for Figure 15.

Figure 17 shows another typical triggered sweep circuit. This circuit is made up of a blocking oscillator and a discharge tube. The grids of both the blocking oscillator tube V_1 and the discharge tube V_2 connect through R_1 and R_3 to negative bias supply $-E_{cc}$. The negative bias is large enough to hold the tubes cut off and as a result, no current flows in either of the tubes.

When a positive trigger is applied to the grids, the negative bias is overcome and there is plate current in both tubes. The circuit now produces a single cycle of oscillation to discharge sawtooth forming capacitor C_2. During the negative alternation of the oscillating cycle the tubes are again cut off. When the tubes are cut off, C_2 charges through R_4 toward the value of the plate-supply voltage $+E_{bb}$. When the trigger is applied again, V_2 conducts and C_2 again discharges

through the tube. Thus the trigger causes the retrace (discharge of C_2) and the sweep (charge of C_2) begins when the tube cuts off.

*   *   *

12.   Referring to the circuit of Figure 15, V_1 is operated as (a) an amplifier, (b) a blocking oscillator, (c) a discharge tube.

13.   Referring to the circuit of Figure 16, V_1 and V_2 are operated as a (a) monostable multivibrator, (b) a blocking oscillator, (c) a push-pull deflection amplifier.

*   *   *

LINEARIZATION

The sawtooth output of most sweep circuits has some nonlinearity. That is, the voltage does not increase by the same amount for equal periods of time. With a non-linear sweep voltage an oscilloscope cannot present accurate graphs of voltage or current versus time. That is, the waveforms that appear on the crt screen are distorted. In some radar displays, a linear sweep is needed to measure the distance to the reflecting object. If the sweep is nonlinear the distance to the reflecting object cannot be measured accurately.

You can probably imagine what would happen to a televised picture if the sweep voltage were nonlinear. The picture squeezes together as the sweep speed reduces due to less increase in sawtooth voltage for a given time period. Or, if the sawtooth voltage increase is greater for a given time period of each cycle, that portion of the picture stretches out.

Some nonlinearity is characteristic of a capacitor's charge curve. Going back to Figure 9B for a moment, at the very beginning of the charge curve the voltage increases very fast. But as the capacitor charges, the voltage increases less and less for equal periods of time. In fact, during the first RC time constant, a capacitor charges to about 63% of the applied voltage.

During the second time constant it charges to about 86% of the applied voltage, which is an increase of only 86 — 63, or 23%. That is, during the first RC time constant the voltage increase across the capacitor is 63% of the applied voltage, but during the second RC time constant the voltage increase across the capacitor is only 23% of the applied voltage. This action continues until during the fifth time constant the increase is only about 1% of the applied voltage.

If only a small portion of a capacitor's charge curve is used for the sweep, the amount of nonlinearity is greatly reduced. However, when even more accurate linearity is needed, special circuits must be used to improve the linearity. The use of these circuits is known as **LINEARIZATION.**

Linearization of the sweep is usually not used in general-purpose oscilloscopes. However, laboratory type oscilloscopes, radar, and television sets generally use some type of linearization to improve the display. Sometimes more than one type of linearization is used in the same sweep circuit.

One way to improve the linearity of a sawtooth is to replace the capacitor's charging resistance with a **CONSTANT-CURRENT PENTODE.** With the proper screen grid voltage, the plate current of a pentode remains constant, within certain limits, regardless of its plate voltage. If the current which charges the capacitor is made constant, the charge builds up at a linear rate. The resultant capacitor voltage increase is therefore linear.

Figure 18 shows a thyratron sawtooth generator which uses a constant-current pentode, V_2. R_1 is the plate load for V_2 and C_1 holds the screen grid at a constant voltage. Potentiometer R_2 connected across battery B_1 allows the control grid bias of V_2 to be varied. When plate voltage is applied to this circuit, the sawtooth-forming capacitor C_2 charges through pentode V_2. The voltage across the capacitor increases as the charge builds up. Since the plate current of V_2 remains

uniform, the voltage across the capacitor increases at a linear rate. The capacitor discharges when the ionization voltage of the thyratron is reached.

The frequency of the sawtooth output can be varied either by switching in different value capacitors across the thyratron, or changing the bias on the control grid of V_2. A change in bias changes the tube's

The sweep circuits of this oscilloscope can be adjusted for two modes of operation. In one mode the sweep generator is free running, and in the other mode it must be triggered.
Courtesy Hewlett-Packard Co.

plate resistance which, in turn, determines the amount of capacitor charging current. This has the same effect as switching in different charging resistors in series with C_2.

Most sweep circuits use a slow charge (trace) and a rapid discharge (retrace) of a capacitor to produce a slowly increasing and rapidly decreasing waveform. The circuit of Figure 19, however, uses the reverse method. The capacitor charges rapidly and discharges slowly at a linear rate through the constant-current pentode. The output voltage increases rapidly and decreases slowly. The rapid increase produces the sweep retrace and the slow discharge produces the sweep trace.

This type of waveform can be inverted by an ordinary amplifier or applied to the deflection plate opposite that which a positive-going sawtooth would be applied to. However, most high quality equipment uses push-pull deflection and the sawtooth is fed to a phase inverting amplifier.

In Figure 19 the circuit is driven by a series of rectangular gate pulses applied to the grid of V_1. The tube passes plate current in a series of short pulses; one pulse for each positive swing of the input gate. V_1 is cut off for a much longer period of time than it conducts. The sawtooth-forming capacitor is in the cathode circuit of V_1 and is shunted by constant-current pentode V_2.

During the brief intervals when V_1 conducts, C_1 charges through the triode. There is little or no current through V_2 because of its high internal resistance compared to the low reactance of C_1. However, with a positive voltage on its grid, the plate resistance of V_1 is low and the time constant of the charging circuit is very short. Therefore, the capacitor charges rapidly. This produces a rapid increase of capacitor voltage.

At the end of the pulse which causes V_1 to conduct, the triode is cut off. Capacitor C_1 now begins to discharge through the constant-current pentode. Because of the high plate resistance of the pentode, the time constant of the discharge circuit is long. Therefore, the capacitor discharges slowly. Because the plate current of the pentode is uniform, the discharge of the capacitor is linear. The sweep time is con-

trolled by potentiometer R_2. This changes the plate resistance of V_2 and thus the capacitor's discharge time constant.

Another way to improve the linearity of the sawtooth sweep is to insert an additional RC circuit at the output of an ordinary sweep circuit. If the capacitor in this additional circuit is made to discharge for a part of the time that the main sawtooth-forming capacitor is charging, the output voltage waveform is changed.

The usual sweep voltage waveform is convex, or bulges upward away from a linear reference line. (This can be seen in the capacitor charge curve of Figure 9B). The discharge of the additional capacitor produces a concave voltage waveform or one that sags downward away from the reference line. These two waveforms are added together to produce the sweep. If they have the right amplitudes and curvature, the convex and concave distortions cancel and the resulting sawtooth sweep is linear.

Figure 20A shows an ordinary gated sweep circuit and Figure 20B shows this same circuit with the addition of another RC network. In the circuit of Figure 20A, C_1 charges through R_2 while V_1 is cut off. This produces a nonlinear voltage rise across C_1. When a positive pulse causes V_1 to conduct, C_1 quickly discharges through the tube.

In the circuit of Figure 20B, capacitors C_{1A} and C_{1B} take the place of capacitor C_1. Another circuit made up of R_3C_2 is added in parallel with C_{1A}. Capacitors C_{1A} and C_2 usually have about the same values. Resistor R_3 is fairly large, about .5 megohm. The sawtooth output voltage is the sum of the voltages across C_{1B} and C_2.

To examine circuit action, assume all the capacitors are fully charged by the power supply. When V_1 starts to conduct, all the capacitors begin to discharge through the tube. Capacitors C_{1A} and C_{1B} discharge rapidly since the low plate resistance of the tube is directly in parallel with this series combination. However, C_2 discharges slowly because its discharge current must pass through the large resistance of R_3.

As a result, when V_1 is again cut off, both C_{1A} and C_{1B} are almost completely discharged, but C_2 has lost only a small part of its charge.

With V_1 cut off, C_{1A} and C_{1B} begin to recharge. At first, the voltage across C_2 is much larger than the voltage across C_{1A} and therefore C_2 continues to discharge through R_3 and into C_{1A}. Thus, at the beginning of the sweep C_{1A} and C_{1B} are being charged by the power supply, C_{1A} is also being charged by C_2, and C_2 is discharging. During the first portion of the sweep, the voltage across C_{1A} rises and the voltage across C_2 falls. Near the end of the sweep, when the voltage across C_{1A} equals the voltage across C_2, then C_2 begins to charge.

The sawtooth output is taken across C_{1B} and C_2. The voltage across C_{1B} is the usual nonlinear sweep, but the voltage across C_2 is very different. At the beginning of the sweep the voltage across C_2 decreases since the capacitor is discharging. Near the end of the sweep, when the voltage across C_{1B} begins to flatten out, the voltage across C_2 increases. If the right time constants are used for these circuits, the sum of the voltages across C_{1B} and C_2 is a very linear sawtooth.

Many modifications of this circuit are used for sweep linearization. Figure 21A shows one of these modifications. To examine circuit operation, assume that both C_1 and C_2 are fully charged. When V_1 conducts, both capacitors begin to discharge. Capacitor C_2 discharges rapidly through the tube, but C_1 discharges slowly through R_2 and the tube. Thus, when the tube is cut off, C_2 is almost completely discharged, but C_1 has lost only a small part of its charge.

With the tube cut off, C_2 begins the charge through resistors R_2 and R_3. Because C_1 still is charged to a much higher voltage than that across C_2, C_1 continues to discharge into C_2. When the voltage across C_1 equals that across C_2, then C_1 begins to charge and no longer discharges into C_2.

The sweep voltage is taken only across C_2. This capacitor is charged not only by the power supply but also by the discharge of C_1. The

power supply charge makes up the convex component of a sawtooth, and the charge obtained from C_1 makes up the concave component of a sawtooth. Thus, since the total voltage across C_2 is the result of these two charges, it is a linear sawtooth.

Sometimes resistors R_2 and R_3 are replaced by a potentiometer as shown in Figure 21B. This potentiometer provides a way to change the time constants of both RC circuits to obtain the most linear output waveform. This potentiometer is called the **LINEARITY CONTROL**.

Still another way to improve the linearity of a sawtooth sweep voltage is to use a feedback network. Many feedback circuits are used, but one of the most popular is the **BOOTSTRAP** sweep circuit. The sweep voltage in this circuit appears to raise itself by its own "bootstraps".

Figure 22 shows a simplified schematic diagram of a bootstrap sweep circuit. Tube V_1 is a gated discharge tube for sawtooth-forming capacitor C_1. This capacitor charges from the power supply through resistors R_1 and R_2. The sawtooth voltage across C_1 is coupled directly to the grid of cathode follower V_2. The linear sawtooth output is taken from the cathode follower, across R_3. The gain of the cathode follower is very close to 1. Therefore, the output sawtooth has almost the same amplitude as the sawtooth applied to the V_2 grid.

The sawtooth output voltage is coupled back to the junction of R_1 and R_2 by capacitor C_2. As capacitor C_1 charges, the voltage at the end of R_1 connected to C_1 increases. The feedback sawtooth voltage, which is applied to the other end of R_1, rises by almost the same amount. If the voltages applied to both ends of R_1 increase by the same amount, the voltage across the resistor remains constant. With a constant voltage across R_1, the current through it also remains constant. Since this is the charging current of C_1, the charge on C_1 builds up at a linear rate and produces a linear sawtooth voltage.

By taking the output across cathode resistor R_3, instead of across C_1, the cathode follower acts as a buffer and impedance-matching stage to the following circuit.

In some sweep circuits it is not necessary to use an actual capacitor to form the sawtooth. Instead, the input capacitance of a tube can be used. The input capacitance of a tube can be increased by connecting a feedback capacitor between the plate and grid of the tube. You may recall that this increase in input capacitance is called the Miller effect, after John M. Miller who first discovered and studied this effect.

Miller also discovered that most triodes already have a large feedback capacitance in the form of a grid-to-plate capacitance. In tetrodes

This standard radar display uses intensity modulation of the crt's electron beam to produce a map of the surrounding area.
Courtesy Philco Corp.

and pentodes, however, this control grid-to-plate capacitance is decreased by the addition of the screen grid. Therefore, if a tetrode or pentode is used in a circuit and it is desired that the tube have a large input capacitance, a feedback capacitor must be connected between its control grid and plate.

Figure 23 shows the schematic diagram of a sweep circuit that uses the input capacitance of a pentode as the sawtooth-forming capacitor. In the figure this capacitance is shown by dashed lines and labeled C_1. You may recall that a series RC network such as R_1C_1 is called an integrator. Since C_1 is the input capacitance of an electron tube, the RC network in this circuit is called a **MILLER INTEGRATOR.**

The output of a sweep circuit using a Miller integrator, such as the circuit of Figure 23, is very linear. When a negative gate pulse is applied to the suppressor grid of V_1, the tube is cut off and its plate voltage is equal to E_{bb}. There is a slightly positive voltage on the control grid of V_1. The control grid of V_1 does not reach a very high

voltage because R_1 is large compared to the grid-to-cathode resistance and therefore there is a large voltage across it. Since the tube is cut off there is no Miller effect and the capacitance C_1 is very small; that is, it depends only on the tube's grid-to-cathode capacitance and not on the tube's gain.

The negative-going sawtooth output voltage begins at the end of the negative gate pulse. With the negative voltage no longer present on the suppressor grid, plate current increases and the plate voltage of V_1 begins to decrease. This decrease in plate voltage is coupled to the control grid by C_2, the feedback capacitor.

Now, since the tube is in an amplifying condition (it produces a voltage gain) C_1 increases due to the Miller effect. C_1 begins to slowly charge up toward the $+E_{bb}$ voltage. As C_1 charges, the plate voltage of V_1 continues to decrease until the next gate pulse appears at the suppressor grid of V_1. When the gate pulse appears, the plate voltage again rises to $+E_{bb}$. However, it does not do this immediately since it takes a short time for C_2 to charge through R_2.

*　　　*　　　*

14. In a television system or type B presentation radar system, it is very important that a linear sweep is used. True or False?

15. The circuit of Figure 22 is often referred to as a (a) bootstrap circuit, (b) blocking oscillator.

16. The sawtooth forming capacitance in the Figure 23 circuit is (a) the grid-cathode capacitance of V_1, (b) C_2.

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CIRCULAR SWEEP AND RADIAL DEFLECTION

A sweep which traces a circle on the screen of a crt is used in some displays. Such a sweep can display more accurate information than a simple linear trace. This is because the simple linear trace cannot be longer than the screen diameter, but the circular trace can be

almost as long as the screen circumference. Since the sweep ends at the same point on the screen where it begins, no retrace is used in the circular trace.

The most common way to produce a circular trace on the screen is by using two pure sine waves of the same frequency. Figure 24 shows that these two waves must be equal in amplitude but 90° out of phase. The waveform at the upper left is applied to the vertical deflection plates of an electrostatic crt or the vertical deflection coils of an electromagnetic crt. The waveform at the lower right is applied to the horizontal deflection plates of an electrostatic crt or the horizontal deflection coils of an electromagnetic crt.

At the beginning of the sweep (point 1) there is no horizontal deflection since the lower right waveform is at zero amplitude. However, at point 1 the vertical deflection waveform is at its maximum positive value. Therefore, the electron beam moves upward to the top of the screen. The beam is located at point 1 on the screen.

During the first quarter-cycle of operation, the horizontal deflection waveform moves the spot toward the right of the screen. At the same time the vertical waveform moves the spot downward. Therefore, the electron beam passes through points 2 and 3 to point 4, and forms the first quarter of the circular sweep.

During the second quarter-cycle, the horizontal deflection waveform passes from its maximum positive value to zero, while the vertical deflection waveform passes from zero to its maximum negative value. During this time the electron beam is deflected downward by the vertical deflection waveform and to the left by the horizontal deflection waveform. The electron beam passes through points 5 and 6 to point 7, and forms the second quarter of the circular sweep.

During the third and fourth quarter-cycles of operation, the vertical deflection waveform causes the electron beam to move from the bottom to the top of the screen, and the horizontal deflection waveform

causes the electron beam to move to the left and then to the right. Thus, the electron beam passes through points 8, 9, 10, 11, and 12 back to point 1, its starting point.

Crystal oscillators are often used to generate the sine waves so that a very precise frequency is maintained. A phase-splitting circuit is used to produce the required 90° phase difference between the vertical and horizontal waveforms. The most common phase-splitting circuit is a simple series RC network. Figure 25A shows such a circuit and Figure 25B shows the waveforms in this circuit.

Since the circuit contains a capacitor, the circuit current leads the input voltage. E_R is in phase with the circuit current, but E_C lags the circuit current by 90°. Thus, E_R leads E_C by 90°. These are the two output voltages used to produce the circular sweep. For the amplitude of these two voltages to be the same, the reactance of C must be equal to the resistance of R. Therefore, the resistance of R is variable so that the circuit resistance can be made equal to the capacitive react-ance over a range of frequencies. The variable resistance is also used to make up for any changes in circuit capacitance or resistance.

RADIAL DEFLECTION is usually used with circular sweep. There are two ways to produce radial deflection. One way uses special types of crt's. The other way uses ordinary crt's with special amplifier circuits.

Two special types of crt's are used to produce radial deflection on a circular sweep. One of these has a thin rod electrode which passes through the center of the crt screen. The rod is mounted at right angles to the screen. This is shown in Figure 26A. This type of tube is widely used for some of the radar displays described earlier in the lesson.

A circular sweep is generated by applying sine waves which are 90° out of phase to the usual deflection system of the tube. The electron beam moves between the center electrode and the conductive coating

(second anode) on the inside of the tube's envelope. When an input signal is applied to the center electrode, a radial electrostatic field is produced. This produces the required radial deflection. As shown in Figure 26A, if a single negative pulse is applied, the beam moves away from the center electrode. If a single positive pulse is applied, the beam moves in toward the center electrode.

The other type of special crt has a greater radial deflection sensitivity. Figure 26B shows that this tube has two electrodes shaped something like cones. Actually, they are shaped like the portion of a cone left when its peak is cut off. The outer cone is connected to the accelerating anode, which is at ground potential, and the input signal is applied to the inner cone. The electron beam traces a circular pattern by the usual method, and the beam moves in the space between the cones. When the input signal is applied to the inner cone, a radial electrostatic field is set up between the cones. If the input signal is positive the beam moves toward the inner cone. In this way the electron beam is deflected radially on the screen of the crt.

Figure 27 shows the special push-pull amplifier circuits used to produce circular sweep and radial deflection in an ordinary electrostatic crt. A sine wave is applied to the series RC circuit, R_1 and C_1. The voltage across capacitor C_1 is 90° out of phase with the voltage across R_1. One of these two out-of-phase voltages is applied to V_1 and V_2 by transformer T_1, and the other is applied to V_3 and V_4 by transformer T_2. The impedances of transformers T_1 and T_2 are very high compared to those of C_1 and R_1 so that the transformer inductance does not affect the phase relation of the two voltages.

The transformer secondaries provide voltages which are equal in amplitude but opposite in polarity for the push-pull amplifiers. Common cathode resistor R_2 provides bias for V_1 and V_2, and common cathode resistor R_3 provides bias for V_3 and V_4. The push-pull output of V_1 and V_2 is applied through RC coupling circuits to the vertical deflection plates of a crt. The push-pull output of V_3 and V_4 is coupled

in the same way to the horizontal deflection plates. Thus, balanced horizontal and vertical deflection is provided and a circular sweep results.

The screen voltages of the four amplifier tubes are the same as the voltage at the plate of V_5. This stage serves as an amplifier for the input signal which produces the radial deflection. So long as no input signal is applied to the grid of V_5, the voltage at its plate remains steady. Therefore, the screen voltages of tubes V_1, V_2, V_3, and V_4 are constant. This results in a constant amplifier gain and a circle is traced on the screen.

If a negative pulse is applied to V_5, its plate current decreases and a smaller voltage appears across R_{14}. Therefore, the voltages at the plate of V_5 and the screens of the push-pull amplifiers increase. This increase in the screen voltages raises the gains of the push-pull amplifiers, and the result is that the size of the circular trace increases for the duration of the negative input pulse.

A positive input pulse has the opposite effect. The screen voltages and thus the gains of the push-pull amplifiers decrease. The size of the circular trace decreases so that an inward radial deflection takes place. If an alternating voltage is applied to V_5, the gains of the push-pull amplifiers are increased and decreased alternately. The result is an alternating outward and inward radial deflection of the circular sweep.

*   *   *

17.   **Longer traces may be obtained with circular sweep than with a linear sweep. True or False?**

*   *   *

SAWTOOTH CURRENT GENERATORS

As mentioned before, because of the resistance and inductance in electromagnetic deflection circuits, trapezoidal voltages are often needed to produce sawtooth currents. It has also been mentioned that most

circuits that produce a sawtooth voltage waveform can be made to produce a trapezoidal voltage waveform by simply placing a peaking resistor in series with the sawtooth-forming capacitor. However, to produce the high current necessary for electromagnetic deflection the sweep generator is usually followed by a power amplifier.

Figure 28 shows a typical sweep circuit used to generate a trapezoidal voltage waveform and thus a sawtooth of current in the deflec-
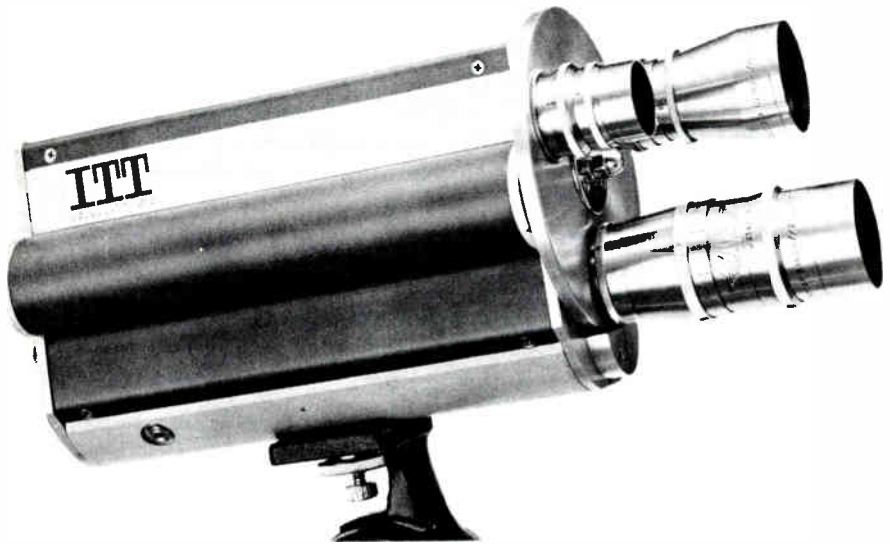
Television cameras incorporate sweep circuits which sweep on electron beam
across the image focused on the camera tube.
Courtesy IT & T Corp., Industrial Prod. Div.

tion coils. The trapezoidal voltage output of sweep generator V_1 is coupled to power amplifier V_2 which supplies the required current to the deflection yoke. A series of trigger pulses is used to trigger the sweep generator. Figure 29 shows these trigger pulses, as well as other waveforms in the circuit of Figure 28.

With V_1 held below cutoff by the $-E_{cc}$ supply, C_2 charges through R_2 and R_3 toward the value of E_{bb}. Since only a small part of the capaci-

tor's charge curve is used, the voltage increase across C_2 is fairly linear. This linear voltage increase is shown between times T_1 and T_2 of Figure 29. Since the charge current is almost constant during the linear increase of capacitor voltage, the voltage across R_2 is almost constant between times T_1 and T_2. Also, R_3 limits the charge current to a low value. Therefore an almost constant low voltage is produced at the upper end of R_2, which is positive with respect to ground.

At time T_2, a trigger pulse causes V_1 to conduct. The low resistance of the triode shunts the series circuit of C_2 and R_2. The capacitor discharges quickly through R_2 and V_1. The voltage across C_2 decreases rapidly from time T_2 to time T_3. During this discharge, a voltage appears across R_2 which is opposite in polarity to that produced when C_2 is charging. The negative voltage produced during the discharge of C_2 has greater amplitude than the positive voltage produced during the charge of C_2. This is because the discharge current is much greater than the charge current.

The output voltage is the sum of the voltages across C_2 and R_2. Since the voltage across C_2 has a sawtooth waveform and the voltage across R_2 is almost rectangular, the output is a trapezoidal voltage as shown in Figure 29. This trapezoidal voltage is applied to the V_2 grid of Figure 28 through the C_3R_4 coupling network. Negative bias is also applied to the grid of V_2 to keep it from going positive.

The trapezoidal voltage is amplified by power amplifier V_2, and applied to the deflection coils of the electromagnetic crt. In Figure 28 the deflection coil circuit is made up of R_5, L_1, and L_2. When the trapezoidal voltage is applied to this circuit, a sawtooth current occurs in deflection coils L_1 and L_2. This produces the required linear sweep.

Figure 30 shows another example of an electromagnetic deflection circuit. V_1, T_1, C_2, R_3, and R_4 are the basic components of a blocking oscillator. The V_1 grid is connected directly to the grid of V_2, which serves as the discharge tube for sawtooth-forming capacitor C_3. Peaking resistor R_5 and variable resistor R_8 are in series with C_3. Thus,

during the C_3 charging period electrons flow from ground through part of R_8, and through R_5 to one plate of C_3. Leaving the other plate, electrons flow through part of the amplitude control potentiometer R_6 to $+E_{bb}$.

During the discharge period, electrons flow from C_3 through R_5 and R_8 to ground and back through V_2 to the other plate of C_3. This results in a trapezoidal voltage across C_3 and R_5 in series, and this voltage is coupled through C_4 to the grids of V_3 and V_4.

As shown, V_3 and V_4 are operated in parallel, with their respective elements tied together. Two tubes operated in parallel provide larger currents than a single tube. R_7 forms the grid resistor for both grids, and R_8 is the common resistor for both cathode circuits. In like manner, the plate currents of both tubes pass through the primary of transformer T_2.

The T_2 secondary is coupled to the coils of the deflection yoke. Resistors R_{10} and R_{11}, each connected in parallel with one of the deflection coils, reduce the voltages induced across the coils during the rapid changes of current. Capacitor C_7 absorbs the energy from the T_2 secondary at the same time, thus reducing any tendency to oscillate.

To decrease distortion of the amplifier plate current waveform, the charge and discharge currents of C_3 are passed through a portion of variable resistor R_8. The upper plate of C_3 becomes more and more positive as this capacitor charges, and this positive increase is applied to the grids of V_3 and V_4. The positive swings on the grids cause the plate currents of these tubes to increase and cause an increase of voltage across resistor R_8. Although C_5 is employed to maintain a constant bias, its filtering action is not completely effective when the voltage changes occur at a low rate.

As C_3 charges, its charge current is decreasing. At the same time the plate currents of V_3 and V_4 are increasing. As all of these currents occur through R_8, the decreasing capacitor charge current counteracts

the effects of the increasing plate currents, thus tending to maintain a constant bias.

During the discharge of C_3, electrons leave this capacitor and flow through R_5 into C_5. From the lower plate of C_5, electrons flow to ground, then through V_2 to the upper plate of C_3. This would seem to discharge C_5 as well as C_3, and to some extent it does. However, the capacitance of C_5 is much greater than that of C_3, and a discharge current of sufficient amplitude to discharge C_3 results in only a very slight change in the potential across C_5.

The slider on R_8 permits varying the bias voltage so that the tubes operate at the points on their characteristic curves which result in the most linear output waveform. Thus, R_8 serves as a linearity control.

In vacuum tube electromagnetic sweep circuits, an output power amplifier is needed to develop the necessary current swing in the deflection coils. This power amplifier requires a certain amount of driving voltage from the sweep generator. In transistor electromagnetic sweep circuits, a similar two-stage arrangement requires that a power transistor be used in the oscillator stage because of the power needed to drive the output amplifier.

Figure 31 shows a two-stage transistor electromagnetic deflection system. Blocking oscillator Q_1, using a power transistor, develops a negative-going sawtooth across C_3 which is applied to the base of output amplifier Q_2. As the sawtooth at the base of Q_2 becomes more negative the collector current through deflection coils L_1 and L_2 increases.

Notice that the blocking oscillator transformer T_1 contains three windings as compared to only two for the electron tube circuit of Figure 30. An extra winding is added to the transformer in Figure 31 to provide a sync input. This arrangement is needed in the transistor circuit to obtain an impedance match between the sync circuits and the oscillator.

In this circuit, a sawtooth voltage is used instead of trapezoidal voltage. As mentioned before, this is necessary because of the high collector resistance of Q_2, as compared to the low plate resistance of a triode tube. In triode vacuum tube deflection circuits both the plate load inductance and the plate resistance must be considered. That is, to obtain a sawtooth deflection current, a sawtooth voltage must be applied across the resistance and a rectangular voltage must be applied across the inductance. However, since the inductance is so small compared to the resistance in a transistor circuit, the inductance may be neglected and a sawtooth of voltage produces a sawtooth of current.

C_4 and R_4 of Figure 31 form a linearization network. The sawtooth of current flowing through emitter resistor R_6 tends to be concave. Since the voltage across R_6 is fed back to the base of Q_2 by R_4, R_5,

Radar indicators such as this incarparate radial sweep circuits.
Caurtesy Radia Carparatian af America

and C_3 it adds to the sawtooth waveform across C_3, which tends to be convex, and produces a linear rising voltage. This linearization network is especially needed in this sweep circuit because of the nonlinear characteristics of Q_2.

The linearity can be adjusted with R_4, the linearity control, but this control also affects the amplitude of the output. Therefore, readjustment of the output amplitude control R_6 is necessary with each linearity adjustment. Frequency control R_1 controls the free running frequency of the oscillator by changing the base bias of Q_1.

Figure 32 shows an electromagnetic deflection circuit used for much higher sweep frequencies than the circuits of Figures 28 and 30. In Figure 32, V_1, T_1, C_3, R_1, R_3, and R_4, make up a blocking oscillator

which controls the conduction and cutoff periods of discharge tube V_2. The frequency is is controlled by variable resistor R_4, and the trapezoidal voltage is formed across capacitor C_6 and variable peaking resistor R_6. A trapezoidal voltage is needed because of the resistance in series with the deflection coils. Between the V_2 plate and the C_6R_6 combination, coupling capacitor C_5 has a capacitance many times that of C_6 and has very little effect on the charge and discharge of C_6. In this way, a trapezoidal voltage is developed across the C_6R_6 combination, even though it is not connected directly to the V_2 plate.

The magnitude of the negative "spike" of the trapezoidal wave depends on the setting of R_6. This determines the linearity of the output waveform. As shown, transformer T_2 couples the output from amplifier tube V_3 to the coils of the deflection yoke.

*   *   *

18.   The collector resistance of a transistor is generally much higher than the plate resistance of a triode vacuum tube. True or False?

*   *   *

DAMPING TUBE

To provide a very rapid return or flyback of the electron beam from the end of one sweep to the start of the next, it is necessary that the current decrease very rapidly in the deflection coil and in the coupling transformer primary and secondary. The rapid change of current during the return sweep period induces high voltage pulses in these coils. The high voltage pulses tend to throw this tuned circuit into momentary oscillation at its resonant frequency.

V_4 of Figure 32 is called a DAMPING TUBE. It is used to prevent or damp undesired oscillations by drawing a heavy current during the portions of the oscillation which make the damping tube plate positive with respect to its cathode, so that the energy of these oscilla-

tions is absorbed by the V_4 circuit. Thus, the induced voltage waveform is damped very rapidly so far as oscillations are concerned, and the coil current has the desired linear sawtooth shape.

Deflection coil circuit oscillations occur at the beginning of the scanning interval, immediately after the end of the flyback period. As explained, these oscillations are due to the high voltages induced by the rapid change in magnetic flux at the instant the circuit current reverses direction.

At this instant, the upper end of the T_2 secondary winding becomes highly positive and causes heavy conduction of damping tube V_4. The V_4 conduction is not harmful to the scanning motion of the cathode ray tube beam because this conduction current is used for deflection at the beginning of the trace period. The heavier the conduction of the damping tube, the greater its effect and the shorter the duration of the oscillation.

Even after oscillations have ceased, the damper continues to draw a small current for the remainder of the trace. The damping tube may be considered as a low resistance during conduction and an infinite resistance during cutoff. Although it is permissible for the damping diode to conduct during the trace, in order that a rapid decay of current may occur during retrace, the damping tube must be cut off during retrace to provide a high resistance. This requirement is satisfied when tube V_4 is so connected that the induced secondary voltage in T_2 makes the V_4 plate negative during the retrace time.

Diode V_4 has the primary function of damping the deflection coil circuit to prevent oscillation. However, in the circuit arrangement of Figure 32, the energy thus acquired by the V_4 circuit is stored and used, instead of being dissipated in the form of heat. This arrangement is known as a **POWER FEEDBACK** or **VOLTAGE BOOSTER** circuit, and the magnetic energy in the fields of the T_2 secondary and the deflection coils is stored in capacitor C_{12}.

As explained, the sudden reversal of current at the end of the retrace or flyback period induces a high voltage surge in the secondary of transformer T_2. This surge is applied to the plate of tube V_4 in series with the $+E_{bb_2}$ supply voltage connected to the tap on the secondary winding. This increased voltage causes a current surge through V_4 to charge capacitor C_{12} to the indicated polarity. The electron path is from the positive plate of C_{12} through V_4 from cathode to plate, through the secondary winding to the tap, through the plate supply from $+E_{bb_2}$ to ground and back to the negative plate of C_{12}.

Tracing the circuit from the plate of V_3, there is a path through the T_2 primary and coil L_1 to the positive plate of C_{12}, and a second path from the V_3 screen grid through R_{10} to R_{11} to the same plate of C_{12}. Since the V_3 cathode connects through R_9 to ground and the negative plate of C_{12} connects to ground, this capacitor serves as a dc voltage source for V_3. Therefore, by rectifying the voltage produced across the T_2 secondary, tube V_4 and capacitor C_{12} make use of energy that otherwise would be lost.

To obtain a satisfactory sawtooth current waveform, the circuit of Figure 32 contains two linearity controls, coil L_1 and potentiometer R_{12}. Varying the adjustable iron core of L_1 results in changing the inductive reactance in the V_3 plate circuit, while feedback energy is coupled from the slider on R_{12} through R_7 and C_7 to the V_3 grid, and through C_4 to the plate circuit of V_2. Capacitor C_{13} is a dc blocking capacitor which keeps dc current out of the deflection coils.

*   *   *

19.   **A damping tube is used in sweep circuits to (a) prevent undesirable oscillations, (b) increase the power output, (c) produce a sawtooth sweep voltage.**

*   *   *

FLYBACK HIGH VOLTAGE POWER SUPPLIES

The main purpose of an electromagnetic sweep circuit is to provide the time base in a crt. However, many high-frequency sweep circuits are also used in high voltage power supplies at the same time, especially in television systems. The high voltage output of these power supplies is applied to the second anode of the crt. Since the high voltage is obtained from the high voltage pulse present at the plate of the output tube during flyback, this type of supply is called a **FLYBACK POWER SUPPLY.**

Figure 33 shows a basic flyback circuit. For simplicity, the damper tube is not included in this figure. Here, V_1 is the output amplifier of the sweep circuit and T_1 is the output transformer, of which secondary winding L_4 connects to the deflection coils. During the portion of the sweep period that V_1 is conductive, its steadily rising plate current produces an expanding magnetic field about primary winding L_2. This field induces a voltage across L_4 which produces a linear rise of current in L_4 and deflection coils L_5 and L_6.

During the flyback interval, V_1 is cut off by the negative voltage on its control grid. Therefore the magnetic field around primary winding L_2 collapses, and due to the autotransformer action a voltage is induced in L_1. Since L_1 is wound with more turns than L_2 the induced voltage is very high.

The field around the deflection coils also collapses, inducing a voltage which is applied to L_4. Transformer T_1 now serves a second purpose, which is to step up the voltage obtained from the deflection coils. For this action L_4 is the primary, while the secondary consists of the total winding, L_1 and L_2. Since the secondary contains several times as many turns as the primary, the peak voltage induced in the secondary by transformer action is equal to several times the peak voltage produced across the deflection coils.

The high voltage induced in L_1 by the L_2 autotransformer action and the voltage induced in the L_1 and L_2 windings by the action of L_4 are

added, and this voltage is applied to the rectifier tube anode. This voltage may be as high as 20,000 volts.

Assume that voltage pulse E_1, produced across L_1 and L_2, makes the upper end of L_1 positive with respect to the lower end of L_2. Since L_3 connects to the low voltage supply positive terminal, the output of the $+E_{bb}$ supply and positive pulse E_1 are applied series aiding to the plate of rectifier tube V_2.

With the plate of V_2 positive due to these applied voltages, electrons flow from the filament of V_2 to its plate, through L_1 and L_2 to $+E_{bb}$ of the low voltage supply, from the negative terminal of the low voltage supply to the lower plate of C_1, and from the upper plate of C_1 to the filament of V_2.

When the flyback pulse causes V_2 to conduct, electron flow charges C_1 to the polarity indicated, and to a voltage almost equal to the sum of $+E_{bb}$ and the pulse peak across L_1 and L_2. That is, neglecting the relatively small voltage between the cathode and

In electromognetically deflected cothode roy tubes, the sowtooth currents in the deflection coils produce mognetic fields which move the electron beom to the proper ploces on the foce of the crt.

Courtesy Thordorson-Meissner

plate of V_2, the total voltage E_{c_1} is equal to $E_1 + E_{bb}$. As indicated, the voltage across C_1 is applied to the anode of the crt. Once C_1 is charged, the voltage across it remains nearly constant, since the only discharge path is the high resistance circuit of the crt anode.

At all times, the V_2 filament is positive with respect to ground by the amount of the voltage across C_1. In the period between one retrace interval and the next, the V_2 plate is at approximately the same volt-

age as the plate of V_1, since they connect through L_1. At this time the V_2 filament is more positive than the plate, and the tube is non-conductive.

The only time V_2 conducts to replenish the charge on C_1 is on the peak of the positive pulse produced across L_1 and L_2 during retrace. Therefore, these brief intervals are the only times V_2 requires filament power. Thus, only the rapid change of flux in T_1 during flyback produces sufficient current in L_3 for proper operation of the V_2 filament.

*   *   *

20.   When does V_2 in Figure 33 conduct?

*   *   *

Figure 34 is a more complete schematic diagram of a flyback power supply. Here, the pentode tube V_1 is the deflection circuit output amplifier, V_2 is the high voltage rectifier, V_3 the damping tube, and V_4 the crt. The output transformer contains the tapped primary L_1 and secondaries L_2 and L_3. L_2 supplies sawtooth current through L_4 and C_3 to the deflection coils, while damping tube V_3 prevents oscillation in this circuit. Tube V_3 and the filter composed of C_1, L_5, and C_2 form the boost voltage circuit.

Briefly reviewing the boost circuit action, when the upper end of winding L_2 is positive, the voltage across L_2 is applied series-aiding with the low-voltage supply output $+E_{bb}$, causing conduction of V_3 so that C_2 is charged to the sum of these applied voltages. The voltage across C_2 is applied through L_5 to charge C_1. The voltage across C_1 supplies the plate circuit of amplifier tube V_1.

The flyback voltage supply includes the winding L_1, rectifier tube V_2, and the filter consisting of C_5, R_3, and C_6. The output filter capacitor, indicated as C_6, is formed by the capacitance between the inner and outer conductive coatings of crt V_4. As shown, R_3 connects to the internal coating which is joined to the anode inside of the tube. Thus, this coating serves as the positive plate, the glass envelope as the

dielectric, and the grounded external coating as the negative plate of the output filter capacitor. If the tube does not have both an inner and outer conductive coating, an actual capacitor is connected in place of C_6.

As explained for Figure 33, during the flyback interval the rapid change of current in the deflection coils develops a voltage which is applied to winding L_2 of the transformer of Figure 34. As a result, a positive voltage pulse of high amplitude is produced across winding L_1. Capacitor C_1 is connected between the lower end of L_1 and ground so that, whenever the upper end of L_1 is positive, the voltage E_{L_1} and the voltage across C_1 are applied series-aiding to the circuit of rectifier tube V_2. The resulting conduction of V_2 causes input filter capacitor C_5 to charge to the polarity indicated.

At this time, electron flow is from the filament to the plate of V_2, down through L_1 to the C_1 positive plate, and from the negative plate of this capacitor to ground. From ground the electrons flow to
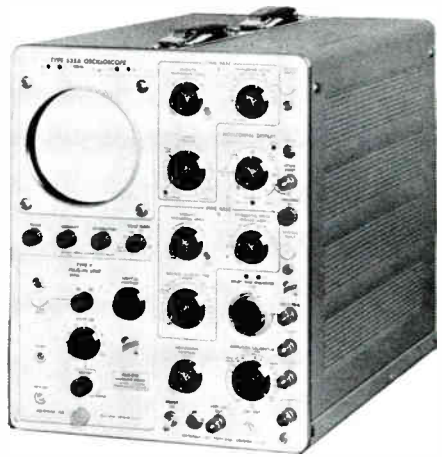
The controls on the right side of this oscilloscope control the scope's sweep circuits. The sweep circuits deflect the spot on the crt screen to produce the trace.

Courtesy Tektronix, Inc.

the C_5 negative plate and from its positive plate to the filament of V_2. This charges C_5 to the sum of the peak voltage across L_1 and C_1. Capacitor C_6 charges through R_3 to the same voltage as C_5, and thus the high voltage output is applied directly to the V_4 anode. The charging of C_5 slightly discharges C_1, but since C_1 is much larger than C_5, the voltage across C_1 decreases very little.

As explained for the similar arrangement of Figure 33 the filament voltage for V_2 is induced in L_3 by the magnetic field of the deflection

transformer. Series resistor R_1 serves to limit the current and prevent excessive filament heating. Capacitor C_3 is a dc blocking capacitor which is included so that only the alternating deflection current is carried by the coils. Connected across V_3, resistor R_2 conducts in parallel with the damping tube. This resistor provides additional damping action, and prevents excessive differences in potential between the plate and cathode of V_3. C_4 suppresses oscillations in the deflection coils which would otherwise cause ripples in the scanning pattern.

*   *   *

21.   **What components form the boost voltage circuit in Figure 34?**

22.   **C_6 in Figure 34 is formed by the coating on the glass envelope of V_4. True or False?**

*   *   *

Figure 35 shows a transistor electromagnetic sweep circuit and flyback power supply. Rectangular voltage pulses from a pulse generator are applied to driver transistor Q_1. During the trace period, forward bias (negative at the base) is applied between the base and emitter of the driver, and the transistor operates in a saturated condition. During retrace, the positive pulse at the driver input cuts off Q_1. When Q_1 is cut off, the collapsing magnetic field around T_1 induces a voltage pulse across the primary winding of T_1. After being stepped down in voltage, this pulse is used to cut off output transistor Q_2.

When Q_2 is cut off, the magnetic field around T_2 collapses and the T_2 primary circuit oscillates for one-half cycle. This produces a flyback pulse across the primary of T_2 and causes the sawtooth current in deflection coils L_2 and L_3 to increase to some maximum value. Then, when Q_2 comes out of cutoff, the deflection coil current slowly decreases until the next positive driving pulse is fed to Q_1. Notice that in this transistor circuit a rectangular voltage waveform and not a sawtooth waveform produces a sawtooth current in the deflection

coils. This is because the transistor's collector resistance is effectively in parallel with the deflection coils, instead of in series with them.

No damping diode is needed in this circuit since the transistor Q_2 can conduct a small current in the reverse direction. This provides enough damping to prevent the circuit from oscillating. However, the large flyback pulse that appears across the primary of T_2 when the magnetic field around the transformer collapses cannot be greater than the collector breakdown voltage of Q_2. To reduce the amplitude of this pulse, the L_1C_2 network is tuned to the pulse's third harmonic so that the voltage across L_1C_2 opposes the flyback pulse at its peak.

High voltage is obtained from transformer T_3. The flyback pulse that appears across the primary winding of T_2 is stepped up by T_3 and then rectified by V_1. V_1 is usually a high-vacuum tube since most semiconductor diodes have too low a voltage breakdown rating to handle the high voltages present here. However, several semiconductor diodes connected in series could be used in place of V_1.

Diode D_1 is connected so that it conducts during retrace, but does not conduct during the trace. Its purpose is to prevent damped oscillations in T_3 from causing ripples in the deflection coil scanning current during the trace. The transistors used in both the driver and output stage have their collectors grounded to the chassis for best heat conduction.

*　　　　　*　　　　　*

23. **What type of voltage waveform is used in the circuit of Figure 35 to produce the sawtooth current in the deflection coils?**

*　　　　　*　　　　　*

SUMMARY

Cathode ray tubes are used in a great deal of electronic equipment. As examples, oscilloscopes, radar systems, and TV systems all incorporate crt's. There are many different ways to display information on the face of a crt. However, almost all forms of displays require

sweep circuits. The sweep circuits may move the crt electron beam from one side to the other, from top to bottom, from center to outer edge, in a circle, or some combination of these motions.

Circular sweep requires two sine waves that are 90° out of phase. One sine wave deflects the electron beam horizontally and the other sine wave deflects the beam vertically to produce a circular sweep. Most types of sweep require some form of sawtooth waveform. The electrostatic crt requires a sawtooth voltage waveform and the electromagnetic crt requires a sawtooth current waveform.

To produce a sawtooth current in a deflection circuit where the resistance is much greater than the inductive reactance, a sawtooth voltage waveform may be used if the resistance is in series with the deflection coils. If the large resistance is in parallel with the deflection coils a rectangular voltage pulse may be used to produce a sawtooth current. However, if the resistance is not much greater than the inductive reactance a trapezoidal voltage waveform must be used.

Sawtooth voltage waveforms may be developed by slowly charging a capacitor through a large resistance and then quickly discharging it through a small resistance. Sawtooth voltage waveforms may also be developed by slowly discharging a capacitor through a large resistance and then quickly charging it through a small resistance. Since the resistance of an electron tube or transistor can be easily controlled, tubes and transistors are often used as either the charging or discharging resistance.

To develop a trapezoidal waveform, a small resistor may be placed in series with the sawtooth-forming capacitor. The sum of the sawtooth voltage across the capacitor and the spike across the resistor is a trapezoid.

IMPORTANT DEFINITIONS

CIRCULAR SWEEP—When the electron beam periodically traces a circle on the face of a crt.

DAMPING TUBE—A tube that draws heavy current from the deflection coil circuit at the beginning of the scanning interval, and thus prevents oscillations that would otherwise occur due to the rapid fall of deflection coil current during the flyback interval.

DEFLECTION GENERATORS—See SWEEP CIRCUITS.

DEFLECTION MODULATION—A way of causing an electron beam to display information on a crt. The information changes the position of (deflects) the electron beam.

FLYBACK—See RETRACE.

INTENSITY MODULATION—A way of causing an electron beam to display information on a crt. The information changes the strength (intensity) of the electron beam causing it to show up brighter or dimmer on the screen.

LINEARIZATION—[*lin* i er igh ZAY sh'n]—The use of special circuits in a sweep generator to improve the linearity of the sawtooth output.

RADIAL DEFLECTION—When the crt electron beam starts at the center of the screen and moves toward the outer edge.

RETRACE—The action that occurs when the electron beam "snaps" back to the beginning of a trace, or the portion of a sawtooth waveform that causes this action. Also called FLYBACK.

SAWTOOTH—The waveform of a voltage or current that slowly rises from a minimum value to a maximum value and then quickly

IMPORTANT DEFINITIONS—(Cont'd)

drops back to its minimum value, or that slowly falls from a maximum value to a minimum value and then quickly increases to its maximum value. A series of these waveforms looks like the teeth of a wood saw.

SCANNING—A periodic movement of the electron beam in a crt.

SWEEP CIRCUITS—Circuits that produce the voltage (in electrostatic deflection) or current (in electromagnetic deflection) which, in turn, cause movement of the electron beam in a crt. Also called DEFLECTION GENERATORS.

TRACE—The pattern that the electron beam produces on the face of a crt, or the slowly rising or falling portion of a sawtooth waveform that occurs at the same time a pattern is being traced on the crt.

TRAPEZOIDAL WAVEFORM—[*trap* i ZOY d'l]—A waveform in which a rectangular waveform is added to a sawtooth waveform so that the sawtooth effectively is riding on the top of the rectangular pulse.

STUDENT NOTES

STUDENT NOTES
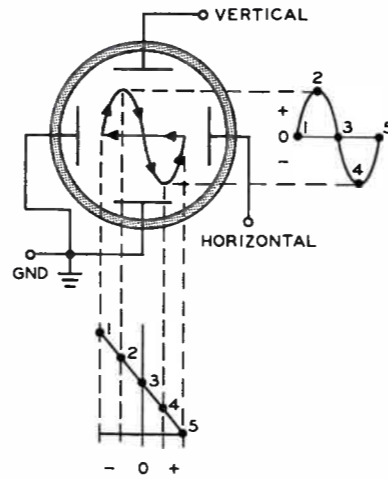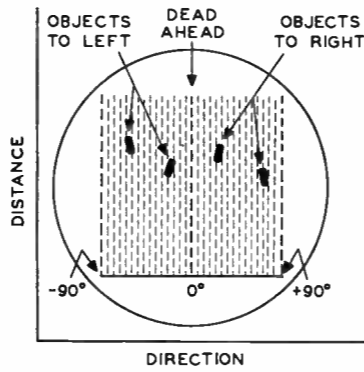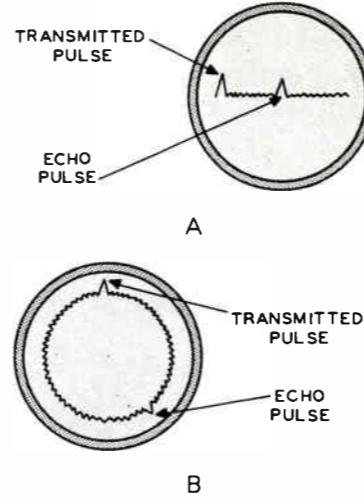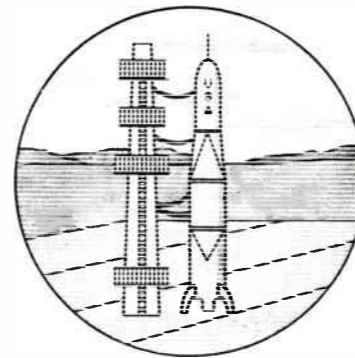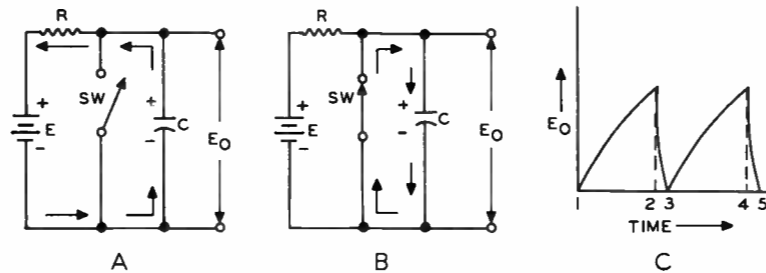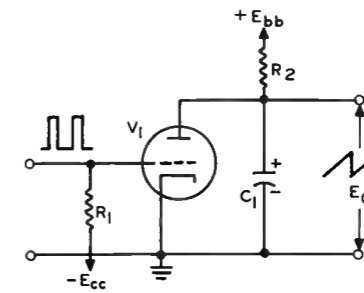
FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

FIGURE 5

FIGURE 6

FIGURE 7

FIGURE 8

FIGURE 9

FIGURE 10

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2624

FIGURE 11

FIGURE 12

FIGURE 13

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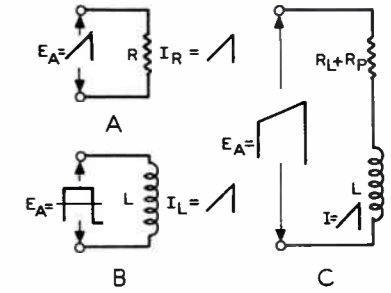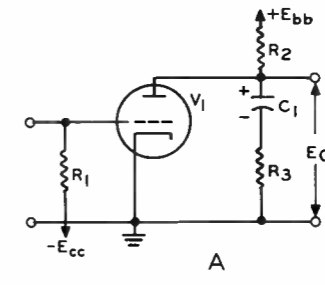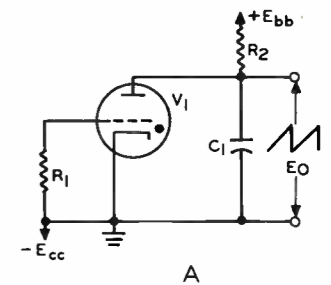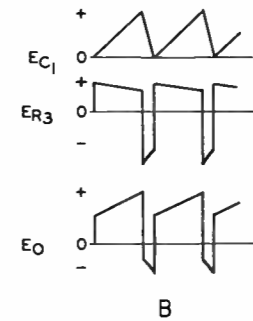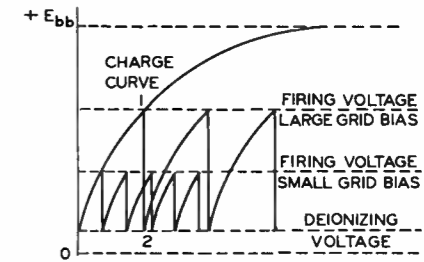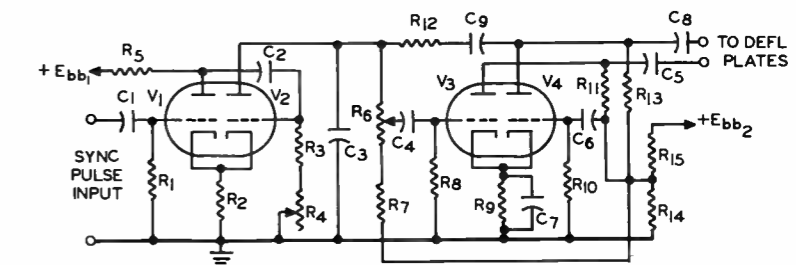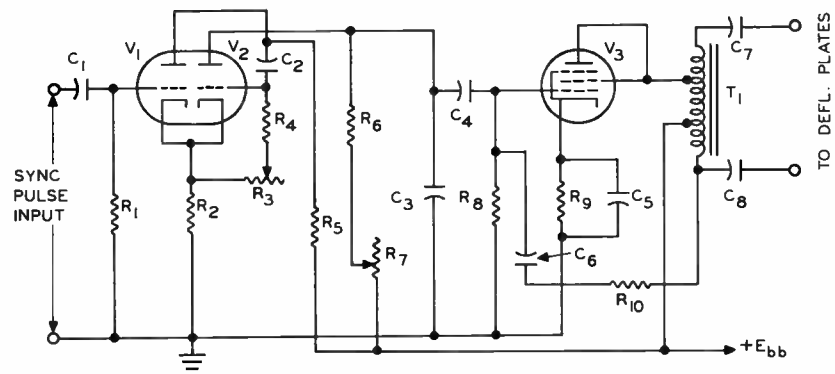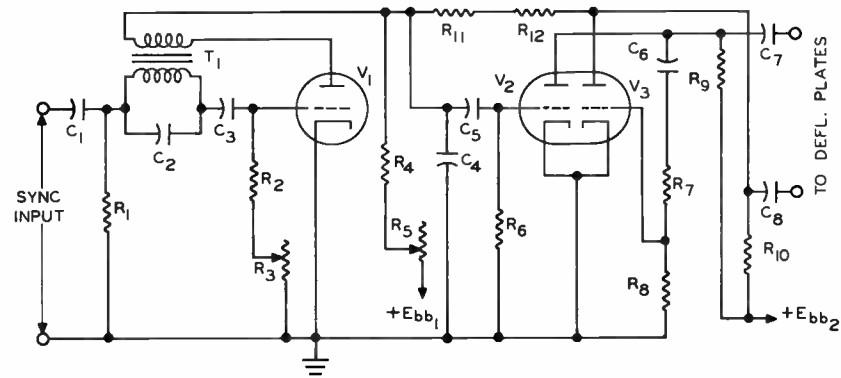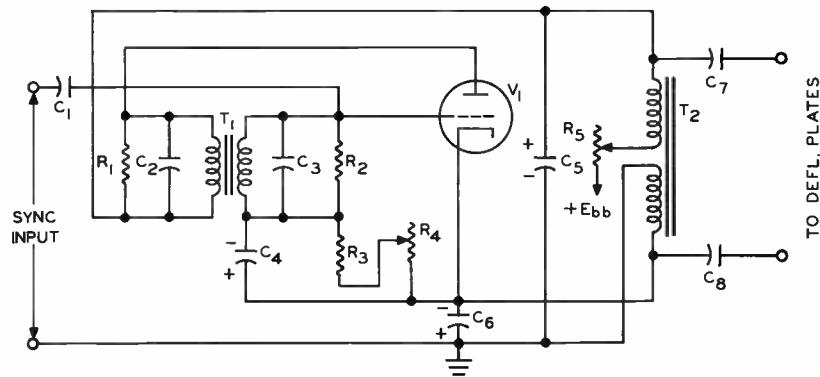
PRACTICE EXERCISE SOLUTIONS

1. False—The sawtooth sweep voltage is usually applied to the horizontal deflection plates of the crt.

2. True

3. True

4. (b) V_1

5. (c) square wave

6. (b) trapezoidal

7. False—Gas tube sweep generators are free-running.

8. (b) push-pull amplifier.

9. True

10. False—Blocking oscillators are free-running and produce continuous sawtooth pulses.

11. (b) Q_1 is cut off.

12. (c) a discharge tube.

13. (a) monostable multivibrator.

14. True

15. (a) bootstrap circuit.

16. (a) the grid-cathode capacitance of V_1.

17. True
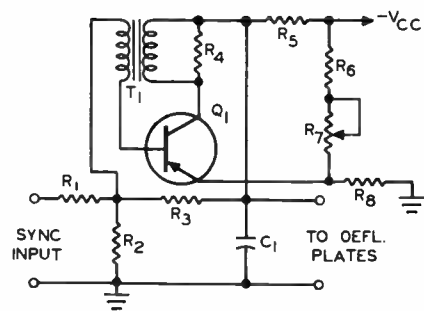
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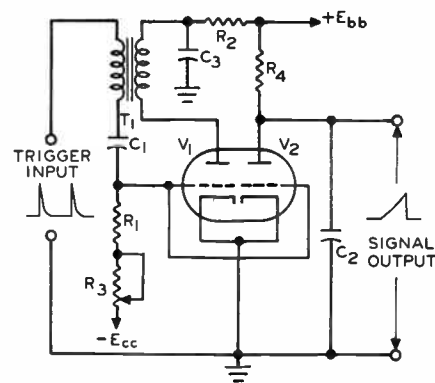
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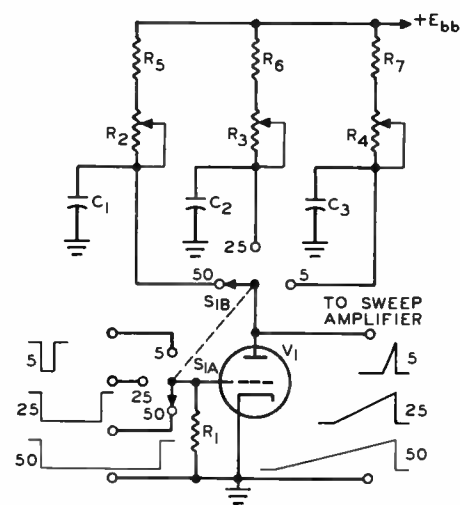
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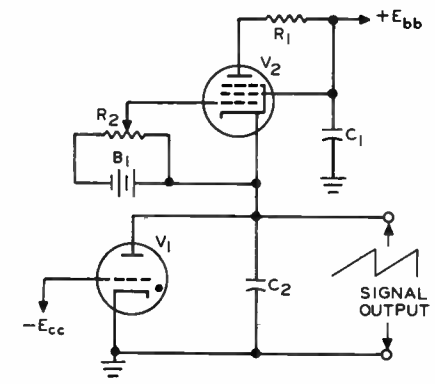
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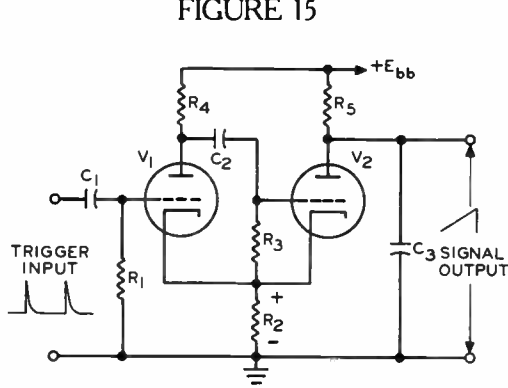
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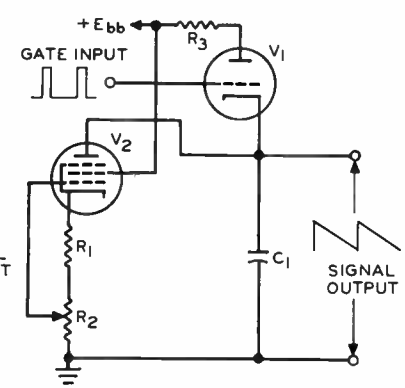
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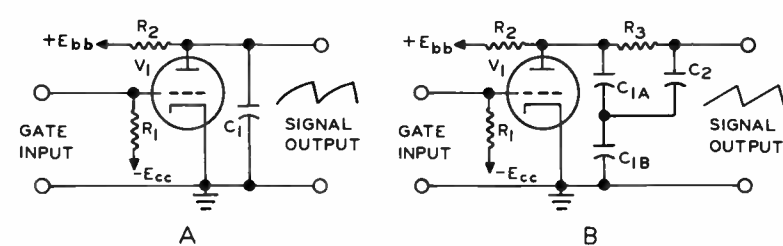
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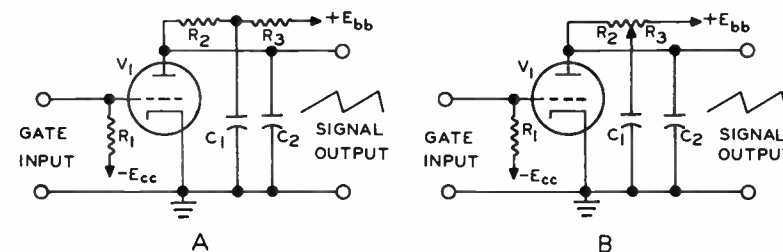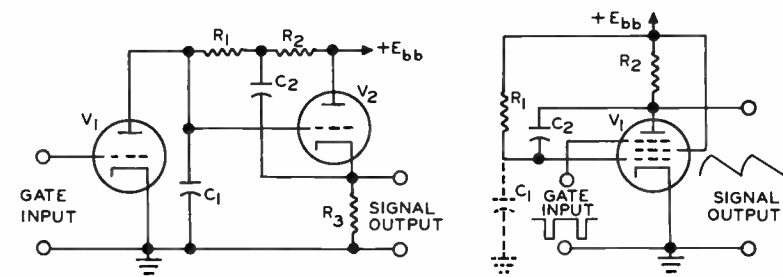
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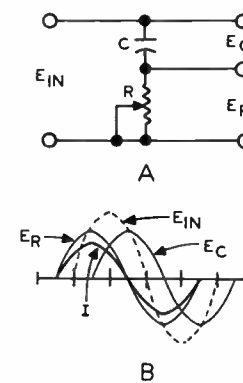
FIGURE 22

FIGURE 23

FIGURE 25
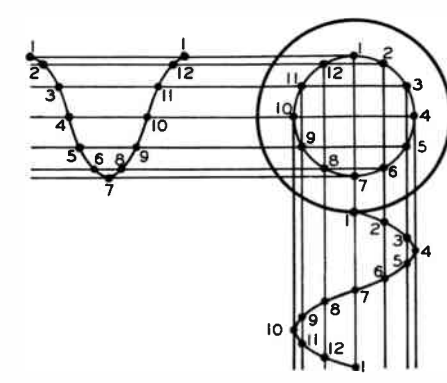
FIGURE 24

FIGURE 26

FIGURE 27

PRACTICE EXERCISE SOLUTIONS—(Cont'd)
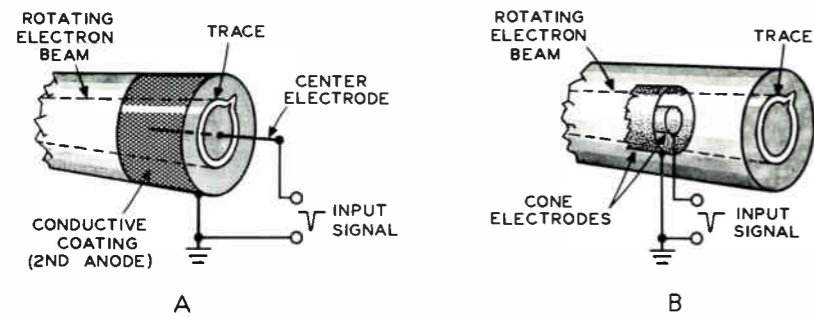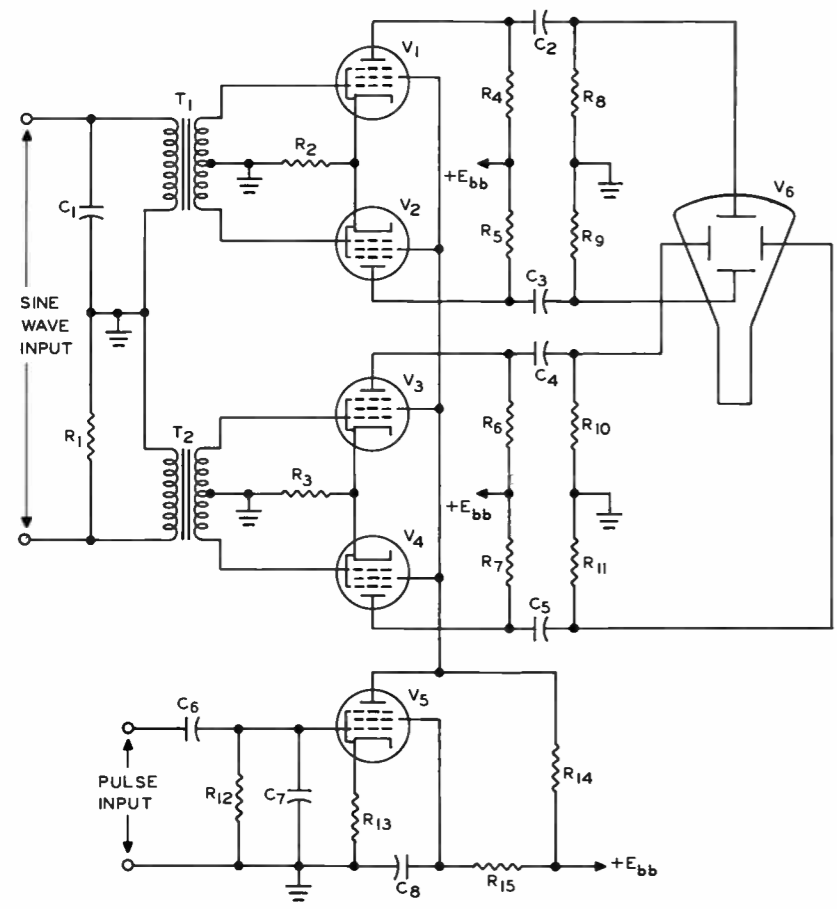
18. **True**

19. (a) **prevent undesirable oscillations.**

20. **During the flyback interval, when V_1 is cut off.**

21. **C_1, L_5 and C_2.**

22. **True**

23. **A rectangular voltage waveform is used.**
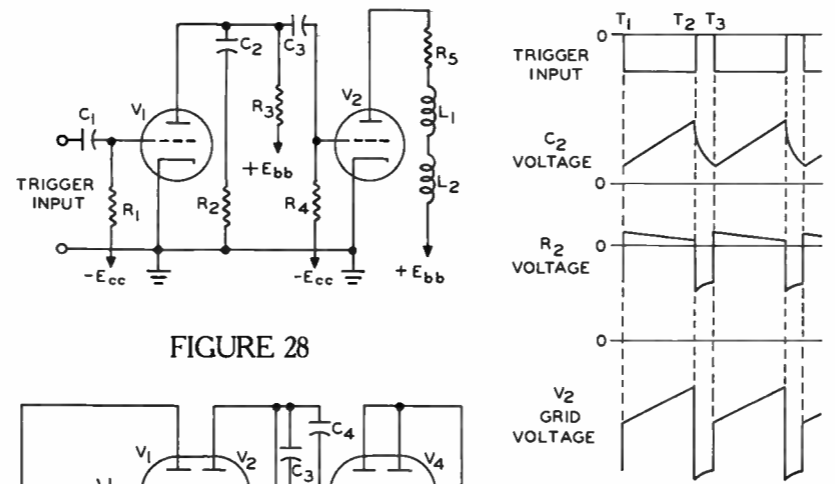
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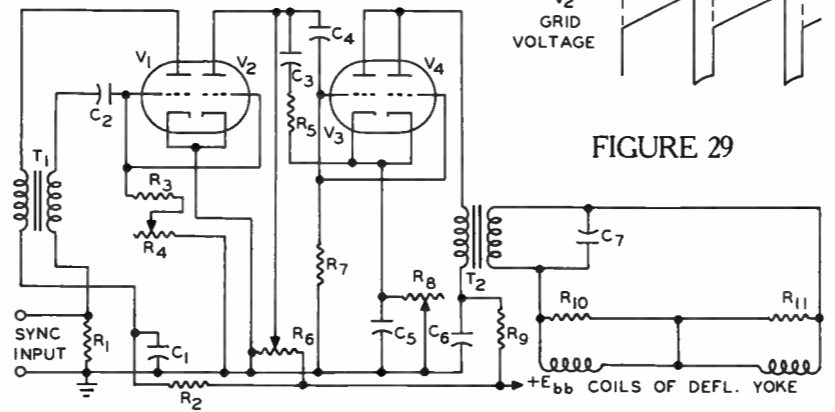
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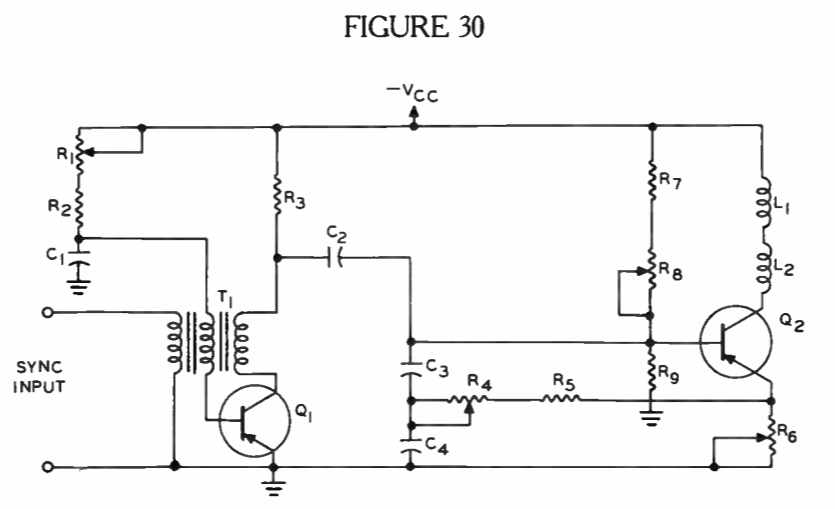
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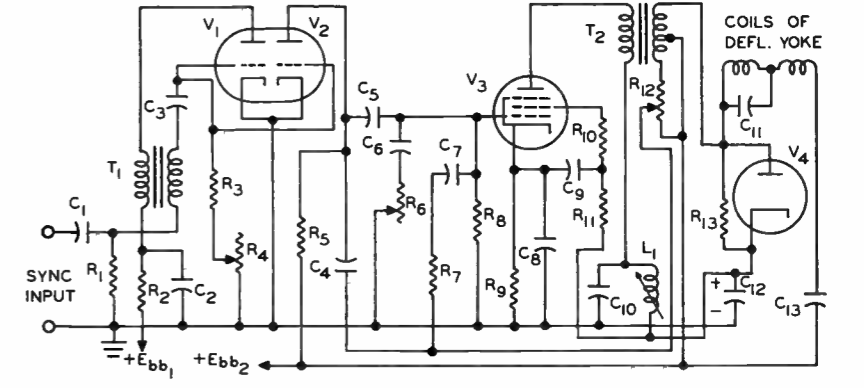
FIGURE 31

FIGURE 32
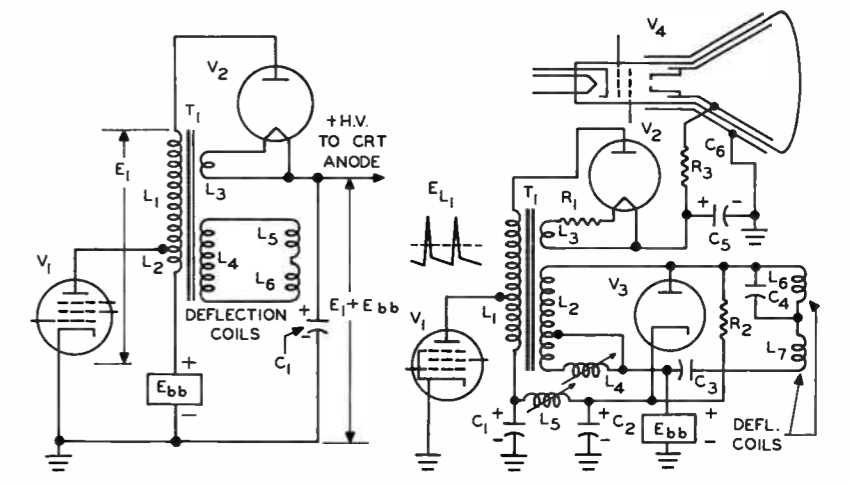
FIGURE 33

FIGURE 34

FIGURE 35

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SWEEP CIRCUITS
QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question, as illustrated in the example below.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

LESSON CODE

2624A

Example: **A part of a human leg is the**

A
B
C
D

(A) wrist. (B) knee. (C) elbow. (D) shoulder.

1. **If the echo received by a radar receiver causes the crt trace to become brighter, the crt**
(A) is intensity modulated. (B) is deflection modulated. (C) uses A-type scan. (D) uses J-type scan.

2. **The VOLTAGE WAVEFORM required to produce a SAWTOOTH CURRENT IN A PURE INDUCTANCE is a**
(A) sine wave. (B) sawtooth. (C) trapezoid. (D) rectangular pulse.

3. **Capacitor C_1 of Figure 9A DISCHARGES**
(A) when a negative trigger pulse is applied to the grid of V_1. (B) when V_1 fires. (C) through R_2 and the E_{bb} supply. (D) when V_1 is cut off.

4. **The sawtooth-forming capacitor in the circuit of Figure 10 is**
(A) C_4. (B) C_3. (C) C_8. (D) C_5.

5. **Sawtooth-forming capacitor C_3 in the circuit of Figure 16 continues to CHARGE as long as**
(A) V_2 is cut off. (B) V_1 is cut off. (C) V_2 conducts. (D) the trigger pulse lasts.

6. **In the sweep circuit of Figure 15, the TIME DURATION of the sweep is determined by**
(A) the value of $+ E_{bb}$. (B) the duration of the gate pulse. (C) the amplitude of the gate pulse. (D) the time constant of the sawtooth-forming capacitor and its series resistance.

7. **A constant-current pentode V_2 is used in the sweep circuit of Figure 18 to**
(A) decrease the firing voltage of V_1. (B) increase the amplitude of the sawtooth. (C) maintain a constant current through V_1 when C_1 is charging. (D) improve the linearity of the sawtooth.

8. **When C_{1A} in the circuit of Figure 20B first begins to charge after V_1 is cut off,**
(A) C_{1B} is still discharging. (B) the voltage across C_{1A} is equal to the voltage across C_2. (C) C_2 also charges. (D) C_2 is still discharging.

9. **In the circuit of Figure 27 the voltage waveform applied to the series combination of C_1 and R_1 is a**
(A) sine wave. (B) rectangular pulse. (C) sawtooth. (D) trapezoid.

10. **In the circuit of Figure 33 the crt anode voltage is produced by charging C_1**
(A) to the plate voltage of V_1. (B) with deflection coil current. (C) during the intervals when V_2 is nonconductive. (D) when the flyback pulse causes V_2 to conduct.

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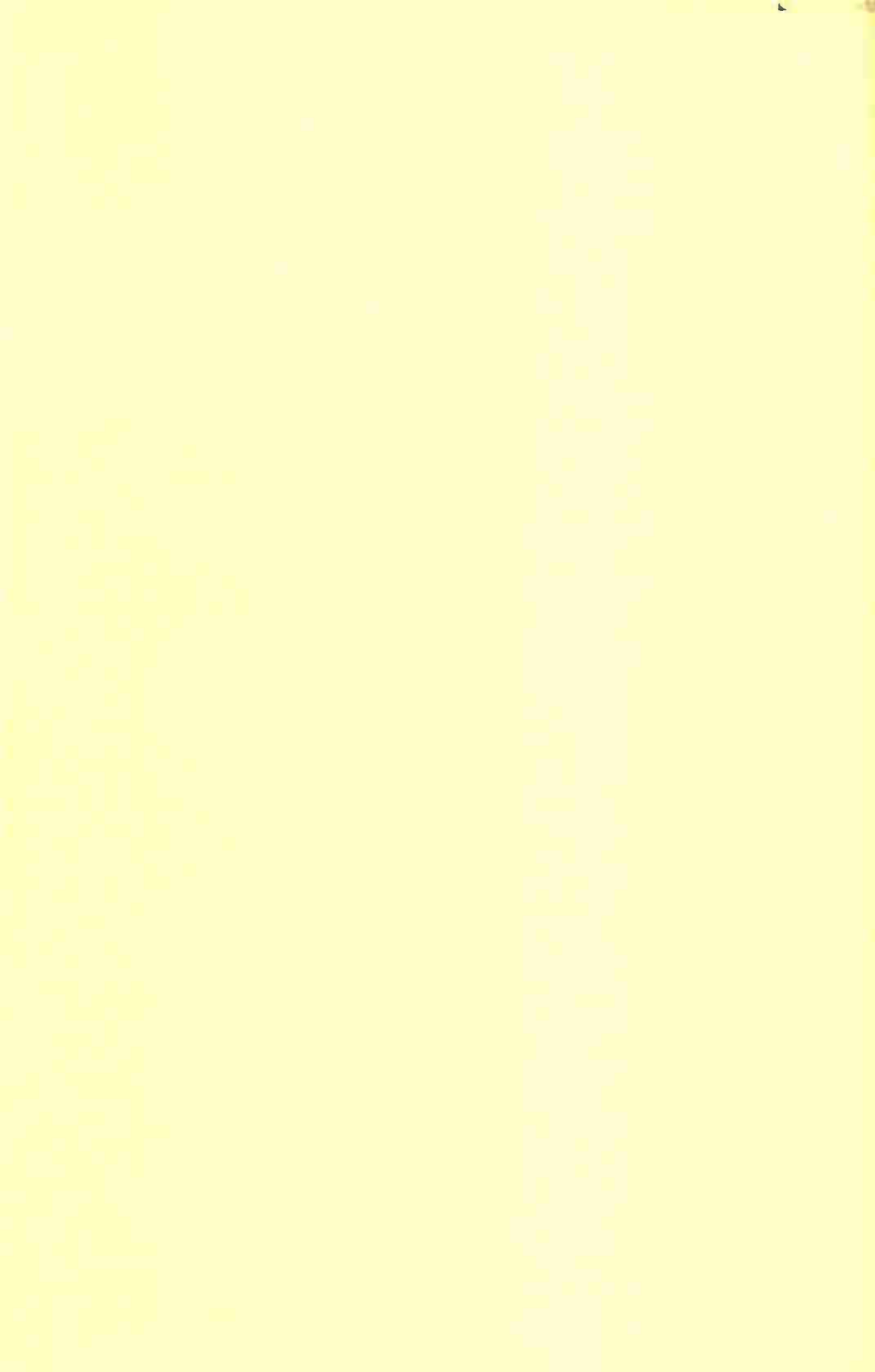
VACUUM TUBE
OSCILLATORS
Lesson 2165A

DeVRY Technical Institute

CHICAGO   TORONTO

VACUUM TUBE OSCILLATORS

Revised 1967

OPPORTUNITY
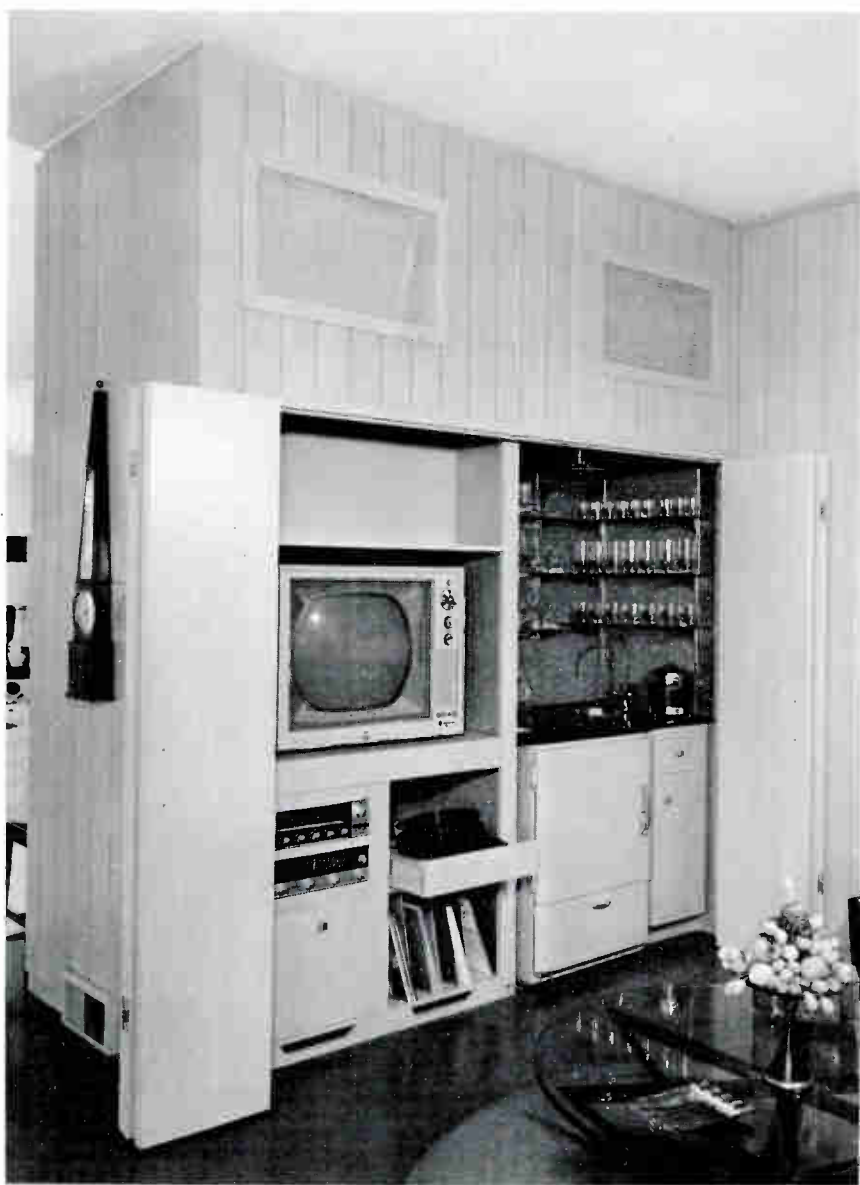
The above photo shows a custom stereo hi-fi installation. The television receiver as well as the AM/ FM and stereo FM receiver employs a number of oscillator circuits.

VACUUM TUBE
OSCILLATORS

CONTENTS

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The greater a man's knowledge of what
has been done , the greater is his power
of knowing what to do.

-- Selected

VACUUM TUBE OSCILLATORS

Electric power is provided by the many commercial power companies. This power in most cases is ac power at a frequency of 60 cps. The power companies employ electromechanical generators, usually called alternators, to develop the ac power. In some areas 25 cycle or 50 cycle ac power is used.

Electronic equipment that operates from the power line usually converts the ac power into dc power. The dc power is then applied to the various circuits in the equipment. In many cases, ac signals of some specific frequency are required in a piece of equipment. Electromechanical generators, due to their size and frequency limitations, are usually not used. Instead, electronic signal generating circuits called OSCILLATORS are used.

Electronic oscillator circuits can generate signals with frequencies ranging from a few cycles per day to more than 30,000,000,000 cycles per second. In addition to a wide range of frequencies, electronic oscillators can develop signals with almost any desired waveshape.

The jobs performed by oscillators in electronic equipment vary. In a digital computer, oscillators develop the timing signals which permit the computer to perform thousands of operations per second. In a TV receiver, oscillators generate the signals which are used to assemble the pictures on the TV screen. In industry, oscillators generate the ac power used to solder metal parts, electronically seal plastic, heat treat metal, glue plywood, and the like.

FEEDBACK OSCILLATORS

Most electronic oscillators are basically amplifiers with part of the output signal fed back to the input in a particular manner. If this feedback signal has the proper phase and

amplitude, the amplifier oscillates. When oscillating, the circuit develops an output signal without any external input signal being applied to the amplifier. Of course, the amplifier must be connected to a power supply. Oscillator circuits which operate on this principle are called **FEED-BACK OSCILLATORS.**

Figures 1 and 2 illustrate the basic operation of a feedback oscillator. An input signal E_{IN} is shown applied to an amplifier in Figure 1. The amplifier increases the amplitude of E_{IN} and at the same time reverses its polarity as shown by the output signal E_O waveshape. This polarity reversal or 180° phase shift is common in many types of amplifiers. A feedback circuit is connected to the output of the amplifier. It reverses the phase of E_O and at the same time reduces its amplitude to produce a feedback signal E_f. E_f has the same amplitude and phase as E_{IN}.

In Figure 2 the feedback signal E_f is connected to the input of the amplifier. Since E_f has the same polarity and phase as E_{IN} the amplifier continues to develop an output signal even when E_{IN} is removed. The amplifier circuit is now oscillating. The circuit continues to develop an output signal, or oscillate, as long as power is applied to the circuit from the power supply. Note again that the feedback circuit provides the input signal for the amplifier and that no external input signal is applied to the amplifier.

To sustain oscillations, certain conditions must be met in the circuit of Figure 2. First of all the feedback signal E_f must have the proper amplitude. Secondly, the feedback signal E_f must have the proper phase or polarity. If both of these conditions are not met, oscillations will not occur.

You might wonder just how oscillations start in a feedback oscillator. When power is first applied to the circuit the sudden increase in amplifier current serves as a very small signal, which is amplified by the circuit. A portion of this amplified signal is fed back to the input through the feedback circuit. This signal is repeatedly amplified and fed back

until the circuit develops a full output signal.

The circuit can also be "started" by the minute signals developed by electrical noise, random variations in electron emission, and other circuit conditions. In this case the noise signal is amplified and fed back to the input circuit. Again the signal is repeatedly amplified and fed back to the amplifier input. By this method the circuit develops a full output signal. The frequency as well as the waveshape of the signal is controlled by component values in the amplifier and feedback circuits.

*   *   *

1. Basically, what is the function of an oscillator? *To generate an alternating current,*
2. What two conditions must be met by the feedback signal to sustain oscillations in a feedback oscillator? *Proper phase + proper amplitude*

*   *   *

There are many different types of oscillators. The main difference between them is the method used to obtain the feedback signals. In general, there are three basic feedback methods. Oscillators can be classed, according to the feedback method used, as LC oscillators, RC oscillators, and crystal oscillators.

LC OSCILLATORS

LC oscillators employ feedback networks consisting of LC circuits. The frequency of the signals generated by the circuit is usually governed by the resonant frequency of the LC circuit. In most cases LC oscillators develop sinusoidal output signals.

The simple circuit shown in Figure 3 illustrates the basic operation of an LC oscillator. V_1 operates as a conventional amplifier. The primary of T_1 serves as the V_1 plate load. The secondary of T_1 provides the input or feedback signal

for V_1. Bias supply E_{cc} provides grid bias for V_1. C_1 together with the primary of T_1 forms a parallel resonant or "tank" circuit.

Circuit operation begins when power is first applied. The sudden increase of V_1 plate current shock excites the tank circuit consisting of C_1 and the T_1 primary. When a tank or parallel LC circuit is excited, it generates a sinusoidal
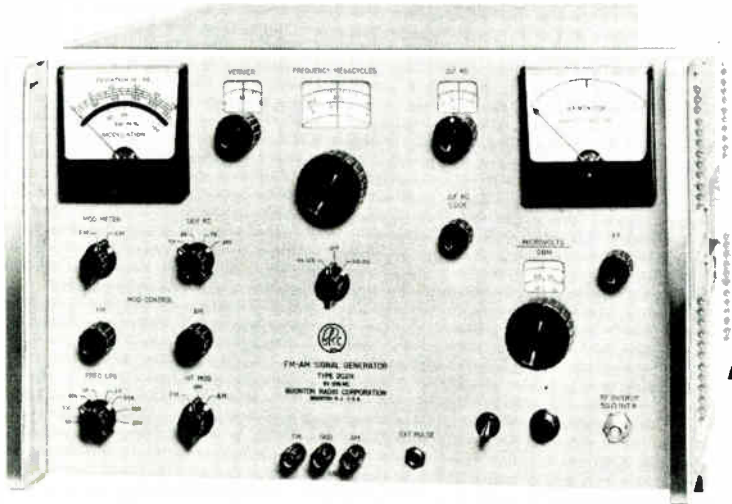
The signal generator shown above can be used to align AM and FM receivers. Generators of this type are basically variable frequency oscillators.

alternating current at its resonant frequency. The alternating current is developed in a tank circuit by the interchange of energy between the inductor and capacitor. The charged capacitor discharges through the inductor, and the inductor then returns the energy to the capacitor. The amount of energy lost during each interchange depends on the circuit resistance.

The alternating current in the T_1 primary induces an ac

voltage into the secondary of T_1. V_1 amplifies this signal.
The resulting alternating V_1 plate current aids the action in
the tank circuit. This feedback action continues until the
V_1 alternating plate current and the tank circuit current
become maximum. The circuit continues to oscillate as
long as power is applied from the power supply.

Figure 4 shows the voltage and current waveforms for the
circuit of Figure 3. The plate current (I_b) waveform is
shown in Figure 4A. Note that the plate voltage waveform
(E_b) in Figure 4B is 180° out of phase with plate current.
Remember, plate voltage and plate current are always 180°
out of phase in a vacuum tube. Figure 4C shows the feed-
back voltage waveform (E_f). Note that the feedback voltage
is 180° out of phase with the plate or output voltage of V_1.
This is the same relationship as shown in Figure 2.

The inversion or phase shift between the plate voltage and
feedback signal is provided by T_1 in Figure 3. The trans-
former secondary is connected so that as V_1 plate current
increases, the grid of V_1 becomes more positive, and vice
versa. If the T_1 secondary leads are reversed, the phase
of the feedback signal is changed and the circuit will not
oscillate. The amplitude of the feedback signal is controlled
by the turns ratio of T_1.

The frequency of the signal generated by the circuit of Fig-
ure 3 is controlled by the resonant frequency of the tank
circuit. The approximate frequency of oscillation in an LC
oscillator can be found by using the formula

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

where f is the frequency in cycles per second at which the
        tank circuit oscillates,
        L is the inductance of the tank circuit coil in henries,
        C is the capacitance of the tank circuit capacitor in
        farads, and
        π is a constant number, approximately 3.1416.

*   *   *

3. In the circuit of Figure 3 what component provides the feedback
   signal? T_1

4. Suppose you construct an oscillator similar to the circuit of Fig-
   ure 3.   If the connections to the secondary of T_1 are reversed
   will the circuit oscillate? Why? *No, The feedback signal*
   must be 180° out of phase with the output.
5. What is the approximate frequency of oscillation in Figure 3 if
   C_1 is 100 pf and the T_1 primary inductance is .04 h?

                         80 kc

*   *   *

GRID LEAK BIAS

The oscillator shown in Figure 3 is operated Class A.   Al-
though Class A operation produces the least distortion, it
has the poorest efficiency. To improve efficiency the circuit
of Figure 3 could be operated Class B or C.   For Class B
operation the bias is increased to the cutoff point and for
Class C operation the bias is increased to beyond cutoff.

The fixed bias arrangement shown in Figure 3 is not nor-
mally used for Class B or C oscillator operation. One rea-
son is that if E_{cc} is increased to provide Class B or C op-
eration, V_1 is normally cut off. When power is applied
there can be no sudden increase of plate current to start
the circuit operation. The oscillator circuit thus would not
be "self starting". An external input signal would have to
be momentarily applied to start the circuit oscillating.

Most vacuum tube LC oscillators employ a special type of
bias called GRID LEAK BIAS. This type of bias permits
the circuit to be self starting even when Class C operation
is used. Figure 5 shows the circuit of Figure 3 using grid
leak bias. C_2 and R_1 form the grid leak bias network.

With the grid leak bias arrangement shown in Figure 5,
there is no bias on V_1 when power is first applied. As a

result, the sudden increase of V_1 plate current starts the oscillating action. The grid of V_1 is driven positive by each positive alternation of the feedback voltage supplied by the T_1 secondary. Grid current flows whenever the grid in a vacuum tube is driven positive. Some of this grid current is carried by C_2 and the secondary of T_1, and charges C_2 to the polarity shown in Figure 6A. Notice that C_2 is negative at the grid end. As the feedback signal goes through its
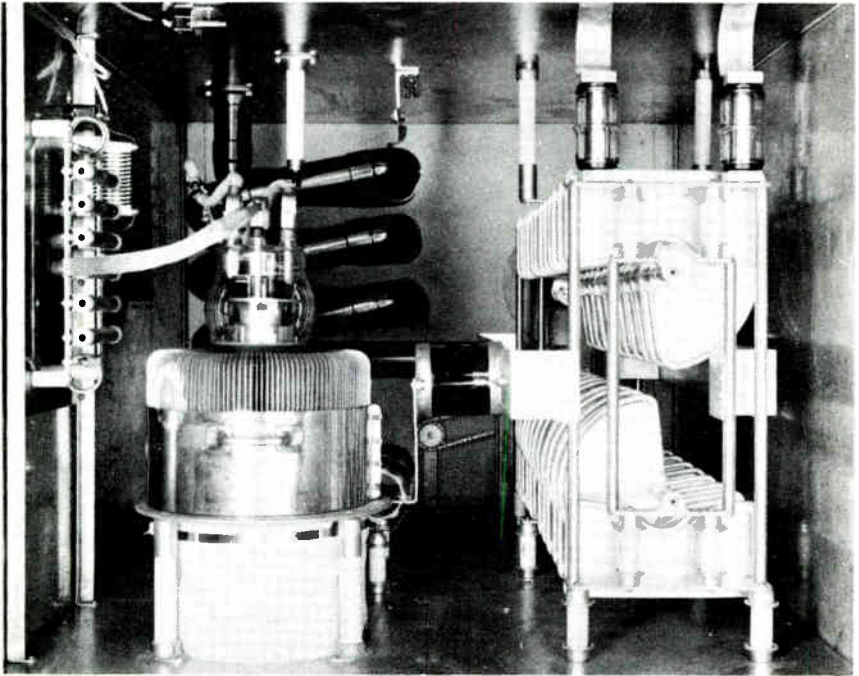
In a dielectric heater, an oscillator, usually an LC oscillator, is used to generate a high frequency signal which in turn is used to heat various materials. The above photo shows the oscillator section of a 50 KW dielectric heater.

Courtesy Industron Corp.

negative alternation, C_2 discharges through R_1 as shown in Figure 6B. The C_2 discharge current makes the grid end

of R_1 negative and the cathode end positive. The voltage developed across R_1 is the grid bias for V_1.

The R_1C_2 time constant is made long so the voltage across R_1 does not get a chance to decrease to any great extent before the next positive alternation of the feedback voltage comes along and recharges it. By properly choosing the values of R_1 and C_2, either Class B or C operation can be obtained. In most cases Class C operation is employed due to its high efficiency.

The grid leak bias arrangement of Figure 5 is referred to as **SHUNT TYPE GRID LEAK BIAS**. This name comes from the fact that the grid leak resistor R_1 is in shunt or parallel with the tube grid-cathode circuit. The grid leak bias network can also be arranged as shown in Figure 7. Note here that the grid leak bias resistor and capacitor are in parallel. However, the grid leak bias resistor R_1 is in series with the V_1 grid cathode circuit. This arrangement is referred to as **SERIES TYPE GRID LEAK BIAS**. With similar component values, series grid leak bias develops a higher bias voltage than shunt grid leak bias.

*   *   *

6. For the most efficient operation an oscillator should be operated
   (a) Class A,   (b) Class B,   (c) Class AB,   (d) Class C.

7. When does the grid leak bias capacitor in Figure 5 charge?
   During the positive alternation of the cycle.
8. The grid leak bias network shown in Figure 5 is referred to as series grid leak bias. True or False?

*   *   *

The oscillator circuit shown in Figure 7 is sometimes called a **TICKLER COIL OSCILLATOR** or **ARMSTRONG OSCILLATOR**. The T_1 secondary and C_1 form the tank circuit. V_1 conducts in pulses, at a frequency determined by the tank circuit. The plate current pulses are coupled by T_1 to the grid tank circuit to maintain oscillations.

The tickler coil or Armstrong oscillator of Figure 7 has several disadvantages. The most important disadvantage is that it has an upper frequency limit around 50 mc (50,000,000 cps) due to the capacitive effects of the feedback transformer.

HARTLEY OSCILLATORS

Feedback can also be obtained by using a tapped coil in the tank circuit. An oscillator circuit that uses this arrangement is referred to as a HARTLEY OSCILLATOR.

Figure 8 shows one type of Hartley oscillator employing the tapped tank circuit coil. V_1 operates as a conventional amplifier. Grid leak bias is provided by R_1 and C_2. L_1 and C_1 form the LC tank circuit. The frequency of oscillation is approximately equal to the resonant frequency of L_1 and C_1. Notice in Figure 8 that the plate supply E_{bb} connects to the tap on L_1. C_3 is a bypass capacitor that places the tap on L_1 at signal ground.

Due to the grid leak bias arrangement there is no bias on V_1 when power is first applied. Thus the circuit IS SELF STARTING. The sudden increase of V_1 plate current when power is applied shock excites the $L_1 C_1$ tank circuit. This causes a pulse of alternating current in the tank circuit. The bottom of L_1 connects through C_2 to the V_1 grid. The tap on L_1 is connected through C_3 to ground, and to the cathode of V_1. Thus, the ac voltage across the B part of tank coil L_1 is applied to the grid-cathode circuit of V_1. V_1 amplifies this feedback voltage. The resultant V_1 plate current aids the action in the $L_1 C_1$ tank circuit. This feedback action continues until the tank circuit alternating current reaches its maximum value. At the same time the V_1 grid leak bias increases until V_1 is operating CLASS C.

With V_1 operating Class C its plate current consists of very short pulses which restore any energy lost in the tank circuit. Due to the tank circuit action, however, the $L_1 C_1$ current as well as the voltage across L_1 and C_1 has a sinusoidal waveshape.

*   *   *

9. An oscillator circuit widely used in broadcast AM radio re-
    ceivers employs a tapped tank circuit coil. What is the name
    of this oscillator circuit? *Hartley*

10. In Figure 8, where is the feedback voltage developed?
    In the B part of L₁

11. Suppose the oscillator of Figure 8 is used to generate ac sig-
    nals for test purposes. To provide a number of different test
    signals the oscillator frequency must be varied. Which com-
    ponents in Figure 8 can be adjusted to vary the frequency?
    L₁ & C₁

*   *   *

There are a number of methods of obtaining an output signal
from an oscillator. Capacitor C_4 connected to the plate of
V_1 in Figure 8 is one method. Another method is to use a
coil inductively coupled to the tank coil.

Care must be taken when an output signal is taken from an
oscillator. If too much energy is removed the circuit may
become unstable. As a result the frequency of oscillation
can change and the circuit may even stop oscillating. To
eliminate this loading problem, a small signal is taken from
an oscillator and then amplified before it is applied to the
load. Amplifiers used for this purpose are usually referred
to as BUFFERS.

In the Hartley oscillator of Figure 8, dc plate current flows
through the top section of L_1. An arrangement such as this
where dc plate current flows through part or all of the tank
circuit is referred to as a SERIES FED OSCILLATOR.

Figure 9 shows another type of Hartley oscillator. L_1 is
the tapped tank coil. L_1 and C_1 form the tank circuit which
controls the frequency of oscillation. C_1 is made variable
in this circuit so the oscillation frequency can be changed.
If desired, L_1 could be made variable and C_1 could be a
fixed capacitance. C_3 and R_1 form a series grid leak bias

network. The output signal appears across L_2, which is inductively coupled to L_1.

In this circuit the tap on L_1 is connected directly to ground and the V_1 cathode. The plate of V_1 is connected to the top of L_1 through C_2. C_2 has a very low reactance at the operating frequency, so from an ac standpoint the top of L_1 is connected to the V_1 plate. Actually the circuits of Figures 8 and 9 are identical from an ac or signal standpoint. In Figure 9, however, the plate of V_1 is connected to the plate supply E_{bb} through the radio frequency choke (RFC). This coil has a high reactance at the operating frequency. This prevents shorting the plate of V_1 to ground through the power supply at signal frequencies.

The miniature triode shown above is designed for use as an oscillator in TV tuners.
Courtesy General Electric Co.
Receiving Tube Dept.

The circuit of Figure 9 operates exactly like the circuit of Figure 8. When power is first applied the sudden increase of V_1 plate current is coupled through C_2 to the L_1C_1 tank. This shock excites the tank circuit. The ac voltage across the B section of L_1 is the feedback signal which is fed to the grid-cathode circuit of V_1. V_1 amplifies the feedback signal to aid the tank circuit action. At the same time the grid leak bias builds up and V_1 operates Class C.

The dc plate current in Figure 9 flows through the r-f choke and not the tank circuit. As a result, the Hartley oscillator of Figure 9 is referred to as a SHUNT FED OSCILLATOR. An advantage of the shunt fed oscillator is that adjustments may be made on the tank circuit without coming in contact with the plate supply. This is not so in the series fed arrangement of Figure 8, where the tank circuit is "hot", and at the high supply voltages used in some high power oscillators, can be dangerous to touch.

*   *   *

12. Does L_1 in Figure 9 carry the V_1 dc plate current? *No*

13. Would you use a series fed or would you use a shunt fed Hart-
ley oscillator if you did not want the tank circuit to carry the
dc plate current?   *Shunt Fed*

*   *   *

COLPITTS OSCILLATORS

An oscillator circuit similar to the Hartley oscillator is
shown in Figure 10. This circuit does not employ a tapped
tank coil. However, two tank capacitors are used to give
the effect of a tapped tank capacitor. This tapped tank ca-
pacitor is the distinguishing feature of the **COLPITTS OS-
CILLATOR.**

C_1, C_2 and L_1 form the tank circuit in Figure 10. Shunt
grid leak bias is provided by R_1 and C_3. The r-f choke
supplies dc to the plate of V_1. The tank circuit is connected
to the V_1 plate through C_4, and thus, no dc plate current is
carried by the tank circuit components. As a result the
Colpitts oscillator of Figure 10 is a shunt fed oscillator.

The operation of the Colpitts oscillator of Figure 10 is sim-
ilar to the operation of a Hartley oscillator. When power is
first applied to the circuit, the sudden increase of V_1 plate
current shock excites the L_1, C_1 and C_2 tank circuit. The
ac voltage that appears across C_2 is applied to the V_1 grid-
cathode circuit. V_1 amplifies this feedback signal. The
resultant V_1 plate current pulses sustain the oscillations in
the tank circuit. As the oscillations build up to their max-
imum amplitude, the grid leak bias on V_1 increases until
V_1 operates Class C.

In the Colpitts oscillator the ratio of C_1 to C_2 determines
the amplitude of the feedback signal. On the other hand, the
position of the tap determines the feedback signal amplitude

in the Hartley oscillator. The output signal can be obtained from the circuit with a capacitor connected to the plate of V_1 or by using a coil inductively coupled to L_1.

*   *   *

14. What is the distinguishing feature of a Colpitts oscillator?
    The tapped tank capacitance.

15. The feedback signal is developed across (a) C_1, (b) C_2, (c) C_3 in the circuit of Figure 10.

16. The circuit of Figure 10 is a (a) shunt, (b) series fed oscillator.

*   *   *

As the operating frequency in a vacuum tube circuit increases, the reactance of the tube interelectrode capacitance becomes important. This capacitance plus other effects in the tube limit the maximum operating frequency. The interelectrode capacitance can be put to use in a high frequency oscillator similar to the Colpitts oscillator. Figure 11 shows such an oscillator called an ULTRAUDION OSCILLATOR. The plate-cathode capacitance C_{pk} and grid-cathode capacitance C_{gk} of the tube form the tapped tank capacitance. C_1 is included in Figure 11 to permit the tank circuit to be tuned to the desired frequency. C_3 and R_1 form the shunt grid leak bias network. C_2 couples the plate of V_1 to the tank circuit.

Aside from the fact that the tapped tank circuit capacitance is the tube interelectrode capacitance, the ultraudion oscillator operates exactly like the Colpitts oscillator. As mentioned earlier it is used in high frequency applications where the tube capacitance is high enough to provide the desired feedback. This type of oscillator is often used in the tuner circuits of TV receivers.

*   *   *

17. Which oscillator circuit is sometimes used in TV receiver tuners and other high frequency circuits? *The Ultraudion Oscillator.*

18. In the circuit of Figure 11, the feedback signal is developed across (a) C_1, (b) C_3, (c) C_{gk}, (d) C_{pk}.

*   *   *

TUNED PLATE TUNED GRID OSCILLATORS

Another basic type of oscillator is the **TUNED PLATE TUNED GRID (TPTG) OSCILLATOR** shown in Figure 12. This circuit is basically an amplifier circuit with tuned circuits in both the plate and grid circuits. The two tuned circuits are not inductively coupled together. However, feedback is provided by the V_1 grid-plate capacitance, C_{gp}, which couples the plate circuit to the grid circuit. Series grid leak bias is provided by R_1 and C_2.

The operation of this circuit is in many ways similar to the operation of a Colpitts or Hartley oscillator. When power is applied the sudden increase of V_1 plate current shock excites the $C_3 L_2$ tank circuit in the plate circuit of V_1. The grid-plate capacitance C_{gp} of the tube couples energy from the plate tank circuit back to the $C_1 L_1$ grid tank circuit. The ac voltage in the grid tank circuit is amplified by V_1 and aids the action in the $C_3 L_2$ plate tank circuit. This action continues until the oscillating current in the plate tank circuit reaches its maximum value. At the same time the grid leak bias on V_1 increases until V_1 operates Class C.

Like the ultraudion oscillator, the TPTG oscillator is used at higher frequencies where the grid-plate capacitance is large enough to sustain oscillations. The frequency of oscillation is slightly less than the resonant frequency of the plate and grid tank circuits. Therefore the tank circuits appear slightly inductive at the operating frequency.

*   *   *

19. What component provides feedback in the oscillator circuit of Figure 12?

C_{gp}.

20. What type of grid leak bias is used in the circuit of Figure 12?

              Serut

     *   *   *

CRYSTAL OSCILLATORS

In many applications, high frequency stability and accuracy of oscillation frequency are required. For example, the frequencies of broadcast radio and TV stations must be very exact and stable. The LC oscillators shown earlier are not stable enough for applications such as these. Temperature changes, component and tube aging, mechanical vibration, etc. can change the frequency of an LC oscillator more than is permitted. A **CRYSTAL OSCILLATOR** can be used for better stability and more precise control of frequency than is possible with LC oscillators.

A crystal oscillator is a special circuit which employs the electromechanical oscillation properties of certain crystals such as quartz, tourmaline, and Rochelle salts to control the oscillator frequency. Of the three crystal types, quartz is the most widely used in oscillator circuits.

The crystal used in a crystal oscillator is a thin slab cut from a natural or man made crystal. If the crystal slab is placed under mechanical strain, electric charges appear on its opposite faces. Also, when electric charges are applied to its opposite faces, the crystal slab tends to bend or warp. This is referred to as the **PIEZOELECTRIC EFFECT.**

In a crystal oscillator, voltage is applied across the crystal element. If the frequency of this voltage is close to the mechanical resonant frequency of the crystal, large amplitude oscillations can occur. As a result of these mechanical movements, the crystal develops an ac voltage with a frequency equal to the mechanical resonant frequency of the crystal. The crystal slab is usually held in a case or holder as shown in Figure 13. The crystal element is held between two metal plates. The plates provide an electric connection to the crystal through the pins. A spring presses the metal

plates against the crystal.

Figure 14 shows the basic circuit of a crystal controlled oscillator. The symbol labeled Y_1 is used to represent the crystal. Actually, the circuit is very similar to the tuned plate tuned grid oscillator. The crystal in the grid circuit acts as a grid tank circuit. C_1 and L_1 form the plate tank circuit. The grid-plate capacitance C_{gp} provides feedback from the plate circuit to the grid circuit. The output signal is taken from the plate of V_1 through C_2. R_1 is the grid load resistor.

When power is first applied to the circuit of Figure 14, the sudden increase in V_1 plate current shock excites the $L_1 C_1$ plate tank circuit. The values of L_1 and C_1 are chosen so their resonant frequency is slightly higher than the mechanical resonant frequency of

Crystal plates for use in crystal controlled oscillators are cut from crystals such as the one shown above.
Courtesy North American Philips Co., Inc.

the crystal. The ac voltage in the $L_1 C_1$ tank circuit is fed back to the crystal through C_{gp}. This voltage causes the crystal to oscillate or vibrate. The crystal vibrations develop an alternating voltage which appears across the crystal. This feedback signal is amplified by V_1, and the amplified signal reinforces the oscillations in the $L_1 C_1$ tank. This process continues until the oscillations reach their maximum amplitude. The frequency of oscillation is changed by changing the crystal.

It may appear as though no bias is provided in the crystal oscillator of Figure 14. However, the capacitance provided by the crystal holder assembly together with R_1 forms a grid leak bias network which develops a bias voltage across R_1.

*   *   *

21. Describe in your own words the piezoelectric effect. *When a xtal
is bent or twisted a difference - potential appears on its opposite sides. If a
difference of potential is applied to opposite side of a xtal it will have a tendency to size*

22. How can you change the frequency of oscillation in Figure 14?
By changing the Crystal.

23. How is bias developed in Figure 14? *Bias is developed by
the combination of R, + P₁, Y₁ has a capacitance apart
between its two holding plates.*

*

To provide a very high natural resonant frequency, a crystal
must be very thin. This inverse relationship between fre-
quency and crystal thickness limits the maximum natural
resonant frequency, as a very thin crystal is very fragile.
Higher operating frequencies are obtained by having the
crystal vibrate at a harmonic of its natural resonant fre-
quency. For example, a crystal with a fundamental fre-
quency of 6 mc could be operated at its second harmonic
(12 mc) or its third harmonic (18 mc). Crystals designed
to operate at harmonics of their natural resonant frequen-
cies are referred to as OVERTONE CRYSTALS.

The amplitude at which a crystal vibrates depends on the
voltage fed back to it. If the feedback voltage is too large
the vibrations may be large enough to crack the crystal.
Tetrode and pentode tubes have small interelectrode ca-
pacitances, and thus may be used to provide safe, low
amounts of feedback voltage.

The plate tank circuit in a crystal oscillator is usually tuned
to a frequency slightly higher than the crystal frequency.
This makes the plate tank circuit appear inductive at the
crystal frequency and makes the oscillator stable. If this
is not done oscillations will stop when a load is connected to
the circuit.

*   *   *

24. What is an overtone crystal? *It is a crystal made to
oscillate at a frequency 2 or 3 times higher
than its natural frequency.*

25. Would the feedback voltage in Figure 14 be reduced if a pentode
    were substituted for V_1? Why? *yes, Plate to Grid
    capacitances would be reduced.*

26. To what frequency would you adjust L_1 and C_1 of Figure 14?
    *a frequency a little higher than that of the
    Crystal.*

                    *   *   *

Temperature has an effect on the frequency of a crystal
oscillator. The exact effect depends largely on how the slab
was cut from the raw or mother crystal. There are many
different types of "crystal cuts". The crystal cut refers to
the angle of the slab with respect to the crystal axis.

The fractional change in frequency per unit change of tem-
perature is called the TEMPERATURE COEFFICIENT. An
X-cut crystal has a negative coefficient. Thus, as temper-
ature increases, the frequency of the crystal decreases,
and vice versa. A Y-cut crystal has a positive temperature
coefficient. As temperature increases, the frequency of the
crystal increases, and vice versa. Another cut known as
the GT cut has a zero temperature coefficient over a certain
temperature range. The frequency of this crystal will not
change as the temperature changes.

To eliminate frequency changes due to temperature changes,
the crystal is often placed in a special heating unit called a
"crystal oven". The crystal oven maintains the crystal at a
constant temperature.

                    *   *   *

27. Which crystal cut would you use for an oscillator in a broadcast
    transmitter where the frequency must remain constant despite
    temperature changes? *GT cut.*

                    *   *   *

ELECTRON COUPLED OSCILLATORS

When a load is connected to an oscillator circuit it removes

energy from the circuit. Also, the inductance and capaci-
tance of the load can change the oscillator frequency. The
effects are more pronounced with an LC oscillator than with
a crystal oscillator. However, loading still has some effect
on crystal oscillator frequency. To reduce the undesirable
loading effects, the oscillator can be operated as an **ELEC-
TRON COUPLED OSCILLATOR (ECO).**

Figure 15 shows an electron coupled Hartley oscillator. In
an electron coupled oscillator the only coupling between the
load and the oscillator is through the electron stream of the
tube. L_1 is the familiar tapped tank coil. C_1 and L_1 de-
termine the frequency of oscillation. C_2 and R_1 form the
grid leak bias network.

Notice that the screen grid of V_1 is connected to the plate
supply $+E_{bb}$ through the r-f choke and R_2. R_2 serves as a
screen dropping resistor and C_6 is a screen bypass capacitor
which places the bottom end of the r-f choke at signal ground.
The r-f choke has a high reactance at the operating fre-
quency. As a result, the screen voltage of V_1 can vary with
changes in signal, and thus the screen of V_1 serves as a
plate. To identify its function as an oscillator plate, and
still distinguish it from the regular plate of the tube, the
screen is often referred to as the "oscillator anode" in a
circuit of this type.

Actually, the screen grid, control grid and cathode of V_1
act like a triode. C_3 is the feedback capacitor which sup-
plies a feedback signal from the screen or anode circuit of
V_1 back to the grid circuit. Neglecting the plate circuit for
the moment, the components connected to the screen, con-
trol grid and cathode form a shunt fed Hartley oscillator
like the circuit of Figure 9.

Since the screen is a fine wire, it captures only a part of
the electrons emitted from the cathode. The rest of the
electrons pass through the screen to the plate of V_1. The
V_1 screen current is in the form of pulses at the frequency
of the L_1C_1 tank circuit. The V_1 plate current pulses sup-

ply energy to the $C_4 L_2$ tank circuit which in turn supplies power to the load.

The advantage of the electron coupled oscillator is that it is connected to the load only through the tube electron stream. This prevents the load from having a direct effect on the
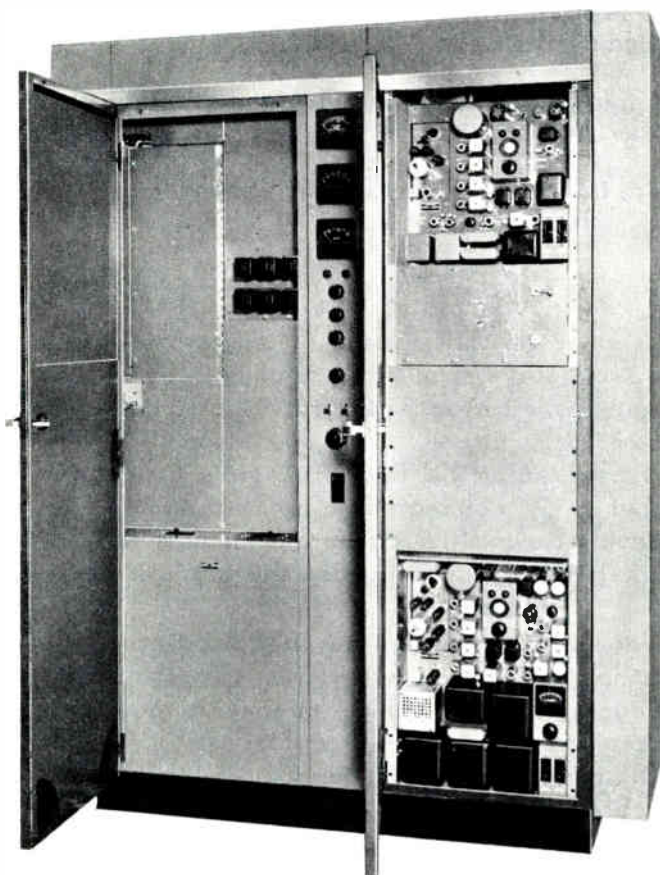
The above photo shows a 10 KW stereo FM transmitter. The oscillator circuits which develop the carrier signal are located in the right hand cabinet.

Courtesy Radio Corporation of America
Broadcast and Communications Products Division

operation of the oscillator circuit. Another advantage of the electron coupled oscillator is that changes in plate voltage

will not affect the oscillator frequency. Therefore, the frequency will remain relatively constant despite power supply variations.

*   *   *

28. What basic oscillator circuit is used to form the electron coupled oscillator of Figure 15? *Hartley*

29. The plate of V_1 in Figure 15 is the oscillator circuit anode. True or False?

30. How is the load coupled to the oscillator circuit in Figure 15?
    By the electron Flow

*   *   *

Figure 16 shows the circuit of another electron coupled Hartley oscillator. The Hartley oscillator in this circuit is a series fed oscillator which is slightly different from the one shown in Figure 8. The operation of this circuit is, however, the same as that of Figure 8. Notice that the cathode of V_1 is connected to the tap on L_1. As a result, plate current flows through the bottom half of L_1. The feedback signal is developed across the top half of L_1.

The screen of V_1 serves as the oscillator anode and is placed at signal ground by bypass capacitor C_5. Because the cathode is not grounded, energy is not fed back from the screen circuit to the grid circuit. The pulses of V_1 cathode current provide the feedback which excites the L_1C_1 tank circuit.

Figure 17 shows a crystal controlled electron coupled oscillator circuit. The screen grid of V_1 serves as the oscillator anode. The frequency of oscillation is controlled by Y_1. The interelectrode capacitances of tetrodes and pentodes are quite low. As a result, C_1 is employed to provide enough feedback voltage to make the crystal vibrate. This circuit is called the modified Pierce oscillator.

*   *   *

31. The electron coupled oscillator in Figure 16 is (a) series fed, (b) shunt fed.

32. What component provides feedback in the circuit of Figure 17?

*   *   *

FREQUENCY STABILITY

In many applications the frequency of an oscillator must be kept constant. Examples of this are the oscillators used to develop the carriers for radio and TV stations. No oscillator, even a crystal oscillator, is perfectly stable. Changes in oscillator frequency are caused by changes in circuit component values, changes in tube characteristics, and changes in the mechanical arrangement of components.

Changes in oscillator frequency due to mechanical movement of components can be reduced by mounting all components firmly. If vibration is present, such as would be in a missile, the whole oscillator assembly is shock mounted. Temperature control also prevents movement of components due to expansion and contraction.

By providing regulated supply voltages, changes in tube characteristics can be reduced. The effects of changes in interelectrode capacitance can be reduced by employing large capacitors in the tank circuit. With this arrangement, the interelectrode capacitance of the tube is only a small part of the total tank circuit capacitance.

Changes of component values are usually caused by temperature changes. Regulating the oscillator circuit temperature reduces these changes considerably. Changes in component values can also be reduced by using temperature compensating capacitors. These capacitors change their capacitance with temperature to offset the other changes in component values.

The frequency stability of an LC oscillator also depends on the loaded Q of the tank circuit. This is particularly true of oscillators which must deliver power to a load. The loaded Q of the tank circuit is written as Q_L and is the figure of merit of the tank circuit under operating conditions. The higher the Q_L, the greater the oscillator stability. Q_L is found by dividing the impedance connected across the tank circuit by the reactance of either the tank circuit inductor or the capacitor at the operating resonant frequency.

$$Q_L = \frac{Z_L}{X}$$

where Q_L is the loaded Q of the tank circuit,
$\quad\quad$ Z_L is the load impedance connected in parallel with the tank circuit, and
$\quad\quad$ X is the reactance of either the tank circuit inductor or capacitor at the operating resonant frequency.

To obtain a large Q_L the load impedance should be much larger than the reactance of the inductor or capacitor. Since X_L is equal to $2\pi fL$, the inductive reactance will be small if a coil with a low inductance is used. Since $X_C = 1/2\pi fC$, the capacitive reactance will be small if a large capacitor is used. Thus, a tank circuit with a small L and a large C has a high Q_L. As a result, the frequency stability of an oscillator is high when its tank circuit has a low L/C ratio.

$\quad\quad\quad$ * $\quad\quad\quad\quad$ * $\quad\quad\quad\quad$ *

33. If an oscillator circuit has large tank circuit capacitors, would you have to be careful about changing tubes so as not to change the oscillator frequency? *No*

34. For good frequency stability an oscillator tank circuit should have (a) a low L/C ratio, (b) a high L/C ratio, (c) a low value of tank circuit capacitance.

$\quad\quad\quad$ * $\quad\quad\quad\quad$ * $\quad\quad\quad\quad$ *

RC OSCILLATORS

RC oscillators employ resistors and capacitors in their feedback networks. As in LC oscillators, the feedback network in an RC oscillator must provide a feedback signal of the proper phase and amplitude to sustain oscillations. In most cases RC oscillators are used to develop signals in the low frequency range, below about 100 kc. LC oscillators on the other hand are used to develop higher frequency signals.

PHASE SHIFT OSCILLATORS

One of the simplest RC oscillators is the **PHASE SHIFT OSCILLATOR** shown in Figure 18. V_1 operates as a conventional amplifier. R_4 and C_4 provide cathode bias. R_5 is a screen dropping resistor and C_5 is a screen bypass capacitor. R_6 is the plate load resistor and C_6 couples the output signal from the V_1 plate. Feedback from the plate of V_1 back to its grid is provided by C_1R_1, C_2R_2 and C_3R_3.

For a moment refer back to the block diagrams of Figures 1 and 2. Note that the amplifier provides a 180° phase shift between its input and output signals. The feedback network shifts the phase of the feedback signal so it is in phase

This variable frequency oscillator, VFO, is used to generate the carrier signals for an amateur radio transmitter. High frequency stability is obtained by careful construction techniques, high quality components, and the use of temperature compensating components.
Courtesy National Radio Company, Inc.

with the input signal, thus causing the amplifier to oscillate.

In the circuit of Figure 18, the voltage at the plate of V_1 is 180° out of phase with the signal at its grid. You may recall that the voltage across a resistor in a series RC network is out of phase with the supply voltage. In Figure 18, R_1 and C_1 are in series with the plate of V_1. The values of R_1 and C_1 are chosen so the voltage across R_1 is 60° out of phase

with the V_1 plate voltage at the oscillator frequency. This voltage is applied to the series combination of C_2 and R_2. The values of R_2 and C_2 are chosen so the voltage across R_2 is 60° out of phase with the voltage across R_1 at the oscillator frequency. The values of C_3 and R_3 are also chosen to provide a 60° phase shift.

Since each series RC circuit is designed to provide a 60° phase shift at the oscillator frequency, the voltage applied to the grid of V_1 is the plate voltage of V_1 shifted 60° + 60° + 60°, or 180°. The V_1 plate voltage is 180° out of phase with its grid voltage. With the 180° phase shift provided by the RC feedback network, the feedback signal applied to the V_1 grid is 180° + 180° = 360° or in phase with the grid voltage. Thus, oscillations occur.

The phase shift oscillator shown in Figure 18 produces a sinusoidal output signal. The frequency of oscillation is determined by the values in the C_1R_1, C_2R_2 and C_3R_3 networks. Since each RC network provides the same phase shift, all the capacitors have the same value and all the resistors have the same value.

The LC oscillators described earlier used grid leak bias to provide Class C operation. A normal Class C amplifier produces the most distortion even though it has the highest efficiency. Due to the characteristics of the tank circuit an LC oscillator develops a sinusoidal output waveshape with low distortion even though the tube operates Class C.

Class A operation is used in the phase shift oscillator of Figure 18 to obtain a sinusoidal output waveshape with low distortion. This is because there is no LC tank circuit to correct distortion in the phase shift oscillator.

The frequency of the phase shift oscillator of Figure 18 can be changed by changing the values of all the resistors or capacitors in the feedback circuit. The phase shift oscillator is often used for fixed frequency applications.

*   *   *

35. A phase shift oscillator is normally used in very high frequency applications.   True or False?

36. How many degrees of phase shift are provided by C_1 and R_1 in the circuit of Figure 18?   *60°*

37. What is the function of R_4 and C_4 in Figure 18? *To produce cathode bias.*

*   *   *

WEIN BRIDGE OSCILLATORS

Another widely used RC oscillator is the **WEIN BRIDGE OSCILLATOR.**   This oscillator makes use of a special RC circuit called the Wein bridge. Figure 19 shows the circuit of a Wein bridge oscillator. V_1 and V_2 operate as conventional amplifiers.   Both V_1 and V_2 provide a 180° phase shift between their grid (input) and plate (output) signals. As a result, the signal at the output terminal, the plate of V_2, is in phase with the signal at the grid of V_1. According to the principles illustrated in Figures 1 and 2, if the signal at the plate of V_2 were coupled to the grid of V_1, the circuit would oscillate.

In Figure 19, the signal at the plate of V_2 is coupled back to the grid of V_1 through the RC network consisting of R_1C_1 and R_2C_2. R_1C_1 and R_2C_2 together with R_3 and R_4 form the Wein bridge. The voltage appearing across R_2 and C_2 is in phase with the signal coupled to the network from the plate of V_2 at only one frequency. This is the frequency at which the circuit oscillates.

Like the phase shift oscillator, the Wein bridge oscillator develops a sinusoidal output wave. The frequency of oscillation is controlled by the values of R_1C_1 and R_2C_2.   For proper circuit operation the values are chosen so the product of R_1 and C_1 equals the product of R_2 and C_2; that is, $R_1C_1 = R_2C_2$.   For this reason, both resistors or both

capacitors must be changed at the same time whenever the oscillation frequency is to be changed. Ganged resistors and capacitors are commonly used in this circuit to change the frequency.

The Wein bridge circuit is widely used as a variable frequency test oscillator. One example is its use as an "audio generator" to supply test signals for testing hi-fi stereo music systems.

*   *   *

38. Which components form the Wein bridge in the circuit of Figure 19? R_1, C_1, R_2, C_2, R_3, C_4

39. Suppose you are going to build a variable frequency audio oscillator for hi-fi testing. If you use the Wein bridge circuit of Figure 19, how could you vary its frequency? With ganged variable pots or ganged variable condensor.

*   *   *

BLOCKING OSCILLATORS

Figure 20 shows the circuit of an RC oscillator called a **BLOCKING OSCILLATOR.** Although this circuit resembles the LC oscillator shown in Figure 3, it does not employ a tank circuit nor does it develop a sinusoidal output signal. Feedback from the plate of V_1 to its grid is provided by T_1 as in an LC oscillator. C_1 and R_1 form an RC network which controls the frequency of oscillation.

Let us examine the circuit operation when power is first applied to the circuit. With no bias on V_1, its plate current rapidly increases to maximum as power is applied. The increasing V_1 plate current in the primary of T_1 induces a feedback voltage in the T_1 secondary. The secondary leads are connected so the grid of V_1 is driven positive at this time. C_1 is charged by V_1 grid current to the polarity shown.

When V_1 plate current reaches its maximum saturated value, a voltage is no longer induced into the T_1 secondary because the primary current is not changing. With no voltage at the secondary of T_1, C_1 begins to discharge through R_1 and the T_1 secondary. C_1 discharge current develops a voltage across R_1 with the polarity shown. This voltage drives V_1 into cutoff. V_1 remains cut off until the voltage across R_1 is less than that required to cut the tube off. Then V_1 conducts again and a new cycle of oscillation begins.

Since V_1 conducts for only short intervals, its plate current consists of pulses as shown in Figure 21B. The V_1 grid voltage has the waveform
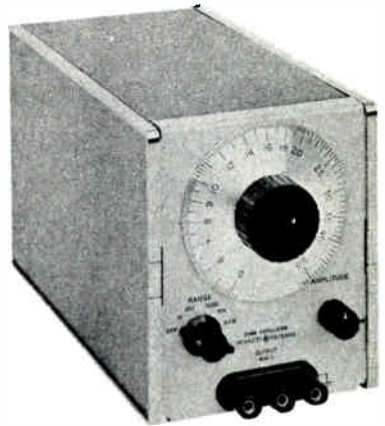
The low frequency oscillator shown above has a frequency range of 5 cps to 500 kc.
Courtesy Hewlett-Packard Co.

shown in Figure 21A. The blocking oscillator is sometimes called a "pulse generator" because it develops an output signal consisting of a series of pulses. As shown, the output signal is usually taken from the plate of V_1.

The frequency of oscillation in the blocking oscillator of Figure 20 is controlled by the values of R_1 and C_1. Increasing the value of either R_1 or C_1 decreases the frequency, and vice versa. The grid voltage waveform shown in Figure 21A is characteristic of the blocking oscillator. This waveform is sometimes referred to as a "cash-register" waveform.

*   *   *

40. The blocking oscillator of Figure 20 develops a sinusoidal output signal waveshape. True or False?

41. How could you increase the operating frequency of the blocking
    oscillator of Figure 20? *By decreasing the values*
    of R_1 & C_1.

*   *

MULTIVIBRATORS

Another type of RC oscillator that develops a non-sinusoidal
output signal is the **MULTIVIBRATOR**. Figure 22 shows the
circuit of a **PLATE COUPLED MULTIVIBRATOR**. Basically
the circuit is a two stage resistance-capacitance coupled
amplifier. C_1 couples the output signal from the plate of V_1
to the grid of V_2. C_2 provides a feedback signal from the
plate of V_2 to the grid of V_1. Both V_1 and V_2 provide a 180°
phase shift between their input (grid) and output (plate) sig-
nals. Thus, the feedback signal applied to the grid of V_1 is
in phase with the V_1 grid voltage. This is necessary for
sustained oscillations.

With the circuit arrangement shown in Figure 22, V_1 and V_2
conduct alternately. Actually they operate like a seesaw.
The frequency of oscillation is determined by the charge and
discharge times of C_1 and C_2.

To examine the circuit while it is operating, suppose V_1 is
just starting to conduct and V_2 is just going into cutoff. As
V_1 begins to conduct, its plate voltage decreases. As a
result, C_1 discharges through R_4 and V_1. The C_1 discharge
current develops a voltage across R_4, driving the grid of
V_2 negative. In turn, V_2 goes into cutoff. With V_2 cut off,
C_2 charges through R_3 and R_2. The C_2 charge current
through R_3 develops a voltage across R_3, driving the grid
of V_1 positive. The circuit remains in this state, V_1 con-
ducting and V_2 cut off, until C_1 has discharged to the point
where V_2 comes out of cutoff.

When V_2 begins to conduct, its plate voltage decreases and
C_2 discharges through R_3 and V_2. The C_2 discharge cur-
rent develops a voltage across R_3 which now drives V_1 into
cutoff. With V_1 cut off, its plate voltage increases and C_1

charges through R_1 and R_4. The C_1 charge current in R_4 drives the grid of V_2 positive. The circuit remains in this state, V_1 cut off and V_2 conducting, until C_2 has discharged to the point where V_1 comes out of cutoff. V_1 then begins to conduct and the cycle repeats.

Both V_1 and V_2 conduct for equal lengths of time if circuit values are chosen so $C_1 = C_2$, $R_1 = R_2$, $R_3 = R_4$, and $V_1 = V_2$. Under these conditions the signals at the plates of V_1 and V_2 have the waveforms shown in Figure 23A. This type of waveform is referred to as a square wave. A multivibrator that produces a square wave output is referred to as a BALANCED MULTIVIBRATOR. The square wave output signal can be taken from either plate as shown.

If the charge and discharge times of C_1 are not equal to the charge and discharge times of C_2, V_1 and V_2 in Figure 22 conduct for different lengths of time. Under these conditions the signals appearing at the plates of V_1 and V_2 have waveforms such as those in Figures 23B and 23C. Notice that the signal of Figure 23B has narrow pulses separated by wide spaces, whereas the signal of Figure 23C has wide pulses separated by narrow spaces. Thus, the signals at the two plates are the opposite of each other as far as pulse width and spacing are concerned. You can use either of these signals as the output by simply connecting to output 1 or output 2, as desired. Multivibrators that produce pulse outputs like those in Figures 23B are called UNBALANCED MULTIVIBRATORS.

Figure 24 shows another multivibrator circuit called the CATHODE COUPLED MULTIVIBRATOR. This circuit operates in a manner similar to the plate coupled multivibrator. V_1 is coupled to V_2 by C_1. However, V_2 is coupled back to V_1 through the common cathode resistor, R_5. This is why the circuit is called a cathode coupled multivibrator.

To examine circuit operation, suppose V_1 is going toward saturation and V_2 is going toward cutoff. With V_1 going toward saturation, C_1 discharges through R_2. The resultant

voltage developed across R_2 drives V_2 into cutoff.

With V_2 cut off, the only current through R_5 is the V_1 plate current.   This current is small and thus only a small bias voltage is developed across R_5.   This bias voltage is not large enough to have any noticeable effect on V_1.   The circuit remains in this state, V_1 conducting and V_2 cut off, until C_1 has discharged to a point where V_2 begins to conduct.

As V_2 begins to conduct, its plate current together with the

Multivibrators and blocking oscillators are often used in digital computers, such as the one shown above, to develop the various timing signals which keep the units synchronized.
Courtesy International Business Machines Corporation

V_1 plate current develops a large bias voltage across R_5. This voltage drives V_1 into cutoff.   In turn, C_1 charges through R_1 and R_2. The C_1 charge current develops a voltage across R_2 which overcomes the bias voltage of R_5 and drives V_2 into saturation. With C_1 charged, a voltage is no longer developed across R_2, and V_2 comes out of saturation.

The reduced V_2 plate current causes a reduction in the bias voltage across R_5. In turn, V_1 comes out of cutoff and C_1 begins to discharge through R_2. The C_1 discharge current develops a voltage across R_2 which drives V_2 into cutoff to start a new cycle.

The cathode coupled multivibrator usually operates as an unbalanced multivibrator. V_2 conducts for a shorter time than V_1. This occurs because the charge time of C_1 is usually shorter than its discharge time.

*   *   *

42. What must the relationship be between component values in the circuit of Figure 22 to obtain a square wave output signal?

   they must be equal in pairs.

43. What type of multivibrator is shown in Figure 22?

   Plate coupled.

44. The synchronizing generator in a digital computer usually develops a rectangular output signal. Would a multivibrator be suitable for this application? Why? *Yes, Because a rectangular waveshape could be obtained with proper component values.* *

SUMMARY

An oscillator is an electronic circuit that converts dc into an ac signal. There are many types of oscillator circuits. Basically, the oscillator is an amplifier with a feedback circuit. This feedback circuit couples the output signal back to the amplifier input. The amplitude and phase of the feedback signal is chosen so the circuit continuously develops an output signal without any other input signal. The frequency of the ac signal generated by the oscillator is usually controlled by the component values in the feedback loop or circuit.

In an LC oscillator the feedback circuit usually takes the form of a parallel resonant circuit. The frequency of oscillation is approximately equal to the resonant frequency

of the LC circuit.

There are many types of LC oscillators. The Hartley oscillator develops the feedback signal by using a tapped coil in the LC circuit. A Colpitts oscillator on the other hand employs a tapped tank circuit capacitor to obtain the feedback signal. An oscillator is said to be series fed if dc plate current flows through part or all of the tank circuit. In a shunt fed oscillator no dc plate current flows through the tank circuit.

The tuned plate tuned grid oscillator employs a parallel LC circuit in both the grid and plate circuits of an amplifier. Feedback to make the circuit oscillate is provided by the grid-plate capacitance of the tube. The interelectrode capacitance is used to advantage in the ultraudion oscillator. This circuit operates like a Colpitts oscillator except that the tube interelectrode capacitance serves as the tapped tank circuit capacitor.

For high accuracy of frequency and for stability, a crystal oscillator can be used. In an oscillator of this type the electromechanical resonant property of certain crystals is used to establish the oscillation frequency.

Electron coupled oscillators employ multi-element tubes. The screen usually serves as the oscillator anode. Coupling between the oscillator and the output plate circuit is through the electron stream in the tube. This system has the advantage of reduced loading on the oscillator circuit and thus improved stability.

LC oscillators are usually used to develop higher frequency signals than are usually developed by RC oscillators. An RC oscillator employs a feedback loop consisting of resistors and capacitors. The phase shift oscillator employs an RC network which shifts the phase of the output signal and applies it back to the grid of the tube. A special RC circuit, called the Wein bridge, is used in the Wein bridge oscillator to develop the feedback signal. Both the phase shift oscillator

and the Wein bridge oscillator develop sinusoidal output signals.

The blocking oscillator and multivibrator develop non-sinusoidal output signals. A blocking oscillator looks like a tickler coil oscillator except that its frequency is controlled by an RC circuit. The multivibrator is basically a two-stage amplifier, with the output of the second stage coupled back to the input of the first, and vice versa. Its frequency is controlled by the values in the RC coupling circuits.

IMPORTANT DEFINITIONS

ARMSTRONG OSCILLATOR - A form of feedback oscillator
with the tuned tank in the tube grid circuit and the
feedback coupling coil in the plate circuit.   Also
called a TICKLER COIL OSCILLATOR.

BLOCKING OSCILLATOR - A non-sinusoidal RC oscillator
employing a transformer for feedback and an RC
circuit to determine its operating frequency.

BUFFER - A circuit, usually an amplifier, used to reduce
undesirable interaction between electronic circuits.

COLPITTS OSCILLATOR - [KOHL pits AHS i lay ter] - An
LC feedback oscillator in which feedback is provided
by a tapped tank circuit capacitance.

CRYSTAL OSCILLATOR - An oscillator which uses a crystal
to control its operating frequency.

ELECTRON COUPLED OSCILLATOR (ECO) - An oscillator
circuit in which the load is coupled to the oscillator
circuit through the electron stream of the tube.

FEEDBACK OSCILLATOR - An amplifier in which part of
the output signal is fed back to the input with the
proper phase and amplitude to sustain oscillation
without any other input signal.

GRID LEAK BIAS - A bias developed by charging a capacitor
with pulses of grid current and allowing it to dis-
charge through a high value resistor, thereby devel-
oping the bias.

HARTLEY OSCILLATOR - [HAHRT lee AHS i lay ter] - An
LC feedback oscillator in which feedback is provided
by a tapped tank coil.

IMPORTANT DEFINITIONS (Continued)

MULTIVIBRATOR - [MUHL tih VIGH brayt'r] - A non-sinusoidal oscillator circuit employing two stages that are interconnected (plate to grid) in such a way that when one conducts it drives the other to cutoff, and vice versa. Thus, the stages keep turning "on" and "off" at a frequency determined by the RC time constants of the coupling networks.

OSCILLATOR - [AHS i lay ter] - An electronic device for converting dc energy into ac energy.

PHASE SHIFT OSCILLATOR - An oscillator circuit which uses an RC phase shift circuit to provide the proper phase of feedback signal. This circuit is widely used as a low frequency (audio) oscillator.

PIEZOELECTRIC EFFECT - [pigh ee zoh i LEK trik] - The property of some crystals to generate a potential when a mechanical force is applied or to produce a mechanical force when a potential is applied.

SERIES FED OSCILLATOR - An oscillator in which the dc plate current is carried by part of the tank circuit.

SHUNT FED OSCILLATOR - An oscillator in which the dc plate current is not carried by any part of the tank circuit.

TEMPERATURE COEFFICIENT - A numerical value that indicates the relation between a temperature change and the resulting change in another property such as the frequency of an oscillator circuit.

TICKLER COIL OSCILLATOR - See ARMSTRONG OSCILLATOR.

IMPORTANT DEFINITIONS (Continued)

TUNED PLATE TUNED GRID (TPTG) OSCILLATOR - An oscillator with tuned circuits in the grid and plate circuits. Feedback is provided by the tube inter-electrode capacitance.

ULTRAUDION OSCILLATOR - [uhl trah AW di ahn AHS i lay ter] - A form of Colpitts oscillator in which the tube interelectrode capacitance forms the tapped tank circuit capacitance.

WEIN BRIDGE OSCILLATOR - An RC oscillator using a special RC circuit called the Wein bridge to obtain the proper phase feedback signal. Like the phase shift oscillator, this circuit is widely used in low frequency applications.

STUDENT NOTES

$$S = \frac{.16}{\sqrt{.04 \times 100 \times 10 - 12}} = \frac{.16}{\sqrt{4 \times 10^{-12}}} =$$

$$\frac{.16}{2 \times 10^{-6}} = .08 \times 10^{6} = 80 \, \text{kc}$$

PRACTICE EXERCISE SOLUTIONS

1. The function of an oscillator is to generate an ac signal of some specific frequency and waveshape.

2. The feedback signal must have the proper phase and amplitude.

3. T_1 provides the feedback signal.

4. No. Reversing the T_1 primary connections reverses the phase of the feedback signal.

5. 79,500 cps or 79.5 kc -- The frequency of oscillation is found using the resonant frequency formula as shown below.

$$f = \frac{1}{2\pi \sqrt{100 \text{ pf} \times .04\text{h}}} = \frac{.159}{\sqrt{100 \times 10^{-12} \times 4 \times 10^{-2}}}$$

$$= \frac{.159}{\sqrt{1 \times 10^{-10} \times 4 \times 10^{-2}}}$$

$$f = \frac{.159}{\sqrt{4 \times 10^{-12}}} = \frac{.159}{2 \times 10^{-6}}$$

$$= .0795 \times 10^6 = 79,500 \text{ cps or } 79.5 \text{ kc}$$

6. (d) Class C.

7. The grid leak capacitor C_2 charges when the grid of V_1 is driven positive.

8. False -- This is shunt type grid leak bias.

9. Hartley oscillator

10. Across the bottom of the tank coil, section B of L_1.

11. L_1 and C_1 determine the frequency of oscillation. The frequency of oscillation can be varied by varying the value of either C_1 or L_1.
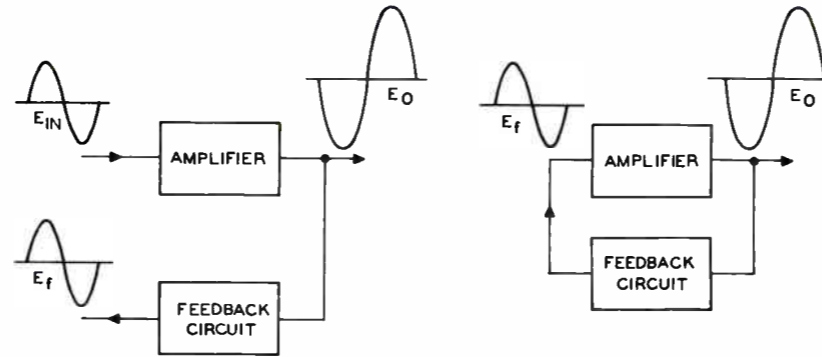
FIGURE 1

FIGURE 2
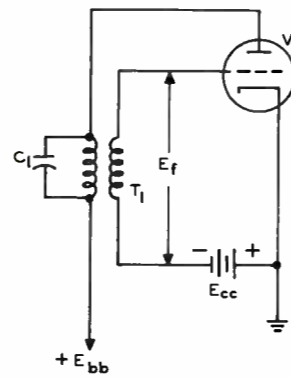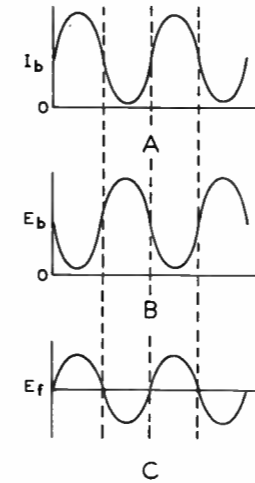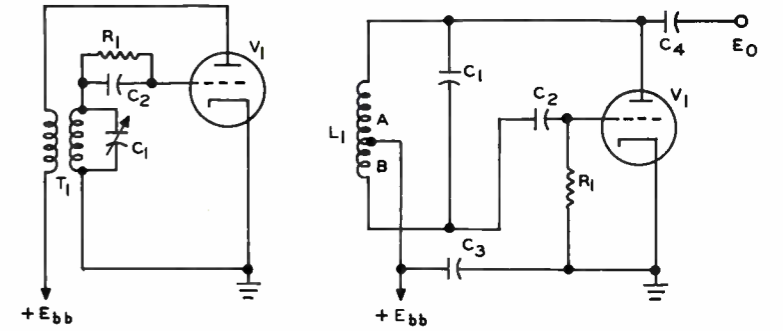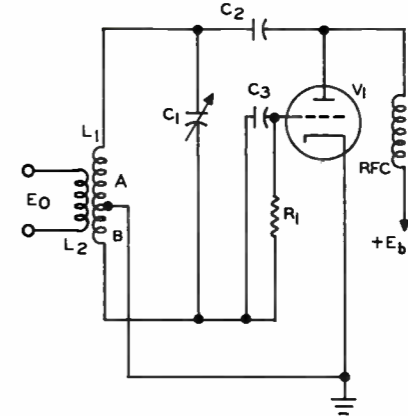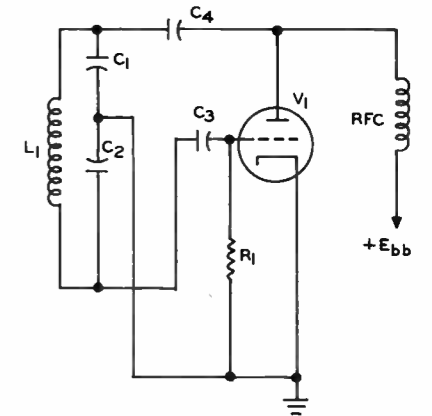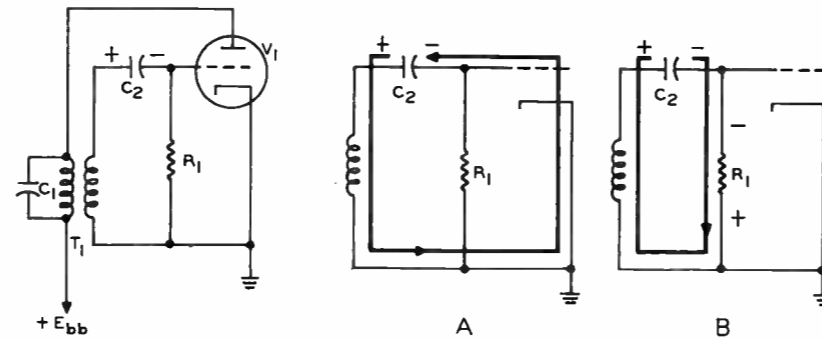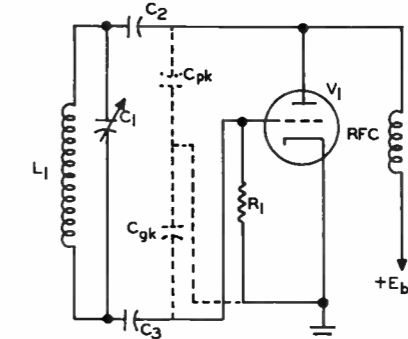
FIGURE 3

FIGURE 4

FIGURE 5

FIGURE 6

FIGURE 7

FIGURE 8

FIGURE 9

FIGURE 10

FIGURE 11

FIGURE 12

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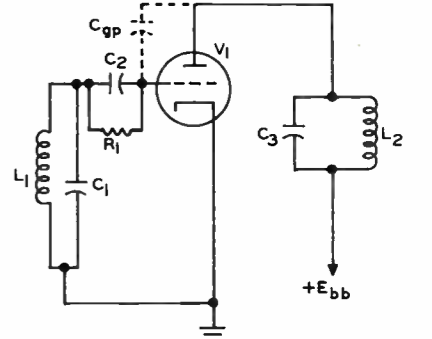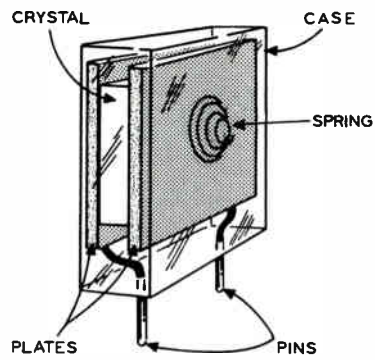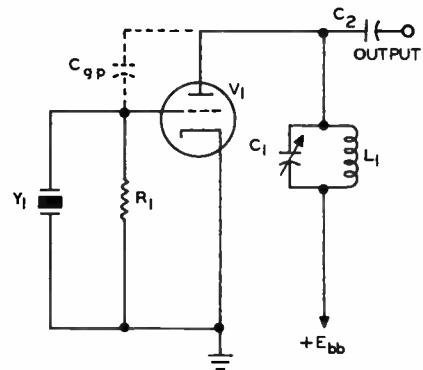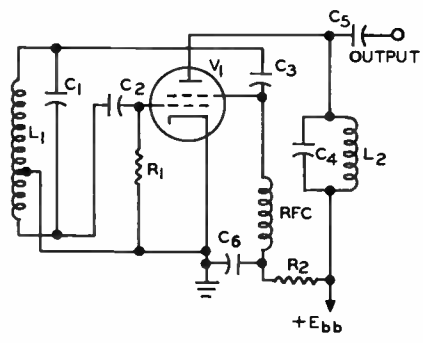
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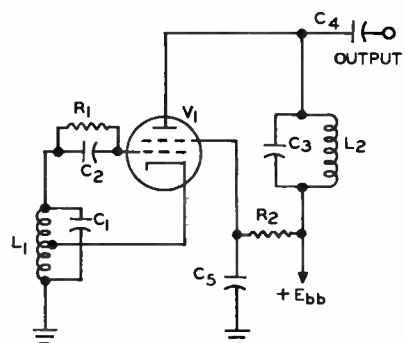
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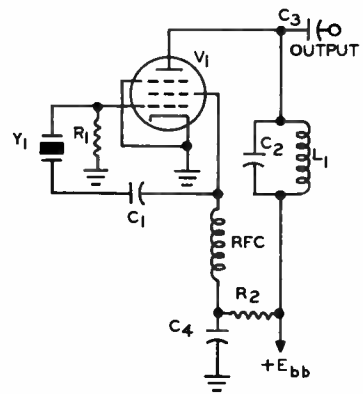
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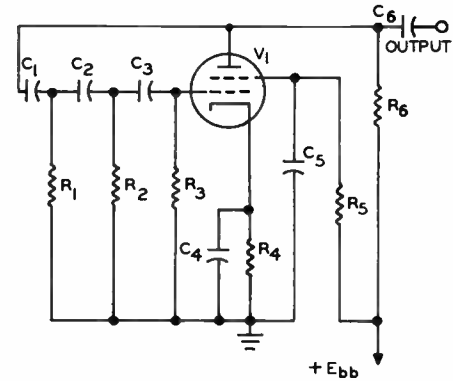
FIGURE 16

FIGURE 17

FIGURE 18

PRACTICE EXERCISE SOLUTIONS (Continued)

12. No -- The dc plate current is carried by the r-f choke.

13. You would use a shunt fed Hartley oscillator.

14. the tapped or split tank capacitor

15. (b) C_2

16. (a) shunt

17. ultraudion oscillator

18. (c) C_{gk}.

19. The grid-plate capacitance C_{gp} provides the feedback.

20. series grid leak bias

21. The piezoelectric effect refers to the fact that an electric charge appears across certain crystals when a mechanical force is applied. Also, when a voltage is applied across the crystal a mechanical deformation of the crystal occurs.

22. change the crystal Y_1

23. Bias is provided by R_1 and the crystal holder capacitance. These components form a grid leak bias network.

24. A crystal that is designed to operate at a harmonic of its fundamental frequency.

25. Yes. A pentode has a low interelectrode capacitance which reduces the feedback voltage.

26. For proper operation you would adjust L_1 and C_1 to a frequency slightly higher than the crystal frequency.

27. a GT cut

28. shunt fed Hartley oscillator

29. False -- The screen grid of V_1 serves as the oscillator anode.
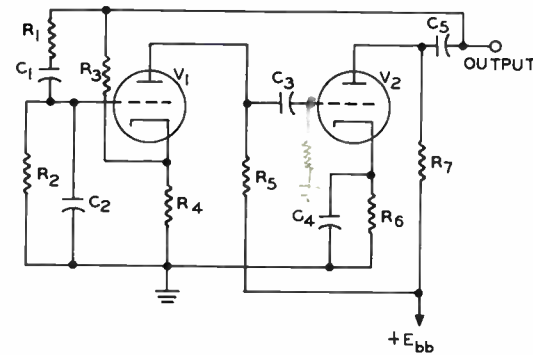
FIGURE 19
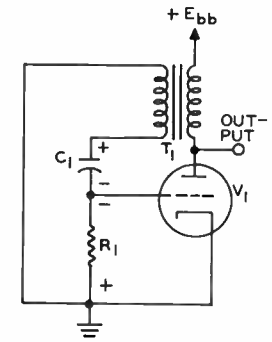
FIGURE 20

FIGURE 21

FIGURE 22

FIGURE 23

FIGURE 24

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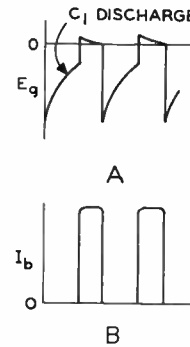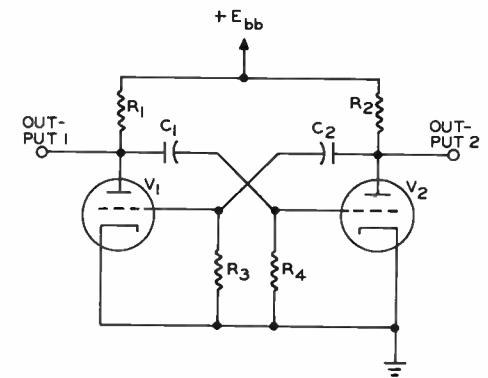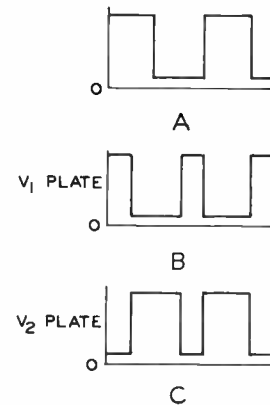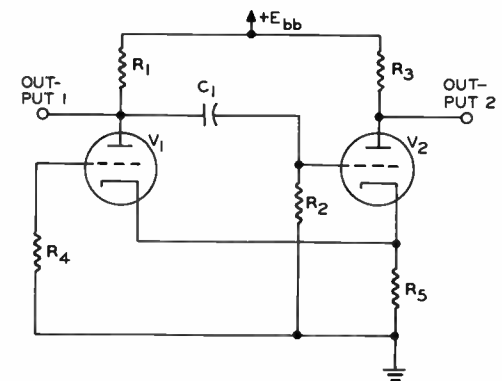
PRACTICE EXERCISE SOLUTIONS (Continued)

30. The load is coupled to the oscillator circuit through the electron stream of the tube.

31. (a) series fed.

32. C_1

33. No -- The large tank capacitance means that the tube interelectrode capacitance is only a small part of the total tank capacitance. Therefore, changing the tube and thus the interelectrode capacitance will have little effect on frequency.

34. (a) a low L/C ratio.

35. False -- Phase shift oscillators are normally used in low frequency applications.

36. 60°

37. R_4 and C_4 provide cathode bias.

38. $R_1 C_1$ and $R_2 C_2$ together with R_3 and R_4.

39. The frequency can be varied by varying R_1 and R_2 or C_1 and C_2. In many cases a two-section ganged capacitor is used for C_1 and C_2.

40. False -- The blocking oscillator develops a non-sinusoidal output signal consisting of a series of pulses.

41. You can increase the frequency by decreasing the value of either R_1 or C_1.

42. $R_1 = R_2$, $R_3 = R_4$, $C_1 = C_2$, and $V_1 = V_2$

43. plate coupled multivibrator

44. Yes -- A multivibrator develops a rectangular output signal.

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question, as illustrated in the example below.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

LESSON CODE

2165 A

Example: A railroad car is designed to travel

(A) on rails. (B) on a highway. (C) in the air. (D) under water.

1. If the connections to the secondary of T_1 in Figure 3 are reversed,
(A) the frequency of oscillation is increased. (B) the frequency of oscillation is decreased.
(C) the bias on V_1 increases. (D) oscillations stop.

2. With the GRID LEAK BIAS arrangement shown in Figure 8,
(A) V_1 operates CLASS A and the circuit is NOT SELF STARTING. (B) V_1 operates CLASS C and the circuit IS SELF STARTING. (C) V_1 cannot operate Class C. (D) the circuit operates as a SHUNT FED ARMSTRONG oscillator.

3. The distinguishing feature of a Hartley oscillator is
(A) a tapped tank coil. (B) a tapped tank capacitor. (C) grid leak bias. (D) cathode bias.

4. The FREQUENCY of oscillation in Figure 9 is controlled by
(A) C_2. (B) the r-f choke. (C) C_3 and R_1. (D) L_1 and C_1.

5. The distinguishing feature of a Colpitts oscillator is
(A) a tapped tank circuit capacitance. (B) Class C operation. (C) a tapped tank coil. (D) grid leak bias.

6. FEEDBACK in the TPTG oscillator of Figure 12 is provided by
(A) C_1 and L_1. (B) C_2 and R_1. (C) C_3 and L_2. (D) the V_1 grid-plate capacitance (C_{gp}).

7. In the electron coupled oscillator of Figure 15,
(A) C_6 and R_2 provide cathode bias. (B) L_2 and C_4 control the frequency of oscillation. (C) the V_1 screen grid serves as the oscillator CATHODE. (D) the load is coupled to the oscillator circuit through the electron stream of V_1.

8. The frequency of oscillation in Figure 17 is controlled by
(A) R_1. (B) Y_1. (C) L_1 and C_2. (D) R_2 and C_4.

9. The oscillator circuit shown in Figure 18
(A) develops a non-sinusoidal output signal. (B) is called a Wein bridge oscillator. (C) is called a phase shift oscillator. (D) is called a multivibrator.

10. The multivibrator circuit of Figure 22
(A) is an LC oscillator. (B) develops a sinusoidal output signal. (C) is a cathode coupled multivibrator. (D) develops a non-sinusoidal output signal.

6 2165A

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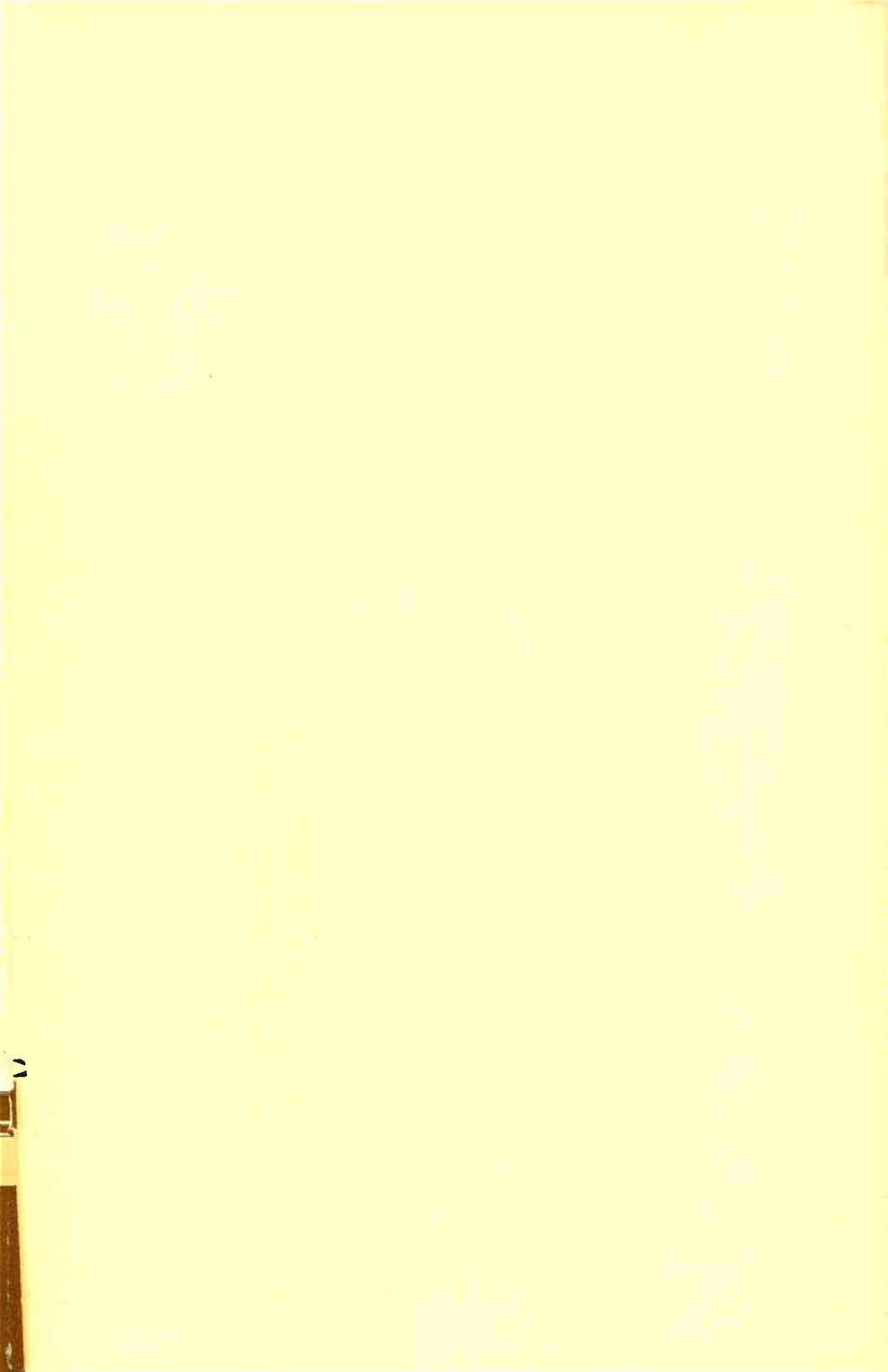
BASIC POWER SUPPLIES
Lesson 2200A

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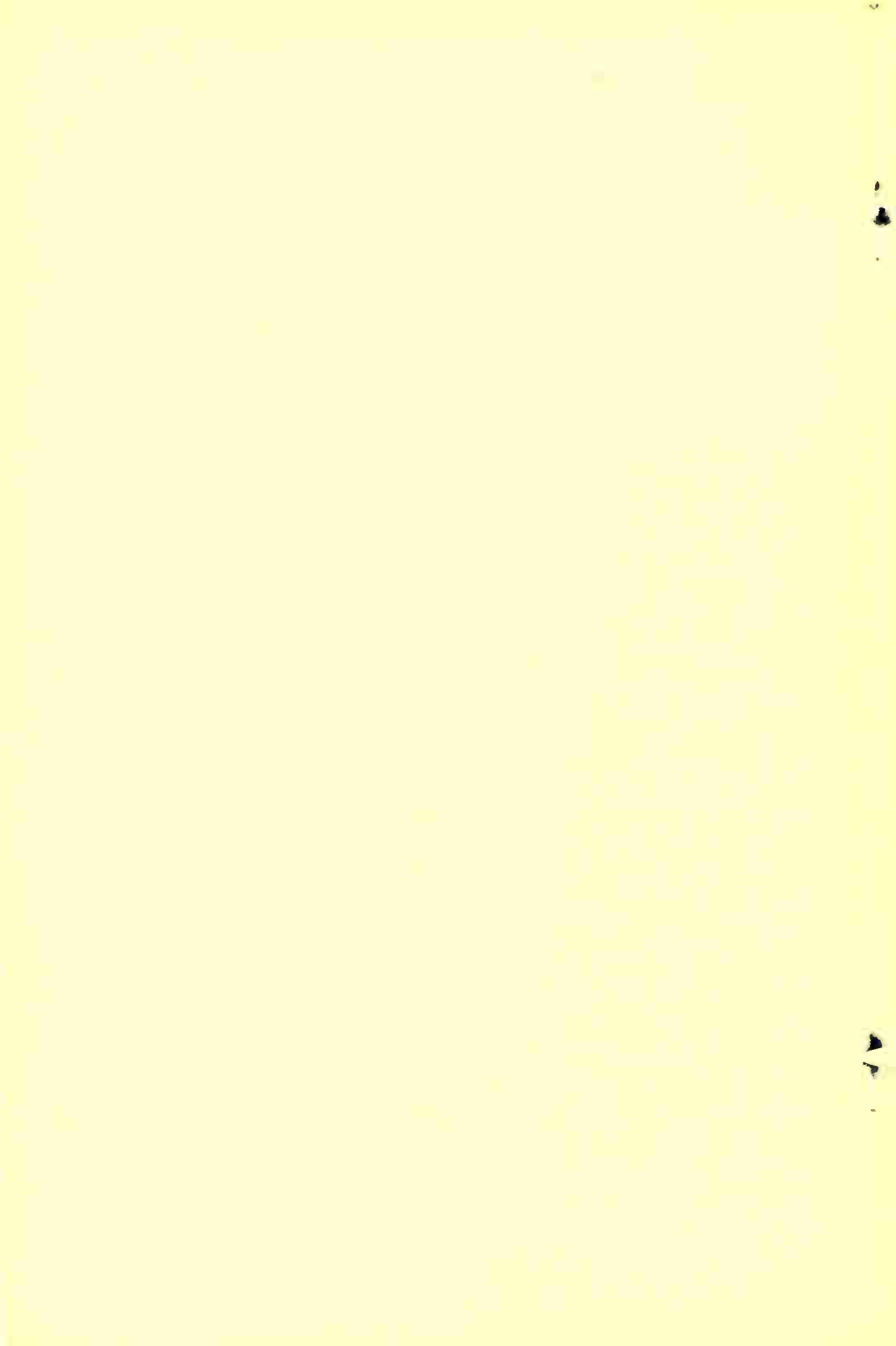
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Revised 1967

OPPORTUNITY
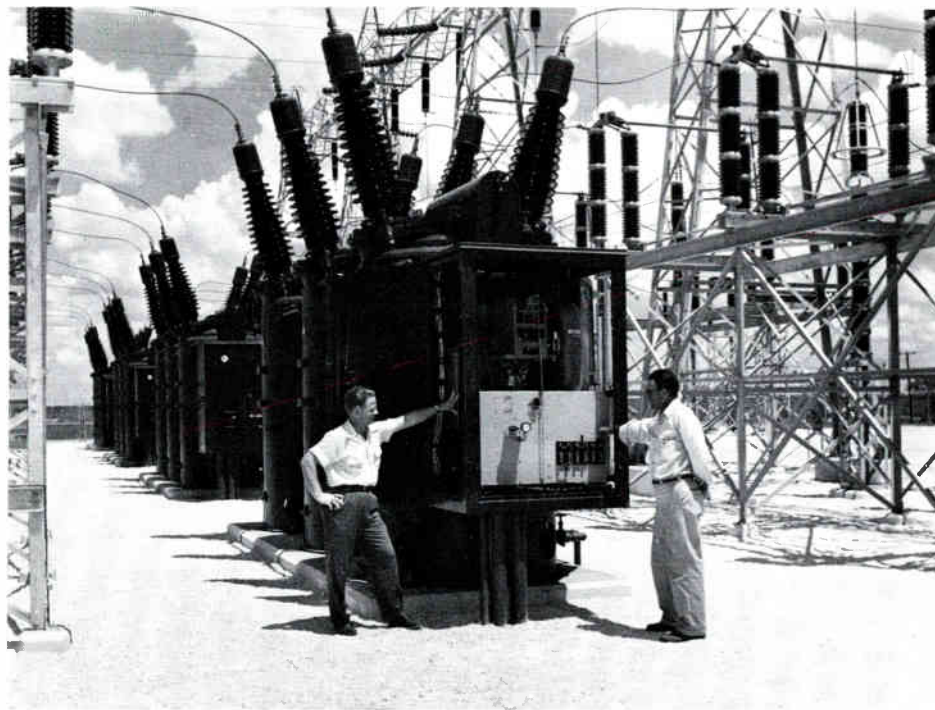
Most of the circuits in electronic equipment require dc voltages. However, electric power for home and industry is ac supplied by power stations such as this. The power supply in the electronic equipment must convert the ac voltage to a suitable dc voltage for the equipment.

Courtesy Allis-Chalmers Mfg. Co.

BASIC POWER SUPPLIES

CONTENTS

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The heights by great men reached and kept
Were not attained by sudden flight,
But they, while their companions slept,
Were toiling upwards in the night.
               -- Longfellow

BASIC POWER SUPPLIES

Most transistor and vacuum tube circuits require dc operating voltages. The common power lines of home and industry, however, provide ac voltages. Typical of these are the lighting circuits which connect to the household wall outlets. To obtain dc operating voltages from these ac lighting circuits, a POWER SUPPLY is used.

The power supply usually contains a RECTIFIER and a FILTER section. As shown in Figure 1, the rectifier converts the ac line voltage into a series of pulses. This type of dc voltage is referred to as PULSATING DC. To obtain a smooth dc output, the pulsating dc voltage is applied to a filter. The dc voltage from the filter is then applied to the various circuits in the equipment.

HALF WAVE POWER SUPPLIES

Figure 2 shows the circuit of a simple rectifier circuit called a HALF WAVE RECTIFIER. D_1, a semiconductor diode, is the rectifier. For simplicity, no filter is shown in Figure 2. The pulsating dc voltage is developed across R_L, which represents the load.

Rectifier Action

Basically a diode is a switch. When its anode is positive with respect to its cathode the diode conducts and acts like a closed switch. When its anode is negative with respect to its cathode, the diode is nonconductive and acts like an open switch.

Let's first consider the operation of the circuit of Figure 2 during the positive alternation of the ac source. During this time point A is positive with respect to point B. Under these conditions the anode of D_1 is connected directly to the positive terminal of the ac source, and the cathode of D_1 is

connected to the negative terminal of the ac source through R_L. As a result D_1 conducts and electrons flow through R_L in the direction shown by the arrows.

Now let's examine circuit operation during the negative alternation of the ac source. During this time point A is negative with respect to point B. Under these conditions the anode of D_1 is connected to the negative terminal of the ac source, and the cathode of D_1 is connected through R_L to the positive terminal of the ac source. As a result D_1 does not conduct.

Figure 3A shows the waveform of the ac source voltage. The positive alternations are shaded to show the conduction of D_1. Since D_1 conducts on the positive alternations of the ac source, the dc voltage appearing across R_L consists of positive pulses as shown in Figure 3B. With D_1 conducting on only the positive alternations of the ac source, the diode is conducting for one half of a complete cycle of the ac source. This is why the circuit is referred to as a half wave rectifier. If D_1 were reversed it would conduct on the negative alternations of the ac source. The dc voltage developed across R_L would then consist of negative pulses.

*   *   *

1. Why is a power supply needed? It supplies the correct operating voltages to a circuit.
2. Could you replace D_1 in Figure 2 with a vacuum diode? Yes
3. What would happen to the voltage developed across R_L in Figure 2 if D_1 was reversed? It would be the same amplitude, but would consist of the negative alternations.

*   *   *

Complete Supply

Figure 4 shows a complete power supply employing a vacuum tube half wave rectifier. The ac voltage applied to the V_1 rectifier plate is obtained from secondary 2 of trans-

former T_1.   The primary of T_1 is connected to the 120 volt
lighting circuit (ac line).   The filament of V_1 is connected
to secondary 1 of T_1.   If a semiconductor diode was used,
the T_1 filament winding would not be required.   The filter
in the power supply of Figure 4 is shown as a block.   Filter
circuits are explained later in this lesson.

The operation of V_1 in Figure 4 is the same as that of D_1 in
Figure 2. V_1 conducts when its plate is positive with re-
spect to its cathode.   That is, when the top end of secondary
2 is positive with respect to the bottom end.   On the other
alternation of the secondary voltage, V_1 is nonconductive.
During the conduction of V_1, electrons flow through the load
in the direction shown by the arrows.   The filter smooths
out the pulsating dc developed by V_1.

If the ac line voltage (approximately 120 volts) is applied
directly to the rectifier as in Figure 2, the maximum dc
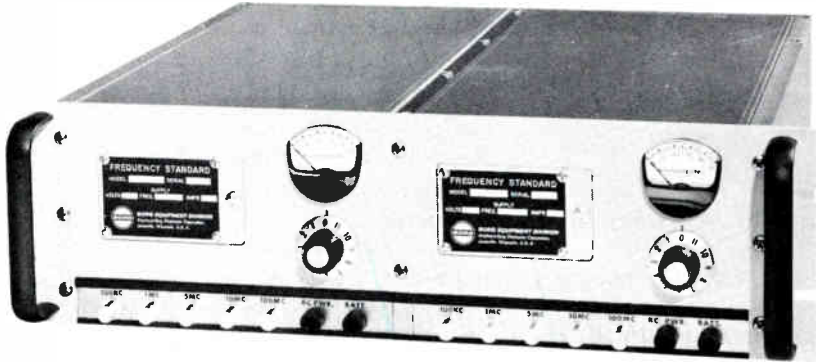
The precision frequency standard shown above employs an emergency power supply. Under normal
conditions the unit operates from a power supply connected to the ac line. If a power failure occurs,
the unit automatically switches over to internal batteries.

Courtesy Borg Electronics

output voltage that can be obtained is about equal to the peak
value of the ac line voltage (1.414 × 120, or about 170 volts).
With a transformer, dc voltages higher or lower than the ac
line voltage can easily be obtained.   By employing a step-up

transformer, the power supply can provide a dc output volt-
age higher than the ac line voltage.   High dc voltages are
required for many vacuum tube circuits as well as some
semiconductor circuits.   Low dc voltages, as are often re-
quired in semiconductor circuits, are obtained by using a
step-down transformer.   The transformer used in a power
supply is usually called a POWER TRANSFORMER.

*   *   *

4.   What is the purpose of a power supply filter? *To smooth out
     the pulsating D.C.*
5.   Would secondary 1 on T_1 be necessary if V_1 in Figure 4 was
     replaced by a semiconductor diode?.
                                        No

*   *   *

In electronic equipment one terminal of the power supply is
usually connected to the common point in the circuit.   The
other terminal is connected to the points that require the
dc operating voltage.   Often the common point is the chassis.
The ground symbol in Figure 4 indicates that the negative
terminal of the power supply is connected to the common or
ground point.   Thus, the other power supply terminal would
be connected to the points requiring a positive dc voltage.

Some circuits require operating voltages which are negative
with respect to the common point in the circuit.   A negative
voltage may be obtained in Figure 4 by grounding the posi-
tive terminal of the supply.   Another method is to leave the
ground point where it is and reverse the plate and cathode
connections to V_1.

*   *   *

6.   What is the effect on the operation of the circuit of Figure 4 if
     the ground point is moved to the positive terminal of the supply?
     A negative output voltage is obtained.
                    *   *   *

FULL WAVE POWER SUPPLIES

A disadvantage of the half wave power supply is that it sup-plies only one pulse of voltage and current to the load during each cycle of the ac supply. The voltage and current pulse occurs during one alternation of the ac supply. During the other alternation of the ac supply the rectifier is nonconduc-tive and no voltage or current is applied to the load. The FULL WAVE RECTIFIER overcomes this disadvantage.

Figure 5 shows the circuit of a full wave rectifier. The cir-cuit uses two diodes and is arranged so that one diode con-ducts during one alternation of the ac supply and the other diode conducts during the other alternation. Note that a center tapped power transformer is employed in this cir-cuit.

To examine circuit operation suppose the top of the T_1 sec-ondary is negative with respect to the bottom end. Under these conditions the top of the secondary is negative with respect to the center tap while the bottom is positive with respect to the center tap. The center tap of the T_1 secondary connects through R_L to the anodes of both diodes. As a result the cathode of D_1 is negative with respect to its anode and thus D_1 conducts. At the same time the cathode of D_2 is positive with respect to its anode and D_2 does not conduct. With D_1 conducting, electrons flow through load resistor R_L in the direction shown by the solid line I_{D_1} arrows.

Now let's consider the other alternation, when the top of the T_1 secondary is positive with respect to the bottom end. Under these conditions the top of the secondary is positive with respect to the center tap while the bottom end is nega-tive with respect to the center tap. As a result the cathode of D_2 is negative with respect to its anode and thus D_2 con-ducts. At the same time the cathode of D_1 is positive with respect to its anode and D_1 does not conduct. With D_2 con-ducting, electrons flow through the load resistor in the direction shown by the dashed line I_{D_2} arrows. Notice that the current through R_L is in the same direction regardless

of which diode conducts.

In summary, one diode conducts on one alternation and the other diode conducts on the other alternation of the ac input

A full wave vacuum tube power supply is used in the stereophonic FM tuner shown above. The power transformer is the large black object at the rear of the chassis.

Courtesy H.H. Scott, Inc.

voltage in a full wave rectifier. Thus, there are two volt-age and current pulses applied to the load during each cycle of the ac line voltage in a full wave rectifier.

Figures 6A and 6B illustrate the operation of the full wave circuit. Figure 6A shows the waveform of the ac input volt-age. Figure 6B shows the waveform of the pulsating dc appearing across R_L. Notice that there is one voltage pulse for each alternation of the ac voltage. This makes it easier to obtain a smooth dc output voltage.

*   *   *

7. In general, does a full wave supply have a greater output cur-rent capability than a half wave supply? Why? *Yes, Because it is also supplying the other half of the cycle.*

8. With the top of the T_1 secondary in Figure 5 negative with re-spect to the bottom, (a) D_1, (b) D_2 conducts.

*   *   *

In Figure 5 the positive terminal of the power supply is con-
nected to the common point in the circuit as indicated by the
ground symbol.   As a result, the dc output voltage of the
supply is negative with respect to ground.   This is why the
voltage pulses in Figure 6B are negative.   To obtain a posi-
tive output voltage with respect to ground, we can simply
reverse the connections to D_1 and D_2.   Most vacuum tube
circuits require a positive supply voltage.   In transistor
circuits, positive or negative supply voltages are required,
depending on whether NPN or PNP transistors are used.

By using a power transformer in the full wave rectifier of
Figure 5, either a high or a low dc output voltage can be
obtained. A step-up transformer is used to obtain a high dc
output voltage. A low dc output voltage is obtained by using
a step-down transformer.

One more thing to take note of in connection with the full
wave supply is that each diode receives its voltage from only
half of the secondary winding. Thus, the pulsating dc output
is about equal to half the peak voltage of the full secondary.

*   *   *

9.   Vacuum tube circuits usually require operating voltages which
     are (a) negative, (b) positive with respect to ground.

10. Suppose you are building a power supply for a transistor cir-
     cuit that requires an operating voltage of 25 volts. Would you
     use a step-up or a step-down transformer in the power supply?

                         Step Down
*   *   *

Figure 7 shows the circuit of a vacuum tube full wave power
supply employing a duo-diode tube as a rectifier.   The pri-
mary of the power transformer T_1 is tapped so the circuit
can be operated from either a 120 volt or a 240 volt ac line.

Two filament windings are included on T_1.   One filament
winding, SEC 1, is used to supply the other tube filaments

in the equipment.   The other filament winding, SEC 2, is
used to supply the filament of rectifier tube V_1. A separate
filament winding is needed because V_1 is a directly heated
tube.   As a result the dc output voltage of the power supply
appears on the rectifier filament winding.   If the rectifier
filament winding was used for other tubes, the power supply
voltage would appear on the filaments of these tubes.   This
could cause arcing between the cathodes and filaments in the
tubes.   If the power supply employed an indirectly heated
rectifier tube (separate heater and cathode) the same fila-
ment winding could be used for all the tubes in the equip-
ment.

The overall operation in the power supply of Figure 7 is
similar to that of Figure 5.   However, the negative side of
the power supply of Figure 7 is connected to the common or
ground point in the circuit, so the pulsations across the load
are positive with respect to ground. As mentioned earlier,
it is common practice to ground the negative side of the sup-
ply in vacuum tube circuits, since vacuum tubes usually re-
quire positive operating potentials.

*   *   *

11.   If you were asked to construct a small, compact power supply,
       would you use semiconductor diodes or would you use vacuum
       diodes?   Semiconductor diodes

12.   What is the name given to the rectifier tube used in Figure 7?
       Duo - Diode

*   *   *

FILTER SYSTEMS

The filter system in a power supply smooths the pulsating
dc developed by the rectifier.   There are many different
types of filter systems.   The most common ones use com-
binations of inductors, resistors and capacitors.

Filter Capacitor

One of the simplest power supply filters is a capacitor con-
nected across the load as shown in Figure 8. R_L represents
the load and C_1 is the filter capacitor. The basic operation
of the power supply does not change with the addition of C_1.
When the secondary voltage makes the anode of D_1 positive
with respect to its cathode, D_1 conducts. When D_1 conducts,
electrons flow through R_L. C_1 charges as shown by the
solid line arrows.

On the other alternation of the secondary voltage, when D_1
is cut off, C_1 discharges through R_L as shown by the dashed
line arrows. Note that the C_1 discharge current through R_L
is in the same direction as the current produced by the con-
duction of D_1. Therefore, C_1 supplies current to the load
during the time that the diode is cut off. This is the way a
smoother dc output voltage is obtained.

*   *   *

13.   In the circuit of Figure 8, when does C_1 charge and when does
       it discharge? C_1 charges while D_1 conducts + C_1 discharges
       while D_1 is cut off.
14.   How does C_1 in Figure 8 provide filtering? By charging then
discharging through the load to provide voltage while
D_1 is cut off.

*   *   *

Figure 9 illustrates the operation of the circuit of Figure 8
in greater detail. The dashed line pulses represent the
pulsating dc developed by the rectifier. Let's examine the
operation from the instant the power supply is turned on.
The first positive alternation of the T_1 secondary voltage is
shown between points 1 and 3. As the T_1 secondary voltage
increases to maximum at point 2, the voltage across C_1 and
R_L increases as indicated by the solid line in Figure 9.
Therefore, at point 2, the voltage across C_1 and R_L equals
the peak of the secondary voltage.

From points 2 to 3, the secondary voltage decreases to zero.

When the secondary voltage becomes less than the voltage across C_1 and R_L, D_1 stops conducting. This occurs because the voltage across C_1 makes the cathode of D_1 more positive than its anode when the secondary voltage becomes less than E_{C_1}. With D_1 cut off, C_1 discharges through R_L. The voltage across R_L and C_1 decreases as shown by the sloping solid line between points 2 and 5.

The next positive alternation of the T_1 secondary voltage begins at point 4. However, D_1 does not start conducting until point 5, when the secondary voltage is higher than the voltage across C_1. D_1 continues to conduct to the peak of the positive alternation at point 6. This conduction of D_1 recharges C_1 to the peak of the secondary voltage. As the

The electrolytic capacitor shown above is actually three capacitors with a common negative connection in one container. Two of the capacitor sections have a 500 volt rating and are intended for use as power supply filter capacitors. The other section has a 50 volt rating and can be used as a cathode bypass capacitor.

Courtesy Sprague Products Co.

secondary voltage again decreases, D_1 is cut off and C_1 discharges through the load, R_L.

As shown by the shaded portions in Figure 9, D_1 in Figure 8 only conducts for a short period of time during each cycle. The conduction of D_1 is long enough to recharge C_1. As a result THE FILTER CAPACITOR SUPPLIES CURRENT TO THE LOAD MOST OF THE TIME.

Even with a filter capacitor, the dc output voltage of the power supply still has some variations. The variations appear as an ac signal and are applied to each stage connected to the power supply. If the variations are large enough they can cause improper circuit operation. The small variations in the dc output are referred to as RIPPLE as shown in Figure 9. Due to the presence of the ripple

voltage, the power supply output voltage E_{DC} is not quite equal to the peak of the secondary voltage. The dc output voltage is the average value of the ripple voltage as shown in Figure 9.

The amplitude of the ripple voltage depends on the value of the filter capacitor and the amount of load current drawn from the supply. If the load current is increased, the filter capacitor discharges more between the conduction periods of the diode as shown in Figure 10. This increases the amplitude of the ripple voltage and reduces the dc output voltage. (Remember, the dc output voltage is the average, not the peak of the ripple voltage.) Increasing the value of the filter capacitor increases the amount of current that can be supplied to the load. In turn, the ripple voltage is reduced and the dc output voltage E_{DC} is increased. Thus, as the current requirements of the supply are increased the value of the filter capacitor must be increased.

Depending on the output voltage and load requirements, the filter capacitor may have a value anywhere from a few micro-farads to several thousand microfarads. High value filter capacitors are usually used in low voltage supplies designed for semiconductor circuits. Due to the large values re-quired, electrolytic capacitors are usually used as power supply filter capacitors.

R_1 in Figure 8 is a current limiting resistor. Its purpose is to limit the current through D_1 when the circuit is first turned on. If R_1 were not used, the initial surge of current which charges C_1 could damage D_1. Usually R_1 is less than 100 ohms. A current limiting resistor is usually used in semiconductor power supplies although it is not required in vacuum tube supplies.

*   *   *

15. How can the ripple voltage amplitude be reduced in a power supply? *By increasing the value of the filter condenser.*

16. Suppose you measure the output voltage of a power supply and
find that it is much lower than normal. Assuming the recti-
fier and power transformer are good, what could be the
trouble? *The filter condenser is too low in value,*
or the circuit is drawing too much current.

Let's examine the conditions in Figure 8 during the nega-
tive alternation, when D_1 is cut off. During this time the
top of the T_1 secondary is negative with respect to the
bottom. As a result the secondary voltage is series aiding
with the C_1 voltage, and the total of these voltages appears
across D_1. The peak value of this reverse voltage occurs
during the peak of the negative alternation of the secondary
voltage and is called the **PEAK INVERSE VOLTAGE (PIV)**.
D_1 must be able to withstand this voltage without breaking
down.

Since C_1 charges to the peak of the secondary voltage when
D_1 conducts, the peak inverse voltage is twice the peak
value of the secondary voltage. As an example, suppose the
T_1 secondary voltage is 100 volts. Its peak value is $1.414 \times$
100, or approximately 141 volts. The peak inverse voltage
is 2×141, or 282 volts. D_1 in Figure 8 must therefore have
a PIV rating of at least 282 volts. For a full wave recti-
fier using a center tapped power transformer, the PIV is
the peak value of the entire secondary voltage.

                    *   *   *

17. When selecting a rectifier diode you must make sure it can
handle the expected load current. What other rating is im-
portant? *It's peak inverse voltage rating.*

                    *   *   *

In most applications it is desirable to have the ripple volt-
age as low as possible. The ripple voltage is coupled to the
various circuits in a piece of equipment through the power
supply. Ripple voltage appears as an unwanted signal which

can cause distortion as well as improper circuit operation. As an example, let's consider a hi-fi music system. Any ripple voltage produced by the power supply is applied to the various amplifier stages. These amplifiers amplify the ripple voltage and apply it to the speaker system. If the ripple voltage amplitude is high enough it will appear in the output as an unwanted sound, usually a low frequency hum.

The ripple voltage has a frequency which depends on the frequency of the ac source. The half wave rectifier develops one pulse of current for each cycle of the ac source. As a result, the ripple frequency in a half wave rectifier is the same as the ac source frequency. Thus, for the common 60 hertz (cycles per second) ac line, the ripple frequency of a half wave power supply is 60 hertz (Hz). A full wave supply develops two current pulses for each cycle of the ac source. Therefore, the ripple frequency of a full wave supply is twice that of the ac source. A full wave supply operating from a 60 Hz source has a ripple frequency of 120 Hz.

The obove picture shows o stud mount silicon diode. The diode is mounted, usuolly on o heot sink, by the threoded stud.
Courtesy Hughes Products, Semiconductor Division

*   *   *

18. Suppose an amplifier you are servicing produces a loud hum in the loudspeaker, even when no input signal is applied. What is one probable fault? A Bad Filter Condenser

19. The ripple frequency in a half wave supply operating from a 60 Hz power line is (a) 30 Hz, (b) 60 Hz, (c) 90 Hz. In a full wave supply it is (a) 30 Hz, (b) 60 Hz, (c) 120 Hz.

*   *   *

Figure 11 shows the operation of a capacitor filter in a full

wave supply. Since two current pulses are developed for each cycle of the ac source, a full wave power supply is easier to filter. Thus, lower ripple voltages from a full wave supply can be obtained with the same filter capacitors used in half wave supplies. It is also easier for a full wave rectifier to supply higher load currents.

Filter Inductor

An inductor has the property of opposing any change in the current flowing through it. This property may be used to advantage in a power supply filter system. Figure 12 shows a full wave power supply employing a filter inductor L_1 and a filter capacitor C_1. Since V_1 is an indirectly heated duo-diode, the same filament winding can be used for the other tubes in the equipment.

Notice that L_1 is connected in series with the load represented by R_L. Load current variations due to the pulsating dc developed by V_1 are opposed by L_1. L_1 opposes the current changes by developing a counter electromotive force (cemf) whenever its magnetic field changes due to a change in its current. C_1 provides the normal filter capacitor action as described earlier.

Because the filter inductor is in series with the filter capacitor, the capacitor charges to a voltage slightly less than the peak of the supply voltage. C_1 and L_1 provide a very smooth (low ripple) dc output voltage. The $C_1 L_1$ combination in Figure 12 is sometimes referred to as an L-TYPE FILTER.

The L-type power supply filter in Figure 12 can also be examined from the standpoint of a low-pass filter. L_1 has a high reactance at the ripple frequency of the power supply, while C_1 has a low reactance. Therefore, the ripple voltage is developed across the inductor while the smooth dc voltage appears across C_1 and the load. Filter inductors usually have a value of a few henries or greater. Often a filter inductor is called a CHOKE.

In applications where the load current is small, a resistor can be used in place of a choke in an L-type filter. Chokes are bulkier and more expensive than resistors, so a resistor offers the advantage of economy and smaller size and weight. Even though a resistor is used, the circuit still functions as a low-pass filter. The ripple voltage appears across the filter resistor, and the smooth dc output voltage appears across the filter capacitor and load.

*   *   *

20. Why does a filter inductor smooth the output voltage of a power supply? *It Produces a counter Electromotive force.*

21. If you were building a low cost power supply and wanted to use an L-type filter, what could you use in place of the filter inductor? *A Resistor*

22. What is a filter inductor usually called? *A Choke*

*   *   *

Pi-Type Filter

Another filter circuit that is widely used is the PI-TYPE FILTER shown in Figure 13. This circuit is similar to the L-type filter except that an input filter capacitor C_1 is added. With this addition, the diagram resembles the Greek letter pi (π), hence the name pi-type filter.

In Figure 13, C_2 is called the output filter capacitor. L_1 provides filtering by opposing a change in load current. C_1 and C_2 provide filtering by supplying current to the load when the rectifier is cut off. The pi-type filter provides a smoother dc output voltage than an L-type filter does. For this reason it is widely used. In applications where the load current is low, the filter choke can be replaced by a filter resistor. This saves the cost, size and weight of a filter choke.

*   *   *

23. In Figure 13, C_1 is the (a) input, (b) output filter capacitor
     and C_2 is the (a) input, (b) output filter capacitor.

24. What is the name given to the filter circuit of Figure 13?
         P_i - $Network$
25. To obtain the smoothest dc output voltage from a power supply
     would you use an L-type or a pi-type filter? P_i - $type$ $Filter$

*   *   *

Decoupling Networks

Besides the filter network in the power supply, a piece of
equipment may contain other filter networks.   Figure 14
shows such an arrangement in a transistorized device. D_1,
D_2 and T_1 form a full wave rectifier. R_1 and R_2 are cur-
rent limiting resistors. C_1 and C_2 together with R_3 form a
pi-type filter network.

The output voltage of this power supply is 50 volts, as shown
at point A. The Q_1 stage is connected directly to the power
supply output, point A. If all the stages in the equipment
required the same operating voltage, they could be connec-
ted to point A.   However, this is not always the case.   In
this example the Q_2 stage requires 20 volts.   The 20 volts
for the Q_2 stage is obtained by dropping 30 volts across R_4.
C_3 places point B at signal ground, and thus serves as a by-
pass capacitor. If it was not for C_3, R_4 would become part
of the collector load for Q_2. The variations of Q_2 collector
current would cause variations of voltage across R_4, and the
voltage at point B would vary accordingly.   Since point B is
a dc supply point, this would be undesirable.

In addition to its bypass function, C_3 provides additional
filtering. C_3 and R_4 form an L-type filter network which
is often called a DECOUPLING NETWORK.

R_5 and C_4 form another L-type filter or decoupling network.

R_5 is chosen to provide the required 10 volts for the Q_3 stage. C_4 places point C at ac or signal ground.

*   *   *

26. What are the functions of R_4 and C_3 in Figure 14? *By drops the 50v. To 20v. & C_1 places point B at signal ground.*
27. PNP transistors are shown in Figure 14. If NPN transistors were used, what changes would be necessary? *Q_1 + Q_2 would have to be reversed along with C_1, C_2, C_3 + C_4.*

*   *   *

REGULATION

As shown earlier, the filter capacitors discharge to a greater extent between the rectifier conduction periods when the load current is increased. This reduces the dc output of the power supply and increases the ripple voltage amplitude. The internal resistance of a power supply also tends to reduce the output voltage of the supply when load current is increased, and vice versa. The internal resistance of the power supply consists of the resistance of the rectifier diodes, the resistance of the power transformer windings, the resistance of the filter inductor or resistor, and the like.

Figure 15 shows the equivalent circuit of a power supply. B_1 represents the dc output voltage developed by the power supply. R_I represents the internal resistance of the supply. Note that the internal resistance R_I and the load, represented by R_L, are in series. Thus, the power supply output voltage B_1 divides between R_I and R_L.

Assume that R_L in Figure 15 is decreased. This causes an increase in the load current and thus an increase in the voltage developed across the internal resistance of the power supply. In turn, the dc voltage developed across the load R_L decreases. Now suppose R_L is increased, causing a decrease in load current. With the load current reduced the voltage developed across the internal resistance of the

power supply decreases. In turn, the output voltage devel-
oped across the load R$_L$ increases.   Thus, as load current
increases, the power supply output voltage decreases, and
vice versa.

It is desirable to keep the power supply voltage as constant
as possible. Power supply voltage variations can cause im-
proper circuit operation.   Small output voltage variations

The electronically regulated power supply shown above is designed to maintain a constant output
voltage under varying load conditions. It can supply up to 400 VDC at 150 ma.

Courtesy Pacotronics, Inc.

are obtained by using components with a low internal re-
sistance.   As a rule, silicon and germanium diodes have a
lower forward resistance than selenium diodes.   This is
sometimes a source of trouble when a germanium or silicon
diode is used to replace a selenium unit.   The increased
output voltage of the power supply can cause a breakdown
in the equipment.   Often a series resistance must be added
so the resistance of the original selenium unit is duplicated.

Most vacuum diodes have higher forward resistance than selenium, germanium or silicon diodes.

The term **REGULATION** is used to describe the ability of a power supply to provide a constant output voltage under varying load conditions. Let E_N represent the power supply output voltage under no-load conditions. Similarly let E_F represent the power supply output voltage under full load. The power supply percentage of regulation is then expressed as shown below:

$$\% \text{ Regulation} = \frac{E_N - E_F}{E_F} \times 100 \qquad (1)$$

For example, suppose a power supply has a no-load output voltage of 300 volts and a full-load output voltage of 250 volts. The percentage of regulation is

$$\% \text{ Regulation} = \frac{300 - 250}{250} \times 100$$

$$\% \text{ Regulation} = \frac{50}{250} \times 100$$

$$= .2 \times 100 = 20\%$$

As another example, suppose the no-load output voltage of a power supply is 50 volts and the full-load output voltage is 48 volts. The percentage of regulation is

$$\% \text{ Regulation} = \frac{50 - 48}{48} \times 100$$

$$\% \text{ Regulation} = \frac{2}{48} \times 100$$

$$= .0417 \times 100 = 4.17\%$$

The less the output voltage changes under load, the lower the percentage of regulation. A low percentage of regulation indicates a good power supply, and a high percentage of regulation indicates a poor power supply.

*   *   *

28. Suppose you are building a power supply and want to obtain the lowest percentage of regulation. If you have a choice of two power transformers, one with a secondary resistance of 200 ohms and the other with a secondary resistance of 150 ohms, which one would you use? $150 \, \Omega$

29. What is the percentage of regulation of a power supply with a no-load output of 100 volts and full-load output of 80 volts?

$$\frac{100 - 80}{80} = \frac{20}{80} = \frac{2}{8} = 25\%$$

*   *   *

The regulation of a power supply can be improved by em-ploying a BLEEDER RESISTOR . The bleeder resistor is connected across the output terminals of the power supply. Its function is to draw some current from the power supply under no-load conditions. This reduces the no-load output voltage of the power supply. In turn, there is a smaller difference between the no-load and full-load output voltages, and thus a smaller percentage of regulation.

The value of the bleeder resistor is chosen so it draws about 10% or less of the full-load current capability of the power supply. Besides improving regulation, the bleeder resistor helps to discharge the power supply filter capacitors. The filter capacitors can hold a charge for a long period of time and deliver a shock even after the equipment is turned off if they are not discharged. If the power supply you are work-ing on does not employ a bleeder, it is a good idea to dis-charge the capacitors by shorting their terminals.

As a general rule, always discharge the filter capacitors in any power supply, even if the supply has a bleeder resistor. It's possible the bleeder resistor may be open. In equip-ment using high value capacitors, it is a good idea to dis-charge them through a resistor, say 10K ohms. This pre-vents damage to the capacitor by limiting the discharge current.

*   *   *

30. How does a bleeder resistor improve power supply regula-
    tion? *By drawing current under no load conditions,*
    Thus reducing the load, No Load difference,
31. If a power supply does not employ a bleeder resistor, what
    should you do to remove the shock hazard before working on
    the equipment? *Discharge the filter condensers*

*   *   *

BRIDGE RECTIFIERS

Figure 16 shows another type of full wave rectifier circuit
called the **BRIDGE RECTIFIER**.   Notice that the circuit
does not employ a power transformer with a center tapped secondary. Instead the circuit uses four diodes to obtain full wave rectification.

To examine circuit operation, suppose the top of the secondary, point A, is positive with respect to the bottom, point B. With point A positive the cathode of D_1 and the anode of D_4 are positive. At the same time, with point B negative the cathode of D_3 and the anode of D_2 are negative. As a result D_4 and D_3 are conductive while D_1 and D_2 are nonconductive. With D_3 and D_4 conductive, electrons flow from

The above picture shows the advantage of semiconductor components. The small bridge rectifier using silicon diodes can replace the two vacuum tubes and filament transformer shown above.

Courtesy International Rectifier Corp.

point B through D_3 up through R_L and then through D_4 to
point A.

On the other alternation of the ac source, point A is nega-
tive with respect to point B. Thus, the cathode of D_1 and

the anode of D_4 are negative. At the same time the cathode of D_3 and the anode of D_2 are positive. As a result D_1 and D_2 are conductive while D_3 and D_4 are nonconductive. With D_1 and D_2 conductive, electrons flow from point A through D_1, up through R_L and then through D_2 to point B. Note that the current through R_L is in the same direction when either set of diodes conducts. Since D_1 and D_2 conduct on one alternation and D_3 and D_4 conduct on the other, two current pulses are produced for each cycle of the ac supply to provide full wave rectification.

Since a bridge rectifier does not require a tapped transformer, it rectifies the full secondary voltage on each alternation. Thus, the pulsating dc output is about equal to the peak voltage across the entire secondary. Compared to a conventional full wave rectifier, a bridge rectifier provides pulsating dc of about twice the amplitude using a secondary with the same number of turns.

Any of the filter circuits shown earlier can be used with the bridge rectifier of Figure 16. Although semiconductor diodes are shown in Figure 16, vacuum diodes can be used. However, in most cases semiconductor diodes are used because they are smaller and do not require a filament supply.

*   *   *

32. A bridge rectifier is a half wave rectifier. True or False?

33. In the circuit of Figure 16, which diodes conduct when the top of the secondary is positive with respect to the bottom?

$$D_3 + D_4$$

*   *   *

AC/DC POWER SUPPLIES

Many of the small table model vacuum tube radio receivers are called ac/dc radios. This name was given to the receivers since their power supplies can be operated from

either an ac or dc power line. Although dc power lines are not in common use today, the name ac/dc is still used to describe a particular type of power supply. An ac/dc power supply does not employ a power transformer. Instead the rectifier circuit is connected directly to the ac line.

Figure 17 shows a typical ac/dc power supply. D_1 is a semiconductor diode which rectifies the ac line voltage. C_1 and C_2 together with R_2 form a pi-type filter. Since this supply operates directly from the ac line, its maximum output voltage is limited to the peak value of the ac line voltage. In actual practice the output voltage is usually around 150 volts. The rectifier D_1 is protected by current limiting resistor R_1.

Since a power transformer is not used in the ac/dc supply, the tube filaments must be operated from the ac line. This is usually done by connecting the tube filaments in series. Such an arrangement is referred to as a SERIES STRING heater circuit. In this circuit the vacuum tube heaters together with R_3 form a series circuit. The value of R_3 is chosen with respect to the filament resistances so the proper voltages appear across the tube filaments.

The amplifier above employs an ac/dc supply. The large tubular object is a two section filter capacitor. The finned object at the bottom is a selenium rectifier. The large resistor serves as a filter resistor.

Courtesy Photocircuits Corp.

As mentioned earlier the power supply of Figure 17 was originally designed to operate from both ac and dc power lines. To operate this supply from a dc line, input lead A is connected to the positive side of the line and input lead B is connected to the negative side of the line. When operated on dc, D_1 conducts continuously. Actually D_1 acts like a closed switch and merely connects the various circuits in

the equipment to the power line.

The ac/dc supply of Figure 17 offers the advantage of sim-
plicity and low cost.   This is largely due to the fact that no
power transformer is used.   Ac/dc supplies are normally
used in low priced radio receivers and phonographs.

                *   *   *

34. Why is the circuit of Figure 17 called an ac/dc supply?
     Because it can be used with either A.C. or D.C. Line Current.
35. What is the name given to the filament circuit in Figure 17?
     Series   String.
36. Suppose one of the tube filaments burns out (opens) in Fig-
     ure 17.   Would the other tube filaments still operate?
                          No.

                *   *   *

Notice in Figure 17 that one side of the ac line is connected
to the common point in the circuit, which is usually the
chassis. Figures 18 and 19 show the effects of this arrange-
ment.   Figure 18 shows one side of the ac line connected to
the chassis of a radio receiver through the ON/OFF switch.
This side of the ac line is also grounded to a water pipe.
(One side of the ac line is grounded to the cold water pipe
in just about every building.   This is known as the ground
side.)   Thus, if you were to touch a water pipe, sink, radi-
ator, etc. and the radio chassis you would not receive a
shock.   Both the chassis and water pipe are at the same
potential.

Now suppose the line cord is reversed (plug reversed) as
shown in Figure 19.   The ungrounded side of the ac line is
now connected to the receiver chassis through S_1.   With S_1
closed there is a difference in potential of 120 volts between
the chassis and the water pipe.   If you were to touch the
chassis and water pipe you would receive a shock, possibly
quite severe.

The shock hazard is eliminated in a number of ways.   For

one thing the cabinet may be made of plastic, wood, etc.
The mounting screws and knobs are also insulated so a
person cannot come in contact with the chassis. In some
cases a polarized plug is also used so the plug can only be
inserted one way in the ac receptacle. This assures that
the chassis is always connected to the grounded side of the
ac line. Remember this when you service this type of equip-
ment. Make sure all insulating components are in good order.

*   *   *

37. What is the effect in a piece of equipment using an ac/dc sup-
     ply if the line cord is plugged in so the chassis is connected
     to the ungrounded side of the ac line? *The equipment
     will still work But there is a serious shock
     hazard.* *   *   *

VOLTAGE MULTIPLIERS

One of the disadvantages of the ac/dc supply is that its maxi-
mum output voltage is limited to about the peak value of the
ac line voltage. This is because no power transformer is
employed to step up the voltage. However, voltages higher
than the peak of the ac line voltage can be obtained by using
a **VOLTAGE MULTIPLIER** circuit.

Figure 20 shows a voltage multiplier circuit called a **VOLT-
AGE DOUBLER**. As the name implies, this circuit provides
a dc output voltage equal to twice the peak of the ac line
voltage. Basically, the circuit consists of two half wave
rectifier circuits whose output voltages are added together.

To examine circuit operation, suppose point A is positive
with respect to point B. Under these conditions the anode
of D_1 is positive with respect to its cathode. At the same
time the cathode of D_2 is positive with respect to its anode.
As a result D_1 conducts and D_2 is cut off. With D_1 conduc-
tive, C_1 charges through D_1 to the peak of the ac line voltage.

On the other alternation of the ac line voltage, when point A

is negative with respect to point B, the opposite conditions
exist. The anode of D_1 is negative with respect to its cath-
ode, while the cathode of D_2 is negative with respect to its
anode. As a result D_1 is cut off and D_2 conducts. With D_2
conductive, C_2 charges through D_2 to the peak of the ac line
voltage.

D_1 and D_2 conduct alternately and charge both C_1 and C_2
to the peak value of the ac line voltage. Notice the polarities
of the voltages across C_1 and C_2. These two voltages are
series aiding. The dc output voltage is therefore the sum
of the voltages across C_1 and C_2, or two times the peak of
the ac line voltage. The sum of the voltages across C_1 and
C_2 appears across C_3, which provides a filtering action.
If additional filtering is required, any of the filter circuits
shown earlier can be connected to the circuit.

*   *   *

38. What is the advantage of the voltage doubler shown in Fig-
    ure 20? *A higher D.C. output voltage is obtained.*

39. In the circuit of Figure 20, the dc output voltage is the sum
    of the voltages across C_1 and C_2. True or False?

*   *   *

The voltage doubler shown in Figure 20 has one disadvantage.
One side of the ac line is not the common output as in the
ac/dc supply shown earlier. This can cause the generation
of stray 60 hertz signals in the equipment and thus cause
improper operation. Figure 21 shows another voltage dou-
bler circuit which overcomes this problem. This circuit,
like the one of Figure 20, consists of two separate rectifier
circuits.

To examine circuit operation, suppose point A is negative
with respect to point B. Under these conditions the cathode
of D_1 is negative with respect to its anode. At the same
time the anode of D_2 is negative with respect to its cathode.

Thus, D_1 conducts and D_2 is cut off. With D_1 conductive, C_1 charges to the peak of the ac line voltage through D_1.

On the other alternation of the ac line voltage, point A is positive with respect to point B. Under these conditions the cathode of D_1 is positive with respect to its anode. At the same time the anode of D_2 is positive with respect to its cathode. Thus, D_1 is cut off and D_2 conducts. Since C_1 is in series with D_1 and the ac line voltage, the total voltage applied to D_2 is the ac line voltage plus the voltage across C_1. The voltage across C_1 is series aiding with the line voltage on this alternation. Therefore C_2 charges to the peak of the line voltage plus the voltage across C_1. Since C_1 is charged to the peak of the line voltage, C_2 is charged to twice the peak of the line voltage.

This unit can be used to supply dc power for transistors and other low voltage, small current devices. A built-in meter gives a continuous indication of voltage and current.
Courtesy Electro Products Laboratories, Inc.

Notice in Figure 21 that one side of the ac line forms part of the dc output circuit. This side can be grounded as shown. The voltage doubler of Figure 21 is widely used in television receivers, especially the compact portables.

*   *   *

40. What is the advantage of the voltage doubler shown in Figure 21 over the one shown in Figure 20? *One side of The P.C. line can be grounded.*

41. C_2 in Figure 21 charges to (a) the peak, (b) one half of the peak, (c) twice the peak of the ac line voltage.

*   *   *

VOLTAGE DIVIDERS

Frequently it is desirable to obtain more than one dc output voltage from the same power supply. A number of output voltages can be easily obtained by connecting a number of resistors across the power supply output terminals. An arrangement of this type is called a **VOLTAGE DIVIDER**. In addition the voltage divider also serves as a bleeder resistor.

Figure 22 shows a power supply with a three-resistor voltage divider which provides three different output voltages. Output A is the power supply output terminal which supplies +300 volts. Output B supplies 250 volts and output C supplies 100 volts. These voltages are obtained by choosing the proper values for R_1, R_2 and R_3.

To choose the values of R_1, R_2 and R_3, the current required by the load connected to each terminal must be known. Typical values are shown in Figure 22. To calculate the various resistors, start with the bottom resistor, R_3. Since this resistor does not carry any load current its value is determined by assuming a small value of divider or bleeder current. This is the bleeder current drawn from the supply with all of the loads disconnected. In our example a bleeder current I_B of 2 ma is assumed. Since 100 volts appears at output C with respect to ground, the voltage across R_3 must be 100 volts. With 2 ma flowing through R_3 its value can be found by using Ohm's Law:

$$R_3 = \frac{E_{R_3}}{I_B} = \frac{100 \text{ v}}{2 \text{ ma}} = \frac{1 \times 10^2}{2 \times 10^{-3}} = \frac{1 \times 10^2 \times 10^3}{2}$$

$$= .5 \times 10^5 = 50,000 \text{ or } 50K \text{ ohms}$$

Next the value of R_2 is found. Since 100 volts must appear at output C and 250 volts appears at output B, R_2 must drop 150 volts. The current required at output C is 8 ma. Therefore R_2 must carry $I_3 = 8$ ma plus the bleeder current $I_B = 2$ ma. With the voltage across R_2 known, and the current

known, Ohm's Law can be used to determine the value of R_2:

$$R_2 = \frac{ER_2}{I_B + I_3} = \frac{150 \text{ v}}{2 \text{ ma} + 8 \text{ ma}} = \frac{1.5 \times 10^2}{1.0 \times 10^{-2}}$$

$$= \frac{1.5 \times 10^2 \times 10^2}{1}$$

$$= 1.5 \times 10^4 = 15,000 \text{ or } 15\text{K ohms}$$

Finally the value of R_1 can be determined. Since 250 volts must appear at output B and 300 volts appears at output A, R_1 must drop 50 volts. The current required at output B is 40 ma. Therefore, R_1 must carry this current $I_2 = 40$ ma plus the 8 ma at output C plus the 2 ma bleeder current. Using Ohm's Law, the value of R_1 is:

$$R_1 = \frac{ER_1}{I_2 + I_3 + I_B} = \frac{50 \text{ v}}{40 \text{ ma} + 8 \text{ ma} + 2 \text{ ma}} = \frac{5 \times 10^1}{5 \times 10^{-2}}$$

$$= \frac{5 \times 10^1 \times 10^2}{5} = 1 \times 10^3 = 1000 \text{ or } 1\text{K ohm.}$$

*   *   *

42. Determine the value of the voltage divider resistors in Figure 22 if $I_3 = 3$ ma, $I_2 = 20$ ma and $I_B = 2$ ma.

*   *   *

DC-TO-DC CONVERTERS

In some portable equipment it is impractical to use batteries to supply the high voltages required. To obtain these higher voltages, a DC-TO-DC CONVERTER is used. A dc-to-dc converter is shown in Figure 23 in simplified form. The low voltage battery supply is connected to a dc-to-ac converter. This converter can be an electronic device such as a transistorized oscillator or an electromechanical device such as a vibrator. The ac output from the dc-to-ac converter is

applied to a step-up transformer. The desired dc output voltage is then obtained by recitfying and filtering the ac voltage.

Figure 24 shows the circuit of a transistorized dc-to-dc converter. B_1 is the low voltage battery supply. Q_1 and Q_2 together with T_1 form an oscillator circuit which converts the dc battery voltage to ac. The ac voltage appearing at the secondary of T_1 is rectified by the D_1D_2 full wave rectifier. L_1, C_1 and C_2 form a pi-type filter. S_1 is the power switch.

The Q_1Q_2 oscillator circuit works something like a multivibrator circuit. That is, Q_1 and Q_2 conduct alternately. To examine circuit operation, suppose the circuit is oscillating and Q_1 is just beginning to conduct while Q_2 is going into cutoff. The increasing Q_1 collector current in winding B induces a voltage in winding A which drives the base of Q_1

The dc power supply shown above is used to operate 6 and 12 volt automotive equipment in the service shop.

Courtesy ATR Electronics, Inc.

more negative. Since Q_1 is a PNP transistor, this increases the forward bias on Q_1, driving it toward saturation.   At the same time, the increasing Q_1 collector current in winding B induces a voltage in winding D which drives the Q_2 base positive. Thus, Q_2 is driven into cutoff.

Once Q_1 is saturated, its collector current reaches a steady value. Winding B no longer induces a voltage into windings A or D. As a result, the bias on the Q_1 base reduces, causing Q_1 to come out of saturation. The decreasing Q_1 collector current now induces a voltage of the opposite polarity into windings A and D. Thus, the base of Q_1 is driven positive, cutting off Q_1. At the same time the Q_2

base is driven negative, thus driving Q_2 toward saturation. The increasing Q_2 collector current in winding C induces a voltage into windings A and D which aids the action.   Once Q_2 reaches saturation, winding C no longer induces a voltage into windings A and D. The cycle then repeats, with Q_1 going toward saturation and Q_2 going toward cutoff.

The alternate conduction of Q_1 and Q_2 and the resultant changing collector currents in windings B and C induce an alternating voltage into the secondary. This ac voltage is rectified by D_1 and D_2 and then filtered by C_1, C_2 and L_1. R_3 and R_4 are current limiting resistors for D_1 and D_2.

R_1 and R_2 in the oscillator circuit form a voltage divider which supplies forward bias for the base-emitter circuit of Q_1 and Q_2.   The forward bias provided by this network starts the conduction of the transistors when power is applied.

*   *   *

43.   How does the circuit of Figure 24 convert the dc battery voltage into an ac voltage? $Q_1 + Q_2$ form a multivibrator which induces an A.C. voltage in T_1, The output of T_1 is then Rectified back into D.C.

SUMMARY

The power supply in a piece of equipment supplies the necessary operating voltages for the tubes or transistors used in the equipment. Basically a power supply consists of two sections, a rectifier and a filter. The rectifier converts the ac line voltage into a pulsating dc voltage. The filter smooths out the pulsating dc voltage.

The two basic rectifier circuits are the half wave rectifier and the full wave rectifier. The half wave rectifier develops one current pulse for each cycle of the ac line voltage.   On the other hand the full wave rectifier develops two current pulses for each cycle of the ac line voltage.

There are many types of filter circuits that can be used with a rectifier to provide a smooth dc output voltage. The simplest filter is merely a capacitor connected across the output of the rectifier. Better filtering can be obtained by using an L-type or a pi-type filter circuit. Additional filter circuits are also often used in a piece of equipment. These filters, often called decoupling networks, are used to isolate the various stages and to drop the power supply voltage to different values for the various stages.

Regulation of a power supply is its ability to provide a constant output voltage under varying load conditions. Good regulation is obtained by having a low internal resistance in the power supply.

The bridge rectifier is another type of full wave rectifier. This circuit requires four diodes but does not require a center tapped power transformer. The conventional full wave rectifier requires only two diodes but it does require a center tapped power transformer.

A simple and low cost power supply can be made by operating a half wave rectifier directly from the ac line. Since this type of power supply does not use a power transformer, it does not provide any isolation from the ac line. A power supply of this type is usually referred to as an ac/dc supply since it can be operated from either ac or dc power lines.

The simple ac/dc supply has a maximum output voltage approximately equal to the peak of the ac line voltage. Where higher voltages are required, a voltage doubler is used. A voltage doubler can provide a dc output voltage approximately equal to twice the peak of the ac line voltage.

In portable applications where high dc voltages are required, a dc-to-dc converter is used. This converter first converts the low dc battery voltage into an ac voltage. This ac voltage is then applied to a step-up transformer. Finally the ac voltage is rectified and filtered to provide the desired dc output voltage.

IMPORTANT DEFINITIONS

BLEEDER RESISTOR - A resistor which is used to draw a fixed current from a power supply.

CHOKE - The filter inductor in a power supply.

FILTER - The section of a power supply that smooths out the pulsating dc produced by the rectifier, and thus provides a smooth dc output.

FULL WAVE RECTIFIER - A circuit which converts both alternations of an alternating current into a pulsating direct current.

HALF WAVE RECTIFIER - A circuit which converts alternating current into pulsating direct current by conducting current during only one alternation of each cycle of the alternating current.

PEAK INVERSE VOLTAGE (PIV) - The maximum voltage applied across the rectifier in a power supply when it is not conducting.

VOLTAGE DOUBLER - A transformerless power supply that develops a dc output voltage approximately twice the peak value of the ac line voltage.

ESSENTIAL SYMBOLS AND EQUATIONS

E_F - full-load output voltage

E_N - no-load output voltage

$$\% \text{ Regulation} = \frac{E_N - E_F}{E_F} \times 100 \qquad (1)$$

STUDENT NOTES

PRACTICE EXERCISE SOLUTIONS

1. A power supply is needed to convert the ac line voltage into the dc voltage required by many circuits.

2. Yes -- Both vacuum and semiconductor diodes perform the same function.

3. The voltage across R_L would change to negative pulses.

4. The filter smooths the pulsating dc developed by the rectifier.

5. No -- Semiconductor diodes do not have filaments.

6. There is actually no change in the operation of the supply itself. This merely changes the polarity of the power supply output voltage with respect to the ground point.

7. Yes -- A full wave supply produces twice as many current pulses during a cycle of the ac line voltage as a half wave supply.

8. (a) D_1

9. (b) positive

10. You would probably use a step-down transformer to reduce the line voltage to a suitable value.

11. You would probably use semiconductor diodes as they are small and rugged. Since semiconductor diodes do not have filaments, a rectifier filament winding is not required on the power transformer.

12. duo-diode

13. C_1 charges when D_1 conducts and discharges through R_L when D_1 is cut off.

14. C_1 provides filtering by discharging through the load during the time that D_1 is cut off.

15. The ripple voltage can be reduced by increasing the value of the filter capacitor.
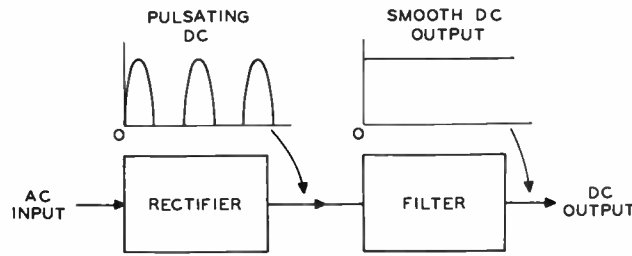
FIGURE 1
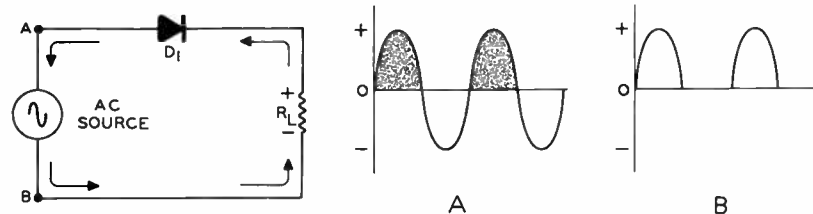
FIGURE 2

FIGURE 3
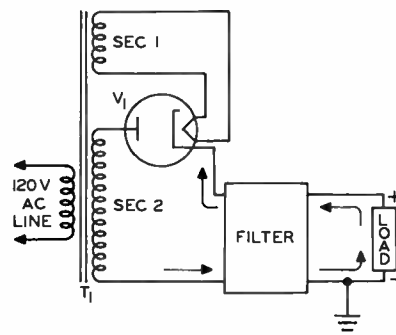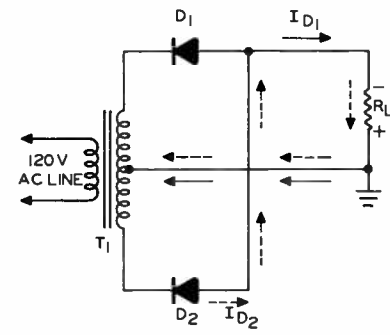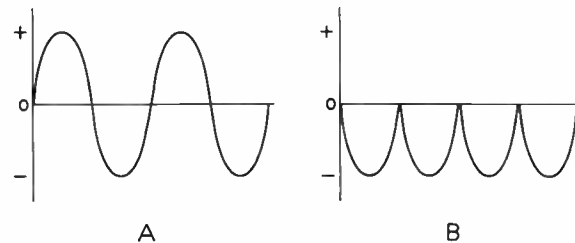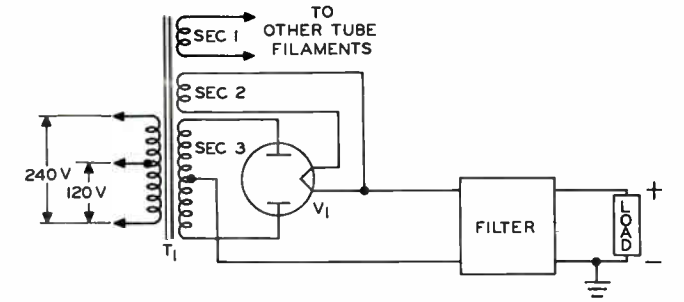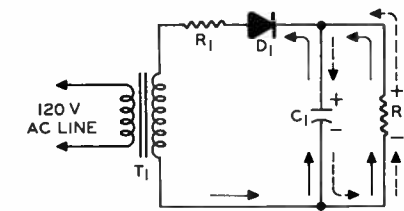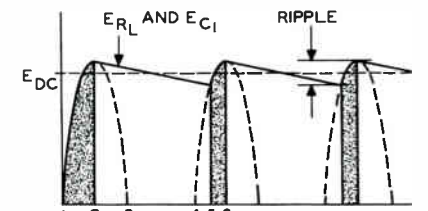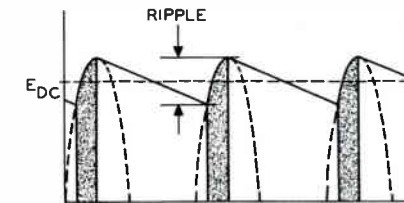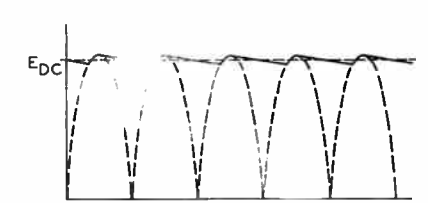
FIGURE 4

FIGURE 5

FIGURE 6

FIGURE 7

FIGURE 8

FIGURE 9

FIGURE 10

FIGURE 11

FIGURE 12

FIGURE 13

FIGURE 14

FIGURE 15

FIGURE 16

FIGURE 17

2200
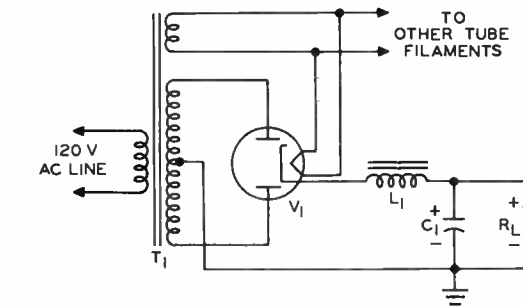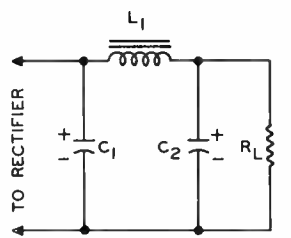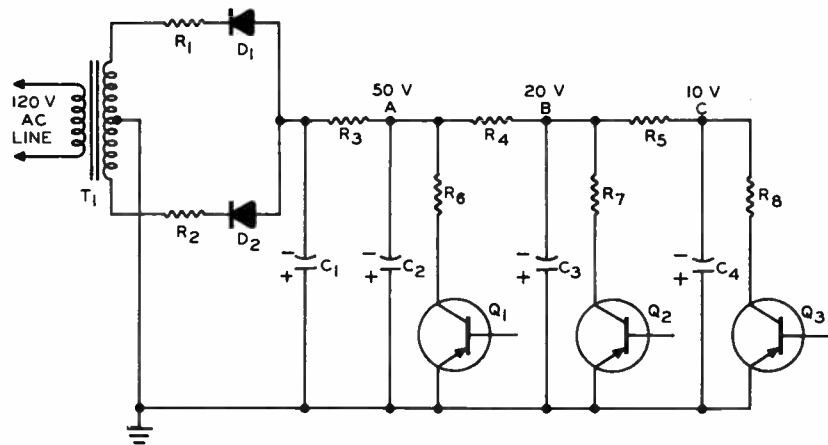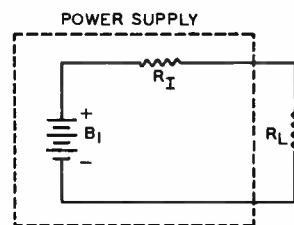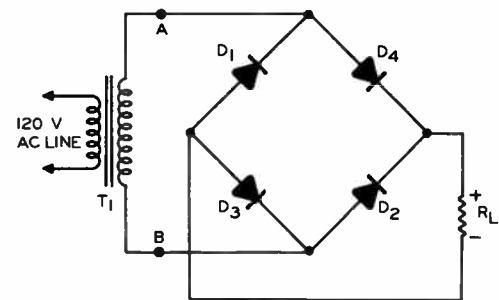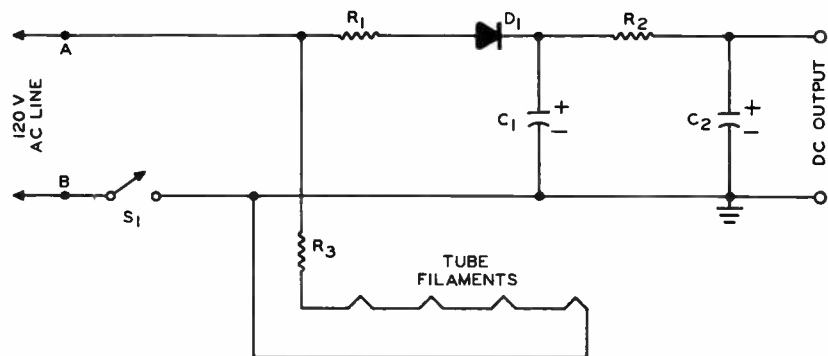
PRACTICE EXERCISE SOLUTIONS (Continued)

16. A defective filter capacitor could be the cause of trouble here. With no filter action the dc output would be pulsating dc. The average value of this voltage is much less than the dc output voltage when it is filtered. Low line voltage or an excessive load on the power supply could also be responsible for reduced output voltage.

17. The peak inverse voltage (PIV) rating is also important. The diode may break down if its PIV rating is not higher than the peak inverse voltage across the diode.

18. A defective filter capacitor is a likely cause.

19. (b) 60 Hz (c) 120 Hz

20. It tends to oppose any change in the current passing through it.

21. a resistor

22. filter choke or simply a choke.

23. (a) input, (b) output

24. pi-type filter

25. You would probably use a pi-type filter.

26. R_4 first of all acts as a dropping resistor to provide the proper voltage for Q_2. C_3 places point B at signal ground. Together R_4 and C_3 form an L-type filter network which provides additional filtering for the power supply voltage.

27. Since NPN transistors require a positive collector voltage, D_1 and D_2 in the power supply must be reversed. With the power supply voltage reversed, the filter capacitors, if they are electrolytics, must also be reversed.

28. You would probably use the transformer with the secondary resistance of 150 ohms to obtain a low internal resistance and thus good regulation.

PRACTICE EXERCISE SOLUTIONS (Continued)

29. 25% -- The percentage of regulation is found as shown below:

$$\% \text{ Regulation} = \frac{E_N - E_F}{E_F} \times 100 = \frac{100 - 80}{80} \times 100$$

$$\% \text{ Regulation} = .25 \times 100 = 25\%$$

30. The bleeder resistor places a load on the power supply so its output voltage is reduced slightly under no-load conditions. This reduces the difference between the no-load and full-load output voltages, thereby improving regulation.

31. Discharge the filter capacitors, preferably through a resistor.

32. False -- The bridge rectifier is a full wave rectifier.

33. D_3 and D_4

34. It can be operated from either an ac or dc power line.

35. series string

36. No -- Since they are all connected in series, one open filament would prevent current from flowing in the other filaments.

37. The chassis of the equipment would be "HOT" with respect to any grounded object such as a water pipe.

38. The voltage doubler can supply a dc output voltage twice the peak of the line voltage.

39. True

40. In the circuit of Figure 21 one side of the ac line forms part of the dc output circuit, and there is less chance of unwanted signals appearing in the output.

41. (c) twice the peak
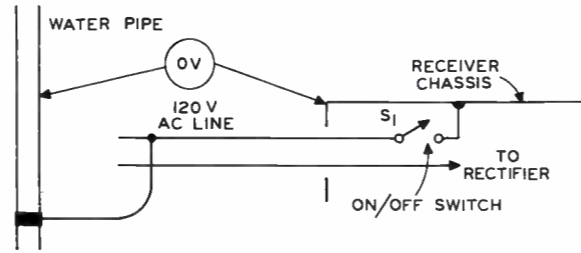
FIGURE 18
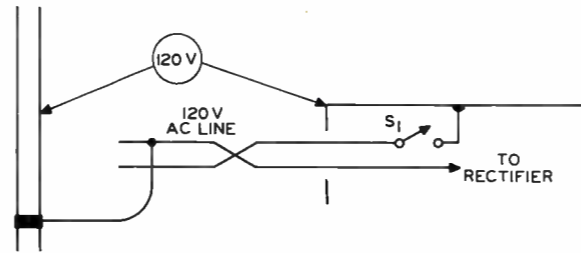
FIGURE 19

FIGURE 20   FIGURE 21

FIGURE 22

FIGURE 23

FIGURE 24

2200   2200
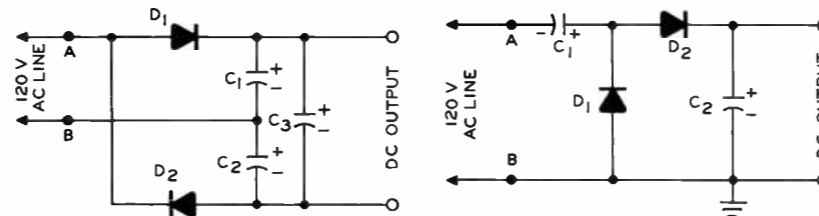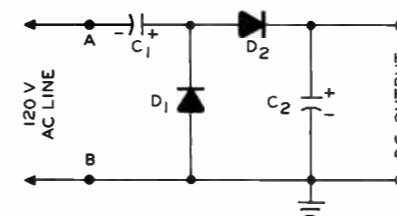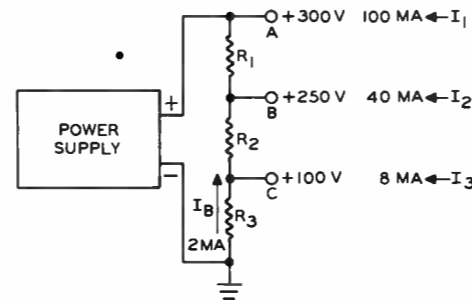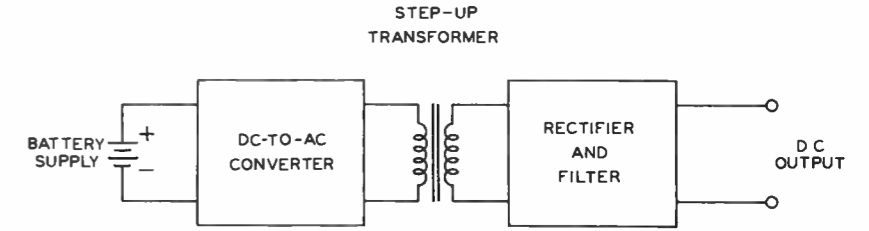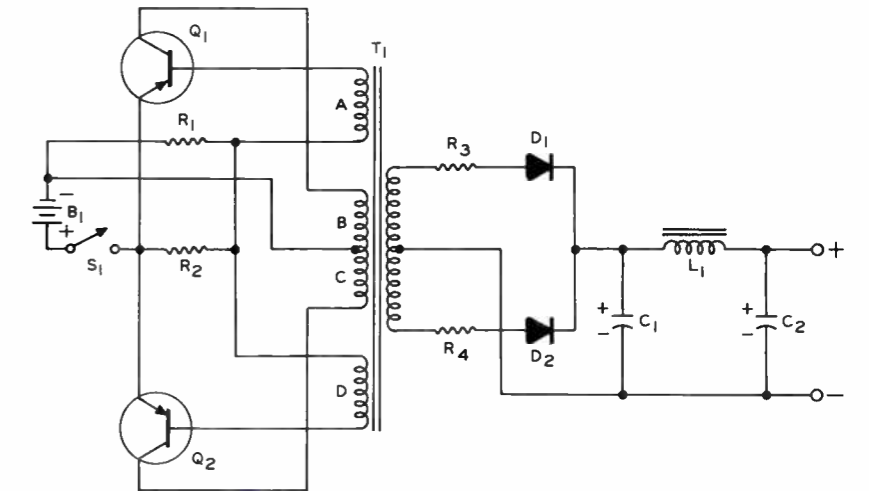
PRACTICE EXERCISE SOLUTIONS (Continued)

42. R_1 = 2K ohms, R_2 = 30K ohms and R_3 = 50K ohms -- Ohm's Law (R = E/I) is used to determine the values of R_1, R_2 and R_3:

$$R_3 = \frac{E_{R_3}}{I_B} = \frac{100 \text{ v}}{2 \text{ ma}} = \frac{1 \times 10^2}{2 \times 10^{-3}}$$

$$= \frac{1 \times 10^2 \times 10^3}{2} = .5 \times 10^5$$

$$= 50,000 \text{ or } 50\text{K ohms}$$

$$R_2 = \frac{E_{R_2}}{I_3 + I_B} = \frac{150 \text{ v}}{3 \text{ ma} + 2 \text{ ma}} = \frac{1.5 \times 10^2}{5 \times 10^{-3}}$$

$$= \frac{1.5 \times 10^2 \times 10^3}{5} = .3 \times 10^5 = 30,000 \text{ or } 30\text{K ohms}$$

$$R_1 = \frac{E_{R_1}}{I_2 + I_3 + I_B} = \frac{50 \text{ v}}{20 \text{ ma} + 3 \text{ ma} + 2 \text{ ma}}$$

$$= \frac{5 \times 10^1}{2.5 \times 10^{-2}} = \frac{5 \times 10^1 \times 10^2}{2.5}$$

$$= 2 \times 10^3 = 2000 \text{ or } 2\text{K ohms}$$

43. The $Q_1 Q_2$ circuit forms an oscillator circuit. The alternate conduction of Q_1 and Q_2 produces changing currents in the T_1 primary. This induces an ac voltage into the secondary winding.

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question, as illustrated in the example below.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

LESSON CODE

2200A

Example: A motorist may proceed across an intersection when the traffic light is
(A) blue. (B) red. (C) black. (D) green.

1. The rectifier in a power supply (A) converts the ac line voltage to pulsating dc. (B) converts the dc line voltage to ac. (C) smooths the pulsating dc developed by the circuit. (D) is always a semiconductor diode.

2. A full wave rectifier operating from a 60 hertz (cycle) line (A) supplies only one voltage pulse per cycle of the ac line voltage. (B) has a ripple frequency of 60 hertz. (C) has a ripple frequency of 30 hertz. (D) supplies two voltage pulses per cycle of the ac line voltage.

3. In the power supply of Figure 8, (A) D_1 conducts for the entire positive alternation. (B) C_1 discharges when D_1 conducts. (C) C_1 discharges through D_1 and the T_1 secondary. (D) C_1 supplies current to the load when D_1 is cut off.

4. Increasing the value of the filter capacitor in a power supply (A) has no effect on the ripple voltage amplitude. (B) reduces the ripple voltage amplitude. (C) decreases the current capacity of the supply. (D) provides poorer filtering.

5. The filter system shown in Figure 13 (A) is a simple capacitor filter. (B) is an L-type filter. (C) does not provide as good filtering as does the simple system in Figure 8. (D) is a pi-type filter.

6. To obtain good power supply regulation, (A) diodes with a high forward resistance should be used. (B) the power transformer should have high resistance windings. (C) a filter inductor with a high internal resistance should be used. (D) the power supply should have a low internal resistance.

7. The circuit of Figure 16 (A) is a half wave rectifier. (B) employs a pi-type filter. (C) employs an L-type filter. (D) is a bridge rectifier.

8. The power supply shown in Figure 17 (A) employs an L-type filter. (B) has a maximum dc output voltage about twice the peak value of the ac line voltage. (C) provides isolation from the ac line. (D) is an ac/dc supply with a series string filament circuit.

9. With the power supply connected as shown in Figure 19, (A) the chassis is "hot" with respect to ground. (B) the chassis and ground are at the same potential. (C) no shock hazard exists. (D) the chassis is isolated from the ac line.

10. In the circuit of Figure 21, (A) D_1 conducts when point A is POSITIVE with respect to point B. (B) C_1 charges to half the peak of the ac line voltage. (C) D_2 conducts when point A is NEGATIVE with respect to point B. (D) C_2 charges to twice the peak of the ac line voltage.

DEDICATED TO PROGRESS THROUGH EDUCATION

ELECTRONIC METERS
Lesson 2203A

DeVRY Technical Institute

CHICAGO   TORONTO

ELECTRONIC METERS

Revised 1967

OPPORTUNITY
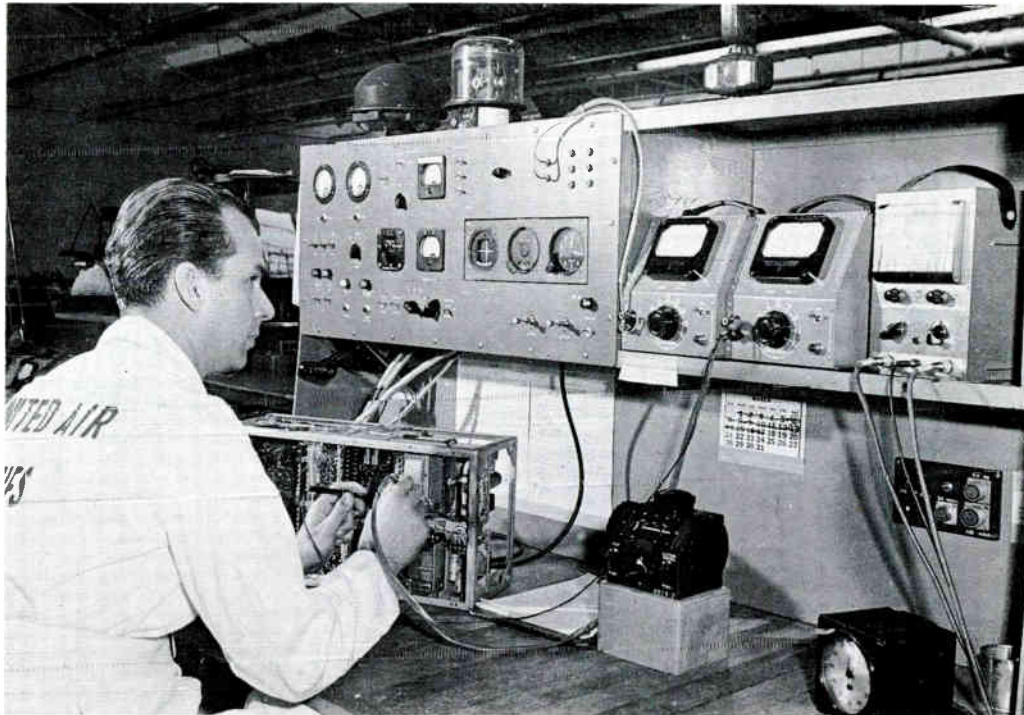
An air line radio-electronic technician using an electronic meter to make accurate voltage measurements an an amplifier used in an automatic pilat system.

Courtesy United Air Lines

ELECTRONIC METERS

CONTENTS

***

There is nothing, I hold, in the way of work,
That a human may not achieve
If he does not falter, or shrink or shirk,
And more than all, if he will believe

And whatever the height you yearn to climb
Tho' it never was trod by the foot of man,
And no matter how steep -- I say you can,
If you will be patient -- and use your time.
                  --Selected

ELECTRONIC METERS

Meters are instruments that measure the effects of electricity. Depending on its circuit arrangement, a meter may measure voltage, current or resistance. There are many types of meters available, including those which use transistors or vacuum tubes to extend the limits of the basic indicator or meter movement and make it more sensitive. We will use the term ELECTRONIC METER to describe a direct reading meter that uses transistors or vacuum tubes. A meter which is only an electromechanical device will be called an ELECTRIC METER.

*   *   *

1. Meters can be divided into two general groups. What are these groups?

*   *   *

METERS AND METER CHARACTERISTICS

Two sections of an electronic meter are basically the same as the corresponding sections of an electric meter. One of these is the meter movement. A D' ARSONVAL METER MOVEMENT is commonly used in both electric and electronic meters. The pointer deflection depends on the amount of current flowing through the meter movement.

The other section that is similar in both types of meter is the input circuit. Meter input circuits are groups of resistors placed in series or parallel with the meter movement in an electric meter, or at the input to a meter amplifier in an electronic meter. These resistors are usually referred to as SHUNTS when used in ammeters, MULTIPLIERS in voltmeters, or simply RANGE RESISTORS in other instruments. They are used to increase the range of measurements that can be made with the meter.

*   *   *

2.   What sections do electric and electronic meters usually have
      in common?

*   *   *

A switch that selects the resistor or combination of resis-
tors to give the desired range of readings is called a RANGE
SWITCH. If the meter is a multiple function unit, such as
a combination ammeter, voltmeter and ohmmeter, it may
also include a FUNCTION SWITCH to select the proper cir-
cuitry for the type of measurement desired.

Figure 1 shows the two meter types in block diagram form.
The electric meter is shown in Figure 1A. This meter is
divided into two blocks; the input circuits and the meter
movement. Figure 1B shows the block diagram of an elec-
tronic meter. This meter is divided into four blocks; the
input circuits, a transistor or vacuum tube amplifier, a
power supply, and a meter movement. Thus, the distin-
guishing feature of an electronic meter, compared to an
electric meter, is the electronic amplifier and the power
supply necessary to operate this amplifier.

LOADING AND IMPEDANCE

Both electric and electronic meters use current from the
circuit under test. There often is a considerable difference,
however, in the amounts of current required. The electric
meter uses some of the test circuit current to operate the
meter movement directly. The electronic meter uses
smaller amounts of test circuit current to develop a signal
for the meter amplifier. The current which operates the
meter movement of the electronic meter is supplied by the
power supply and amplifier.

*   *   *

3.   The electronic meter requires (a) more, (b) less current from
      the test circuit than does the electric meter.

4. When the electronic meter is used to measure the voltage
    drop across a resistor, the current for the meter movement
    is supplied by (a) the test circuit, (b) the power supply and
    amplifier section.

                    *   *   *

The action of a meter using current from a test circuit is
referred to as LOADING. Loading can cause an incorrect
meter reading by disturbing the voltages or currents nor-
mally present in the circuit being tested.

When you connect a meter into a test circuit, a new circuit
is formed. This new circuit consists of the internal resist-
ance of the meter in parallel with a part of the test circuit.
The operating conditions of the circuit under test can change
enough to make your measurements incorrect. The loading
of a test circuit depends on the internal resistance of the
meter being used. Therefore, different meters may have
different loading effects. The internal meter resistance,
often referred to as a meter INPUT RESISTANCE, is the
total resistance a meter offers to the flow of test circuit
current.

                    *   *   *

5. A meter loads a test circuit when the meter uses current from
    the test circuit. True or False?

6. The loading of a test circuit by a meter depends on the (a) inter-
    nal resistance, (b) ability to measure resistance of the meter.

                    *   *   *

The internal resistance of the electric meter of Figure 1A
depends on the combined resistance of the input circuits and
the meter movement. For example, in an electric voltmeter
the multiplier resistors and meter movement are in series
between the meter input jacks. With each change of the
range switch setting, the input resistance of the meter

changes. In comparison, the electronic meter of Figure 1B has a set of voltage divider resistors between the input jacks. The high input resistance of the amplifier is con- nected across a different number of these resistors as the range switch is varied. The meter movement is part of the amplifier. Because of this circuit arrangement, the input resistance of the electronic meter remains high, and almost constant, as the setting of the range switch is changed.

The high input opposition or INPUT IMPEDANCE of an elec- tronic meter is supplied by the input and amplifier sections. The term "impedance" is used because it refers to the total opposition a circuit offers to the flow of current. Impedance is a combination of resistance and reactance. This react- ance includes the capacitive effect of the wiring in the input circuits and the input capacitance of the vacuum tube or transistor.

*   *   *

7. The input impedance of an electronic meter is the total oppo- sition the meter offers to test circuit current. True or False?

*   *   *

Figure 2 shows the effect of input impedance and the loading of test circuits. The test circuit has a total series resist- ance of 40,000 ohms (R_1 = 20,000 ohms and R_2 = 20,000 ohms) connected across a 100 volt battery. Neglecting the meter circuit for a moment, the current through the 40,000 ohm circuit resistance with 100 volts applied is 100/40,000, or .0025 ampere. With two equal value resistors across the 100 volt source, the voltage across each resistor is half the source voltage, or 50 volts.

Now, suppose you connect an electric meter with an internal resistance R_M of 20,000 ohms across resistor R_2 as shown in Figure 2A. With the meter circuit and R_2 in parallel, the effective resistance from point A to point B is 10,000 ohms. The total circuit resistance is 30,000 ohms instead of the original 40,000 ohms. By using Ohm's Law you can show

that the total circuit current increases from .0025 amp to .0033 amp.

The same test circuit is used in Figure 2B, but an electronic meter with a 10 megohm input impedance is connected across R_2. The effective resistance of the parallel combination, R_2 and the electronic meter, is about 19,960 ohms. The total resistance is about 39,960 ohms, and Ohm's Law shows the current to be approximately .002503 amp.
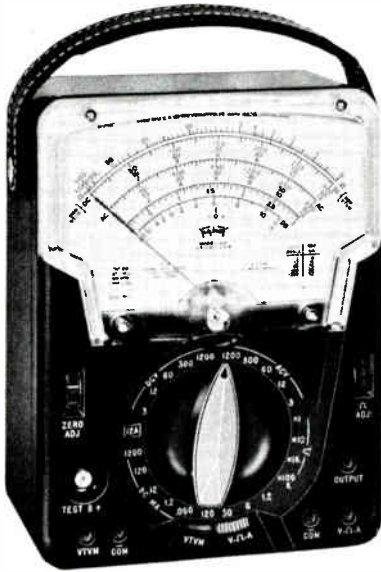
This portable test instrument measures voltage, current and resistance. It can be used as an electric or electronic meter, depending on the position of the switch located near the bottom of the front panel.

Courtesy Triplett Electrical Instrument Co.

Let's compare the effects of the two meter circuits in Figure 2. The electric meter of Figure 2A decreases the circuit resistance from 40,000 ohms to 30,000 ohms and increases the circuit current from .0025 amp to .0033 amp. This is a resistance change of 10,000 ohms and a current change of .0008 amp (.8 ma). The electronic meter of Figure 2B decreases the circuit resistance from 40,000 ohms to 39,960 ohms and increases the circuit current from .0025 amp to .002503 amp. This is a resistance change of only 40 ohms, and a current change of only .000003 amp (.003 ma).

The electric meter causes an error of well over 30%, which cannot be tolerated in most cases. On the other hand, the electronic meter causes an error of less than 1%, which can be disregarded in most cases.

In summary then, we can say that the electronic meter reduces the loading effect caused by a meter being connected

to a circuit because it leaves the circuit operating conditions almost unchanged. This is an advantage, particularly in low power, high impedance circuits where electric meters can cause considerable disturbance and error.

BALANCED BRIDGE

The use of an amplifier provides more than one advantage for the electronic meter. As we have already seen, it helps provide a high input impedance which results in very little loading of the circuit under test. Another advantage is that the amplifier increases the effective sensitivity of the meter movement while isolating the meter movement from the test circuit.

The sensitivity of the meter movement is increased because a very small test signal is amplified to cause greater deflection of the meter pointer. Thus, it can measure voltages that are too small to produce a reading on the average electric meter.

Besides amplification and high input impedance, the amplifier offers protection to the meter movement by isolating it from the test circuit. The internal characteristics of the amplifier limit the amount of plate or collector current which operates the meter movement. This eliminates the chance of damaging the meter movement due to large current or voltages in the circuit under test.

A common circuit used in electronic meter amplifiers is the BRIDGE CIRCUIT. Figure 3A shows a simple bridge arrangement having two circuit branches, $R_1 + R_2$ and $R_3 + R_4$. The same voltage is applied to each branch, between ground and B+. Current I_1 flows through one branch and current I_2 through the other. A meter movement is connected between the upper ends of R_2 and R_4. These points are labeled X and Y. The bridge circuit is now divided into four arms, R_1, R_2, R_3 and R_4.

The meter pointer will deflect an amount proportional to the

current flowing through the meter movement. This current depends on the difference of potential between points X and Y. The potential at X is due to current I_1 flowing through the R_1R_2 branch, and the potential at Y is due to I_2 flowing through the R_3R_4 branch. Any change of resistance in either branch will change the current in that branch and thereby change the potential at point X or Y. If $R_1 = R_3$ and $R_2 = R_4$, the potential at point X equals that at point Y. No current flows in the meter and the bridge is said to be BALANCED.

*   *   *

8. Explain what is meant by balance in a bridge circuit.

*   *   *

Let's replace R_1 with a smaller value of resistance. The total resistance of the left branch decreases and current I_1 increases. More voltage appears across R_2 and less across R_1, making point X more positive than point Y. Current flows through the meter movement from point Y to point X and causes the meter pointer to deflect. Now, the bridge circuit is said to be UNBALANCED.

In an electronic amplifier bridge, a vacuum tube or transistor replaces one or more of the resistors of Figure 3A. Figure 3B shows a vacuum tube bridge. The tube bias is set at a point where the dc plate resistance of the tube is equal to the resistance of R_3. The resistance of R_2 is equal to that of R_4. Under these conditions, the vacuum tube bridge is balanced in the same manner as the resistance bridge of Figure 3A. The meter movement is again placed between the two branches at points X and Y. The meter pointer will rest at its zero point when the bridge is balanced.

The bridge circuit of Figure 3B measures a voltage applied to the grid of tube V_1. When a signal voltage is applied to the grid, the internal resistance of the tube changes and the tube conducts more or less plate current. If the tube conducts more, its internal resistance decreases and the total

resistance in that branch decreases. This causes more current to flow in the branch. The value of R_2 is fixed, and any increase in current through this fixed resistance makes the voltage across R_2 higher than it is when no signal is applied to the tube.

The voltages across R_3 and R_4 remain the same since there is no change in current through the R_3R_4 branch. Thus, point Y is at a fixed potential. If the voltage across R_2 increases, point X becomes positive with respect to point Y. Therefore, a difference of potential exists across the meter movement, between points X and Y, and current flows through the meter.

An increase in positive voltage at the grid of V_1 causes more tube conduction, a greater voltage across R_2, and a higher potential at point X. This increases the difference of potential between X and Y and causes a greater deflection of the meter pointer. Thus, the pointer deflection is proportional to the voltage at the grid of V_1.

The circuit of Figure 3B has been used in actual meters, but there are some disadvantages with the single tube bridge circuit. For example, conduction usually changes as the tube warms up, and also changes as the tube ages. To make up for these changes of resistance in one of the upper arms, another vacuum tube section having the same characteristics is placed in the other upper bridge arm. For best results, the tube sections should be in the same envelope so heating and aging will be the same in each.

This electronic voltmeter measures dc voltages and low frequency ac voltages up to 1500 volts without the use of external multipliers. Its ohmmeter range is from .2 ohm to 1000 megohms.

Courtesy General Radio Company

*   *   *

9.   In Figure 3B, V_1 acts as a variable (a) capacitor, (b) inductor, (c) resistor.

*   *   *

Figure 3C shows the dual vacuum tube bridge circuit. Triode V_1 is called the ACTIVE TUBE , and V_2 is referred to as the REFERENCE TUBE.   Meter indications are due to the differences in conduction of V_1 and V_2. The difference occurs when a signal (the voltage to be measured) is applied to the grid of V_1.

The conduction and plate resistance of tube V_2 remain constant during measurements, and V_2 functions just as the fixed resistor R_3 of Figure 3B did.   However, temperature and aging affect V_2 much the same as V_1. As a result, changes in the average characteristics of V_1 are accompanied by similar changes in V_2 characteristics, and balance in this circuit is affected much less by these factors than it is in the circuit of Figure 3B.

This circuit very often contains a variable resistor in one or more arms to allow exact balance (zero meter reading) before measurements are made. This resistor is called the ZERO ADJUST control. It is usually mounted on the front panel of the meter.

*   *   *

10. What are the reasons for using reference tube V_2 in the circuit of Figure 3C?

11. What is the purpose of a zero adjust control in most electronic meters?

*   *   *

The operating voltages for an electronic meter amplifier are usually supplied by a power supply built into the same case as the amplifier and meter movement.   This power

supply must provide filament voltage and current as well as the bridge circuit voltage and current. The power supply often converts voltages from an external power source to the necessary operating voltages. In other cases the power supply consists of self-contained batteries.

*   *   *

12. If there is no voltage in the bridge section of an electronic meter, what section might be the source of the trouble?

*   *   *

GENERAL PURPOSE VACUUM TUBE VOLTMETER

A VACUUM TUBE VOLTMETER, abbreviated VTVM, is an electronic meter that uses vacuum tubes in the amplifier section. Figure 4 shows the front panel of a typical general purpose instrument of this type. Most general purpose VTVM's can measure ac and dc voltages and a wide range of resistances. Generally, they do not include a circuit for measuring current.

Most general purpose VTVM's are quite similar and can be divided and analyzed in sections as represented by the block diagram in Figure 1B. The complete schematic of the meter of Figure 4 is shown in Figure 5.

Meter Amplifier and Meter Movement

A typical general purpose VTVM makes use of a BALANCED AMPLIFIER. In Figure 5, the balanced amplifier section includes vacuum tubes V_{1A} and V_{1B}, which form a bridge circuit similar to that of Figure 3. For example, calibration controls are added in series with the meter movement. These calibration controls, R_{19}, R_{20} and R_{21}, are switched in series with the meter movement. They determine the amount of meter movement current for the various function switch settings. Different calibration control resistors are switched into the circuits by the function switch.

*   *   *

13. The VTVM amplifier section and meter movement shown in
    Figure 5 form (a) an RC coupled amplifier, (b) a balanced bridge
    circuit.

*   *   *

Simplified diagrams of the VTVM amplifier of Figure 5 are
shown in Figure 6. In Figure 6A, the upper arms of the
bridge circuit are formed by the two triode sections of V_1.
V_{1A} serves as the active tube, and V_{1B} as the reference
tube. Zero adjust control R_{22} acts as both lower arms of
the bridge circuit. The part of R_{22} between the left end and
the slider is the lower arm of the V_{1A} branch, and the part
between the slider and the right end is the lower arm of the
V_{1B} branch.

The grid of V_{1B} is connected directly to ground. The grid
of V_{1A} connects to R_{12} and the input circuits, which also
eventually lead to ground. Resistors R_{25} and R_{26} connect
the grid circuits back to the cathodes of V_{1A} and V_{1B}. The
grid bias is basically the same for both tubes. The meter
movement and calibration controls are between points X
and Y.

Since V_{1A} and V_{1B} are in the same glass envelope, their
characteristics are very similar. In a practical tube, how-
ever, there may be small differences between the two sec-
tions which prevent the meter from reading exactly zero
when there is no input applied. Before making measure-
ments with the VTVM, R_{22} is adjusted until the meter pointer
rests at zero.

To see how the zero adjust control works, let's examine
Figure 6B. The dc plate resistances of V_{1A} and V_{1B} are
represented as resistors R_{V1A} and R_{V1B}. Zero adjust
control R_{22} is represented as two resistors, R_{22A} and
R_{22B}. The subscript A refers to the left branch of the
bridge, and subscript B refers to the right branch. Resist-

ance R_M represents the internal resistance of the meter, and R_C is the resistance of the calibration control in series with the meter movement.

Assume a 150 volt source is applied between B+ and B−, and 50 volts of this appears across R_{23}. Each branch then has 100 volts across it. Assume triode V_{1A} offers a resistance R_{V1A} of 7750 ohms, and V_{1B} offers a resistance R_{V1B} of 7250 ohms, when no voltage is being measured. If the meter is to read zero under these conditions, R_{22} must be adjusted so that the ratio of R_{V1A} to R_{22A} is the same as the ratio of R_{V1B} to R_{22B}. That is, the slider must be moved to the right so there is a little more resistance in series with V_{1A} than there is in series with V_{1B}.

A precision VTVM featuring accurate ac voltage readings from audio to ultra-high frequencies (uhf). It measures dc voltages and a wide range of resistances. High input impedance insures very little loading of almost any ac or dc circuit.

Courtesy Marconi Instruments Ltd.

After the VTVM is balanced, it is ready for measurements. When the test leads are touched to points of different potentials, an input signal is applied to the grid of V_{1A} of Figure 6A. When an input drives the grid of V_{1A} positive, the internal resistance of V_{1A} decreases and its plate current increases. The voltage across R_{V1A} decreases and that across R_{22A} increases. This change makes point X more positive than point Y, and electrons flow through the meter from Y to X, causing the meter pointer to deflect.

The action is strengthened in this circuit by tube V_{1B}. Because R_{23} is in the cathode circuits of both tubes, the plate current of V_{1A} affects the grid bias of V_{1B}. When this current increases, it causes an increase in V_{1B} grid bias, which

raises the resistance $R_{V_{1B}}$. This decreases the voltage at point Y, causing more meter current to flow.

*   *   *

14. If the balanced amplifier is in a balanced condition and a positive voltage is applied to the input of V_{1A} of Figure 6A, what happens to the voltage between points X and Y?

*   *   *

If the input signal drives the grid of V_{1A} negative, the internal resistance of V_{1A} increases and its plate current decreases. Referring to Figure 6B, the voltage across $R_{V_{1A}}$ increases and that across R_{22A} decreases. Point Y is now more positive than point X, and meter current flows from X to Y. Because less current is drawn by the left branch, there is less current through R_{23}, and the voltage across R_{23} decreases. Since R_{23} is in both cathode circuits, the grid-to-cathode bias of V_{1B} is reduced. Triode V_{1B} then conducts harder, causing the voltage across R_{22B} to increase and helping to make point Y even more positive than point X.

*   *   *

15. When an input signal drives the grid of V_{1A} in Figure 6A negative, in which direction does current flow through R_M?

*   *   *

The voltage between points X and Y can be of either polarity. This depends on whether the voltage applied to the grid of V_{1A} is positive or negative. Therefore, current can flow through the meter movement in either direction -- from X to Y or from Y to X. Most meters, however, are arranged to provide deflection in one direction only. Therefore, some provision must be made to reverse the meter movement connections when the current reverses. This is done by means of the switch contacts shown in Figure 6A. They are

a part of the function switch, whose setting determines whether the meter will make positive or negative dc voltage measurements.

Figure 6A also shows resistor R_{12} and capacitor C_3 between the input circuits and the grid of tube V_{1A}. These two components act to filter or remove any variations in dc voltage being measured by the instrument. It is common to find both ac and dc voltages present where we wish to measure only the dc. Both of these voltages appear at the input circuits of the meter. Any voltage at the input circuit causes capacitor C_3 to charge or discharge through R_{12}. If R_{12} has a high value of resistance, C_3 cannot charge or discharge immediately. As a result, the voltage across C_3 cannot change rapidly, and variations (such as ac voltages) are filtered from the signal appearing at the V_{1A} grid.

Power Supply

A power supply is necessary to furnish the required amplifier voltages and currents in a VTVM. In some cases, another supply is added so the meter can make resistance measurements. The complete VTVM schematic of Figure 5 shows two power supplies. The supply used for the vacuum tube circuits operates from an ac power line. The supply used for resistance measurements is made up of two flashlight cells which provide 3 volts dc.

Figure 7 shows a simplified diagram of the VTVM power supply. It includes a simple half wave rectifier. The high voltage secondary of transformer T_1 is connected in series with rectifier V_{2B} and capacitor C_4. Tube V_{2B} conducts when the T_1 secondary voltage makes the plate of V_{2B} positive with respect to its cathode. Capacitor C_4 then charges with the polarity indicated in Figure 7. The charging path of C_4 is from the lower end of the T_1 high voltage secondary to the lower plate of C_4, from its upper plate through V_{2B}, to the upper end of the T_1 high voltage secondary. The energy stored in C_4 furnishes current to operate the tubes and meter of the bridge amplifier.

The heater voltage for all of the vacuum tubes appears be-
tween the X terminal of the T_1 low-voltage secondary wind-
ing and ground.

*   *   *

16. When the VTVM is turned on, the entire B+ to B- voltage of
    Figure 7 appears across the terminals of (a) capacitor C_4,
    (b) resistor R_{24}, (c) resistor R_{26}.

*   *   *

Input Circuits

A function switch is a part of the circuitry included in most
VTVM's. It switches the necessary components into the
meter circuit to allow different types of measurement. For
example, Figure 4 shows the panel view of the function
switch, which enables the meter to measure positive dc volt-
age, negative dc voltage, ac voltage and resistance. This
switch is included in the schematic of Figure 5.

*   *   *

17. What meter switch would you use when you change from ac
    voltage measurements to dc voltage measurements?

*   *   *

Function switch S_1 of Figure 5 is made up of two wafers or
decks mounted on the same shaft. Each deck is divided into
two sections; S_{1A} and S_{1B} on one deck and S_{1C} and S_{1D} on
the other. Sections S_{1C} and S_{1D} connect to the bridge cir-
cuit so the current flows through the meter movement in the
proper direction. Switch sections S_{1A} and S_{1B} connect the
input terminals to the proper input circuits and then to the
meter amplifier.

Each section of each function switch deck has a contact
(terminal 12 of S_{1A} and S_{1D} and terminal 6 of S_{1B} and S_{1C})

which rides continuously on the rotating contactor.   Each
rotating contactor has an extended point or tab which con-
nects to one of the stationary contact points around the
switch wafer as the shaft is rotated through its four posi-
tions. These connect the different input circuits to the am-
plifier and meter movement.

The range switch, S_2, is also a multi-position, multi-deck
switch. It connects different resistances into the input cir-
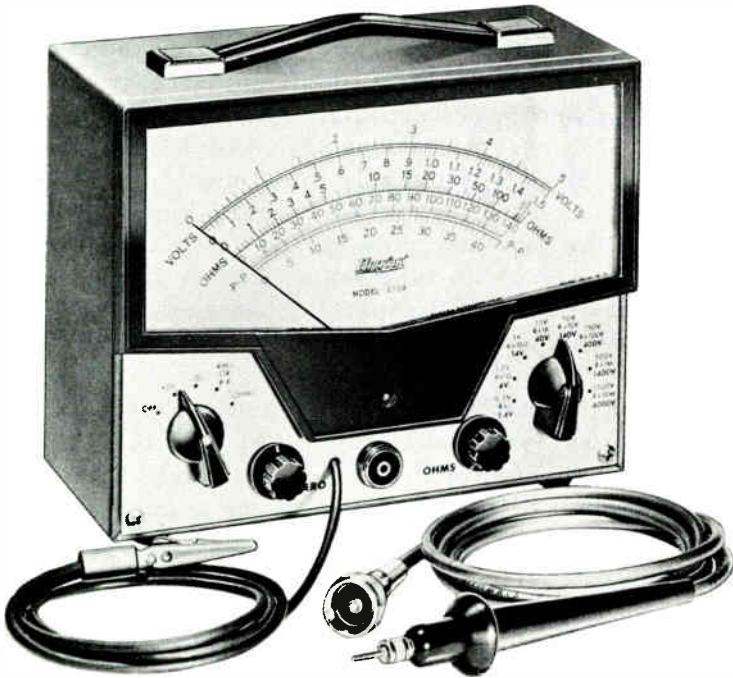
A VTVM which measures ac or dc voltages and resistance. An ac-dc-ohms single unit probe, lower
right, eliminates the need for multiple leads, thus simplifying the meter operation.
Courtesy Hickok Electrical Instrument Co.

cuits of the amplifier.   Different range switch sections are
located at the bottom of Figure 5.   These sections are re-
ferred to as S_{2A}, S_{2B} and S_{2C}. Terminal points which con-
tinuously ride on the rotating contactor of each deck are
labeled "common". All other connections depend on the set-

ting of the range switch.

Let's trace out the meter circuit at one particular setting of the range and function switches. The function switch in Figure 5 is set at +DC and the range switch is set at 150V. The rotating tab of function switch section S_{1A} is at terminal 7, the tab of S_{1B} is at terminal 2, the tab of S_{1C} is at terminal 2, and the tab of S_{1D} is at terminal 8. The rotating tab on each section of the range switch is at terminal 4.

The dc voltage to be measured is applied between input jacks J_1 and J_3 so that J_3 is more positive than J_1. With the function switch in the +DC position there is a path from J_3 through R_1 and S_{1A} (terminal 7 through the tab and ring to terminal 12) to terminal 1 of S_{2B}, which connects through R_6, R_7, R_8, R_9, R_{10} and R_{11} to ground. Since the range switch is set at 150V, there is a path from terminal 4 of S_{2B} through the tab and ring to the "common" contact to terminal 2 of S_{1B}. With function switch S_1 in the +DC position, the path continues through the tab and ring to terminal 6 of S_{1B}, and through R_{12} to the grid of the active tube V_{1A}.

The + side of the meter movement connects through terminal 12 to the ring on S_{1D}, and through the tab to terminal 8, and from this point through DC CAL control R_{19} to the cathode of V_{1A}. The − end of the meter movement connects through terminal 6 to the ring on S_{1C} and through the tab and lug 2 to the cathode of V_{1B}.

A simplified dc input circuit is shown in Figure 8. Here, a voltage reading is being taken in a typical vacuum tube circuit. A black (common) lead connects between the test circuit ground and input jack J_1. A red lead makes contact with the plate of the vacuum tube and connects to input jack J_3. Thus, the meter will measure the plate-to-ground voltage of this circuit.

The plate-to-ground voltage applied between J_3 and J_1 divides between R_1 and range resistors R_6 through R_{11}. With the range switch set at 150V, the contact of S_{2B} is set at the

upper end of R_9 (point 4).   Part of the voltage applied to J_1
and J_3 appears between ground and point 4. This voltage is
applied to the grid of bridge-amplifier tube V_{1A} through
resistor R_{12}.   Here, we see how the dc voltage divides
across the range resistors and is applied to the bridge cir-
cuit.

A negative dc reading is taken when the lead connected to J_3
is at a more negative point than the lead of J_1. In this case,
the function switch is set at -DC.   The input circuits are
the same as in the +DC position.   The rotating tab of S_{1A}
connects to terminal 8 instead of 7, and the tab of S_{1B} con-
nects to terminal 3 instead of 2, but since these sets of ter-
minals are connected together there is no change in circuit
connections.   However, function switch decks S_{1C} and S_{1D}
reverse the meter movement connections.   That is, the
positive terminal of the meter movement is connected to
the cathode of V_{1B} while the negative side is connected to
the cathode of V_{1A} through R_{19} when the function switch is
set at -DC.

Because the meter movement responds only to dc, only dc
voltages should be applied to the grid of V_{1A}.   This is true
regardless of the type of measurement being made. There-
fore, to measure an ac voltage the input circuits must in-
clude some means of changing the ac voltage to dc voltage.
This is done with a half wave rectifier V_{2A}. When an ac
voltage is applied to the meter input jacks the rectifier cir-
cuit produces a dc voltage whose amplitude depends on the '
peak value of the applied ac.

                *   *   *

18.   In most general purpose VTVM's, why is it necessary to have
      a rectifier in the input circuits to change an incoming ac test
      signal into a dc signal?

                *   *   *

Figure 9 shows the simplified ac input circuit. Assume the

voltage of an ac generator is being measured. This signal is applied across inputs J_1 and J_2. Assume the range switch is set at 5V and the function switch at AC. Capacitor C_1 is large enough to have low reactance at most frequencies. Thus, the ac voltage applied between J_1 and J_2 also appears across R_2, R_3 and R_4 in series. On high voltage ranges these resistors act as a voltage divider to reduce the ac voltage applied to the rectifier circuit.

This VTVM measures dc voltage, current and resistance with laboratory accuracy for production line applications.
Courtesy Hewlett-Packard Company

When an ac test signal makes J_2 negative with respect to J_1, V_{2A} conducts. Electrons flow from J_2 to C_1, through S_{2A}, C_2, V_{2A} and R_{25}, and through the ground connection to J_1. The circuit is completed through the circuit under test -- in this case, the generator. When V_{2A} conducts, its internal resistance is very low. C_2 charges to approximately the peak value of the ac voltage appearing at the contact of switch S_{2A}. The polarity of this charge is shown in Figure 9. As you will see, capacitor C_2 has a very high resistance discharge path. Hence, it remains almost completely charged and V_{2A} conducts only small currents after the first few negative alternations of the ac input signal.

When J_2 is positive, for practical purposes you can consider V_{2A} as being out of the circuit. The positive alternations produced at S_{2A} by the signal being measured add to the charge of C_2. Thus, a pulsating dc voltage appears at the junction of R_5 and C_2. This pulsating dc is applied through R_5, terminals 9 and 12 of S_{1A}, and terminal 1 of S_{2B}, to the

voltage divider made up of resistors R_6 through R_{11}. These resistors divide the pulsating dc voltage to provide proper grid voltage for V_{1A}.

Resistor R_{12} and capacitor C_3 act to filter the pulsations appearing on the dc voltage. C_3 cannot charge and discharge rapidly due to the series resistor R_{12}. As a result, the voltage at C_3 remains nearly pure dc at about the peak level of the pulsating dc voltage between the S_{2C} common terminal and ground. When the meter is set to the 5V ac range, the voltage across C_3 is the peak value across the entire voltage divider, resistors R_6, R_7, R_8, R_9, R_{10} and R_{11}. This voltage makes the upper plate of C_3 positive. This is the signal applied to the grid of the meter amplifier, which then causes the meter pointer to deflect.

A diode such as V_{2A} tends to allow a very small plate current to flow even when no positive plate voltage is applied. When applied to the meter amplifier, this can cause a small meter deflection even though no input voltage is being measured. To avoid this false indication, a small negative voltage is applied to the plate of V_{2A} from the slider on R_{25}. R_{25} is called the BALANCE CONTROL.

The balance voltage is obtained from the power supply as shown in Figure 7. The voltage of C_4 is applied across R_{24}, R_{25} and R_{26}. When V_{2B} conducts, C_4 charges and a part of the C_4 voltage exists across each resistor. The junction between R_{24} and R_{25} is grounded. Since the lower plate of C_4 is negative, the voltage of the slider of R_{25} is negative with respect to ground. The plate of V_{2A} is connected to the slider of R_{25}, so it is also at a small negative voltage.

Balance control R_{25} is set so that V_{2A} plate current is reduced to zero when no dc voltage is being measured. This adjustment is critical because too much negative voltage at the V_{2A} plate could keep the tube from conducting when an ac signal is measured. This could produce a false reading.

*   *   *

19.   The ac balance control is adjusted for what condition?

*   *   *

To measure resistance, the function switch of the meter is set at OHMS. From Figure 5 you can see that function switch section S_{1A} makes no connections at this setting. Thus, range switch sections S_{2A} and S_{2B} are removed from the input circuit at this setting of the function switch. The rotating tabs and ring of S_{1B} make connections between terminals 5, 11 and 6 of S_{1B}. This connects J_2 to the "common" terminal of range switch section S_{2C}. Depending on the range switch setting, any one of six resistors, R_{13} to R_{18}, is selected as a multiplier by section S_{2C}.

In the bridge amplifier circuit, S_{1C} connects terminals 5 and 6, and S_{1D} connects terminals 11 and 12, when the function switch is in the OHMS position. This provides a path from the cathode of V_{1B} through terminals 5 and 6 of S_{1C} to the – terminal of the meter movement, and from the + terminal of the meter movement through terminals 11 and 12 of S_{1D}, through OHMS ADJUST control R_{21} to the cathode of V_{1A}.

A general purpose electronic voltmeter for precision measurement of ac voltages.
Courtesy Ballantine Laboratories, Inc.

Figure 10 is a simplified diagram of the input circuit when the function switch is set to measure ohms. R_X in this diagram is some unknown resistor you wish to measure.

The range switch is at $R \times 1K$. Figure 10 shows that R_{15} and R_X form a series circuit with the battery. The voltage across R_X is the same as the voltage between S_{1B} and ground.

Different values of R_X will cause different values of current to flow in the R_{15}, R_X circuit. The voltage across R_X depends on the current through it. Therefore, the voltage across R_X, and thus the voltage between S_{1B} and ground, depends on the resistance of R_X.

Notice that the V_{1A} control grid is connected to S_{1B} through R_{12}. As no current flows from the grid of V_{1A}, the voltage at the grid is the same as that at S_{1B}. Thus, any voltage developed between S_{1B} and ground is also impressed on the grid of amplifier tube V_{1A}. This grid voltage results in a deflection of the meter pointer. The meter scale is calibrated directly in terms of the resistance appearing between J_2 and J_1.

Resistors R_{13}, R_{14}, R_{16}, R_{17} and R_{18} may be switched into the circuit in place of R_{15} by the range switch. This is done so that a wide variety of measured resistors can be read in a convenient area of the meter face. If the resistor selected by S_{2C} is somewhere near the value of the measured resistor R_X, the reading will be near the center area of the meter face and can be more easily read. Range switch S_2 is labeled according to the estimated range of resistance to be measured.

Operating the Meter

All of the VTVM sections shown in Figure 1B are usually contained in a portable case. This case allows easy handling and protects the components from being damaged. A typical meter case and control panel is shown in Figure 4. This meter has an on-off control, ohms adjust and zero adjust controls, and function and range switches.

The on-off switch of this meter is mounted with the ohms adjust control. The on-off switch turns the meter power on

or off. The ohms adjust control changes the resistance in
series with the meter movement when resistance is being
measured. It is adjusted to set the meter pointer at infinity
(∞) on the OHMS scale when the test leads are open and the
function switch is set to the OHMS position. The zero adjust
control balances the bridge circuit so the meter pointer
rests at zero on the left side of the scale for any function
and range switch settings.

By properly setting the function switch, the meter can be
used to measure dc voltage, ac voltage, or resistance. The
range switch determines the amount of input signal applied
to the meter amplifier. To protect the components of a
meter, always set the range switch at its highest range be-
fore measuring voltage. Then you can lower the range
switch setting for readable pointer deflection, if necessary,
as the measurements are being made.

*   *   *

20. Explain how you would set the controls of the VTVM shown in
Figure 4 to make the best measurement of a 100 volt ac signal.

*   *   *

The front control panel of Figure 4 includes three input
jacks for different types of test signals. The COMMON in-
put jack is usually connected to a ground point of a test cir-
cuit. The AC-OHMS input jack is used when making resist-
ance or ac voltage measurements. The DC-RF input jack is
used for dc voltages, and may also be used as the input for
a special probe which rectifies r-f signals.

The meter movement is located on the upper half of the con-
trol panel. This meter has three scales. The top scale is
an ohmmeter scale labeled with the word OHMS. This scale
begins with 0 on the left and ends with ∞ on the right. An
infinite reading means the measured resistance is so high
that the meter pointer cannot deflect enough to give a read-
ing on that range. Since this scale is non-linear, look at

the divisions on both sides of the pointer when taking read-
ings to determine the correct value of meter deflection.

There are two voltage scales beneath the OHMS scale. The
upper VOLTS scale starts at 0 on the left and ends with 5.0
at the right. The lower VOLTS scale starts with 0 and ends
at 15. These voltage scales are used to measure positive
or negative dc voltages and ac voltages.

The settings of the function and range switches tell you which
scale to read. If the function switch is set to +DC, -DC or
AC, you use one of the VOLTS scales. If the range switch
is set at 5V, 50V or 500V, you use the 0-5.0 scale. If the
range switch is at 15V, 150V or 1500V, you use the 0-15
scale. In each case, you multiply the scale indications by
the proper multiplier for the range you are using ($\times 1$ on the
5V or 15V range, $\times 10$ on the 50V or 150V range, or $\times 100$ on
the 500V or 1500V range). With the function switch set to
OHMS, you read the OHMS scale and multiply the scale
indication by the multiplier setting of the range switch ($\times 1$,
$\times 10$, etc.).

*   *   *

21. Assume you connect the VTVM of Figure 4 across a resistor
    in an industrial control circuit. With the function switch set
    at + DC and the range switch at 150V, if the pointer deflects
    to the dashed lines position, you are measuring (a) 10.5 volts,
    (b) 105 volts. (c) 1050 volts.

*   *   *

In Figure 5, the balanced amplifier has three variable re-
sistors; R_{19}, R_{20} and R_{21}. The ohms adjust control, R_{21},
is mounted on the front panel. As explained, it is used to
adjust the pointer to infinity before a resistance test is made.
R_{19} and R_{20} are used to calibrate the meter for ac and dc
voltage measurements, and are referred to as CALIBRATION
CONTROLS. These two controls, along with ac balance
control R_{25}, are usually mounted on the rear of the meter

because they seldom need adjustment.

After the instrument ages, tubes or other component values may change slightly. Recalibration may become necessary. You recalibrate the meter by applying a known voltage to the proper input and adjusting the corresponding calibration control. These controls are adjusted until the meter pointer indicates the known applied voltage.

*   *   *

22. After the meter ages, the VTVM calibration controls are used to recalibrate the meter so its deflection is correct. True or False?

*   *   *

GENERAL PURPOSE TRANSISTORIZED METER

The most modern general purpose electronic meter is the TRANSISTORIZED METER, abbreviated TRVM. The TRVM uses transistors rather than vacuum tubes in its amplifier section. There are several advantages in using transistors instead of vacuum tubes. For example, the TRVM requires lower operating voltages for the meter amplifier. Also, no filament supply is necessary. Because of these reduced power requirements, it is more practical to operate a transistorized meter from self contained batteries. This makes it more portable and adaptable to field work than most general purpose VTVM's.

*   *   *

23. The TRVM can be more portable than most VTVM's because of its total independence from an external ac power source. True or False?

*   *   *

The general purpose TRVM of Figure 11 can be used to

measure ac or dc voltages and resistance as do most VTVM's.
In addition, this TRVM can measure a wide range of direct
current.   This is an advantage, particularly when working
on transistor circuits.   Most general purpose vacuum tube
voltmeters do not measure current directly.

*   *   *

24. Comparing a general purpose VTVM with the TRVM under
    discussion, the TRVM has the advantage because it is able to
    measure direct _____.

*   *   *

Meter Amplifier and Meter Movement

Figure 12 shows the full schematic of a general purpose
TRVM developed by DeVRY Technical Institute. The TRVM
can be analyzed by dividing it into the same sections as the
other electronic meters.   These are shown in Figure 1B as
input circuits, amplifier, power supply, and meter move-
ment.   The TRVM of Figure 12 includes a four transistor,
two stage DIFFERENTIAL AMPLIFIER.

Figure 13A is a partial schematic to help explain the differ-
ential amplifier operation. In this circuit, resistors R_3 and
R_4 are part of a voltage divider between the input circuits
and the transistors.   Capacitor C_4 offers a low impedance
path between one of the input jacks and the metal case when
the meter is used for ac measurements.   This provides a
shielding effect and prevents erratic readings caused by any
stray signals.   Resistor R_5, a current limiting resistor,
prevents overloading of Q_1 and Q_3 and also reduces the ef-
fects of the transistors on the input circuit.   Capacitor C_3
filters any pulsating dc signal from the input circuits to the
amplifier.

Feedback resistors R_6 and R_{12} stabilize the operation of Q_1
and Q_3, and increase the impedance between the bases of
the transistors.   Resistors R_8 and R_{10} provide additional

stabilization and further increase the base-to-base imped-
ance. Zero adjust control P_2 is adjusted to obtain exact
balance in the amplifier cir-
cuits. It is set so the meter
pointer rests exactly over zero
on the meter scale when no
signal is applied. Resistors
R_7 and R_{13} are the collector
load resistors for Q_1 and Q_3.
R_9 and R_{11} are emitter load
resistors for Q_2 and Q_4. The
output to the meter movement
is developed across these two
resistors.

Assume a dc voltage is being
measured that makes point A
more positive than point B of
Figure 13A. This voltage from
the input circuit divides be-
tween R_3 and R_4. Notice that
resistors R_4 and R_5 are in
series between the bases of
Q_1 and Q_3. Any voltage devel-
oped across either of these
resistors will affect the base bias of both transistors. Also,
such a voltage will increase the bias of one transistor and
decrease that of the other. The base bias or current is
only a few microamperes, and the change in this current
due to the voltage across R_4 is not great. It is, however,
amplified by Q_1 and Q_3 so their collector currents vary by
a much greater amount.

When point A is more positive than point B, the base cur-
rent of Q_1 increases slightly and that of Q_3 decreases slightly.
The collector current of Q_1 then increases while that of Q_3
decreases. These changes in Q_1 and Q_3 collector currents
cause corresponding changes in the voltages across R_7 and
R_{13}. These voltages serve as the signals for transistors
Q_2 and Q_4. In turn, changes in Q_2 and Q_4 conduction pro-

The operating principles of this electronic
meter are similar to those of the VTVM. How-
ever, the meter's bandwidth is extended by
using specially designed transistors in the
amplifier section.

Courtesy Keithley Instruments, Inc.

vide the output of the differential amplifier.

*   *   *

25. The base-to-emitter bias of each transistor determines the amount of current flowing through each transistor in the differential amplifier circuit of Figure 12.   True or False?

*   *   *

We have seen that when point A is made more positive than point B, the collector current of Q_1 increases. This causes an increase in voltage across R_7 and a decrease in the voltage at the Q_1 collector.   The bias on Q_2 now changes, because the base of Q_2 is connected to the collector of Q_1.   A decrease in Q_1 collector voltage causes a decrease in base bias of Q_2.   As the forward bias of Q_2 decreases, the conduction of Q_2 also decreases.   Since Q_2 conducts less, its emitter current decreases. As this reduced emitter current flows through R_9, the voltage across R_9 is reduced. The voltage at point X of Figure 13A is thereby made less positive.

When the voltage from the input circuits (between A and B) increases the forward bias of Q_1, it also decreases the forward bias of Q_3. With less forward bias, the conduction of Q_3 decreases, resulting in an increase in the voltage at the collector of Q_4. Since the base of Q_4 is connected to the Q_3 collector, any increase in Q_3 collector voltage causes an increase in the forward bias of Q_4. Therefore, the conduction of Q_4 increases and the voltage across R_{11} increases, making point Y more positive. As the meter movement is connected between points X and Y, the difference in voltage between these two points will cause current in the movement and result in the desired pointer deflection.

Figure 13B shows just a part of the second push-pull amplifier stage with the meter movement connected at points X and Y. This circuit is redrawn to show the similarity to the vacuum tube bridge circuit of Figure 3C. Any difference in

Q_2 and Q_4 emitter currents produces a difference in poten-
tial between points X and Y. This, in turn, causes meter
current. With a decrease in Q_2 emitter current and an in-
crease in Q_4 emitter current, point Y is more positive than
point X. Meter current then flows from point X to point Y
and the meter pointer deflects.

The action of the differential amplifier we have just followed
occurs whenever a positive dc voltage, ac voltage, or resist-
ance is measured by the meter. A negative dc input signal
(point A more negative than B) causes the reverse effect and
meter current flows from Y to X.

*   *   *

26. Figure 3C shows a bridge circuit where only one arm changes
value to produce unbalance. Is this also true of Figure 13B?

*   *   *

Figure 13A shows variable resistances connected in series
with the meter movement. These resistances and the polar-
ity of the meter movement are selected by the function
switch. The variable resistances are adjusted to obtain
proper calibration of the meter for each function. They do
this by reducing current through the meter movement until
deflection of the pointer corresponds to the value of the
measured voltage, current or resistance. The dashed lines
of Figure 13A show the connections at different function
switch settings.

The differential amplifier of the transistorized meter iso-
lates the meter movement from the input signal. This pro-
tects the meter movement from being damaged by excessive
current. For example, in Figure 13A when an improper
input signal makes point A a great deal more positive than
point B, the forward bias at Q_1 is maximum. This is limited
to a safe value by R_5. With maximum forward bias, Q_1
collector current is also maximum. The bias at the base of
Q_2 is reduced to a point where it cuts off all Q_2 collector

current. At the same time, Q_3 is at minimum forward
bias, which cuts off its col-
lector current and increases
its collector voltage. Due to
its maximum forward bias,
Q_4 current is maximum and
cannot be further affected by
any increase in input to the
meter.

The circuit values are chosen
so the current through the
meter movement is limited to
a safe value when Q_2 and Q_3
are both cut off.   Current
through the movement can
never exceed this safe value.
The protective action also oc-
curs if the polarity of the in-

This compoct, completely portable tran-
sistorized meter is designed for accurate
measurements of ac and dc voltages, dc cur-
rent and resistance.

DeVRY Tech Photo

put signal is reversed; then Q_1 and Q_4 collector current
would be cut off.

Power Supply

The current used to deflect the meter pointer is supplied to
the amplifiers by the power supply. The TRVM power sup-
ply consists of four flashlight cells; one C cell and three D
cells.   The D cells are used to supply the operating voltage
and current for the transistor circuits. The single C cell
is used as a constant voltage source when the TRVM is used
to measure resistance.

The D cells are connected in series, and their total voltage
is about 4.6 volts when the cells are new. This voltage is
higher than necessary, as the transistor amplifier circuit
is designed to operate from about a 4 volt power source.
However, cells decrease in voltage as they are used. This
meter can continue to use the supply battery (D cells) until
the voltage drops to 4 volts or slightly less without affecting
the meter accuracy.

A special circuit is used to accommodate changing battery voltage. This circuit includes BATTERY ADJUST control P_3 in Figure 12. The setting of P_3 controls the power supply voltage because the current drawn by the four transistors must pass through part of this control. P_3 is adjusted so the voltage at the collectors of Q_2 and Q_4 is about 4 volts positive with respect to the negative battery terminal. This voltage is measured by the meter movement when the function switch is at the BATT position. A special green mark at mid-scale indicates the proper voltage. As the cells age, the setting of P_3 can be reduced to compensate for the gradual drop in battery voltage.

*   *   *

27. The voltage supplied to the TRVM transistors is controlled by the setting of P_3. What is the advantage of this?

*   *   *

The single C cell is connected into the meter circuit whenever the meter is used to measure resistance. This battery supplies the current necessary to develop a signal for the meter amplifier when the function switch is set at the OHMS position.

After making any measurements, you should turn the meter off. In this way, you extend the life of the cells. Since there are no tube filaments or other circuit elements that require any warm-up, the TRVM is able to operate as soon as it is turned on.

*   *   *

28. Why is it possible to operate the TRVM as soon as it is turned on?

*   *   *

Input Circuits

Figure 11 shows that the TRVM has both FUNCTION and

RANGE switches. The settings of these two switches deter-
mine the type of measurement made and the amount of input
signal required to obtain full scale meter deflection.

*   *   *

29. The function and range switches of the transistorized meter
     of Figure 11 have (a) an opposite, (b) the same electrical
     purpose as the function and range switches of the general
     purpose VTVM.

*   *   *

Figure 14A shows the construction of the range and function
switches. They are multi-position, multi-deck switches.
Figure 14B shows the contact arrangements on the switch
decks, as viewed from the rear of the switch. The range
switch deck is on the left, and the function switch deck is
on the right. Each terminal is labeled as to its operation.

The range switch is a two section, five position switch. As
shown in Figure 14B, it has two terminals, 6 and 12, which
ride continuously on the rotating contacts. These points are
labeled COMMON in Figure 14B. The function switch is a
two section, six position switch. Its common points are
terminals 5A and 11A. Each rotating contactor has an ex-
tended point or tab which connects to stationary contact
points around the switch deck as the shaft is rotated. These
tabs connect the different circuits to the amplifier and meter
movement.

For simplicity, the rotating contacts of the function and
range switches are represented by the short lines with
arrows at their ends in Figure 12. The stationary contacts
are the small numbered circles. The labeling of each con-
trol is as follows: the first letter refers to control opera-
tion, F for FUNCTION or R for RANGE switch; the second
letter refers to the deck; while the number refers to the
terminal.

A simplified drawing of the dc input circuit of the TRVM is shown in Figure 15. The range and function switches are in the same position as shown in Figure 12. This partial circuit is basically the same for both +DC and −DC function switch settings. To understand the switching actions of the function and range switches in the input circuits, let's trace
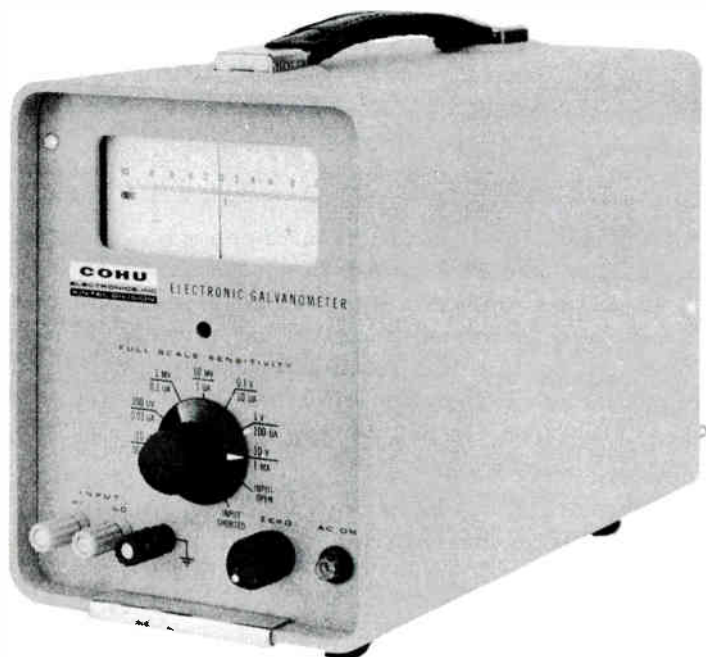
A fully transistorized electronic galvanometer. The transistors are used to provide good stability, accuracy, ruggedness, and dependability.

Courtesy Cohu Electronics, Inc.
Kin Tel Division

out the input circuits for different function and range switch settings.

Figure 15 shows the function switch set at +DC and the range switch set at ×1. The −DC function switch setting is shown by the dashed lines at FB_3 and FC_3 of Figure 13A and FA_9 and FB_9 of Figure 15. In Figure 15, the meter is

being used to measure the cathode-to-ground voltage of a vacuum tube amplifier. The voltage under test is applied to J_1 and J_2 so that J_1 is more positive than J_2. With this range switch setting, the dc input is applied directly to resistors R_3 and R_4 between the input jacks and the transistors.

Now let us consider other settings of the range switch. When the range switch is set at $\times 10$, R_1 is connected into the input circuit in series with R_3 and R_4 across input jacks J_1 to J_2. The dc test voltage divides between R_1, R_3 and R_4. The voltage across R_4 is the signal applied to the transistors.

Resistors R_{19} and R_1 are connected across the meter input when the range switch is set at $\times 100$. The series combination of R_3 and R_4 is in parallel with R_{19}, so the voltage across R_{19} is the dc signal for resistors R_3 and R_4. Again, the voltage across R_4 is applied to the transistors.

When the range switch is set at $\times 1000$, R_1 and R_{18} are connected into the dc input circuit. This circuit operates in the same manner as the $\times 100$ setting, except that R_{18} instead of R_{19} is in parallel with the series conduction of R_3 and R_4. Each range switch resistor has a 1% tolerance, so the voltage readings are very accurate for any range switch setting.

*   *   *

30. Why is the signal applied to the transistor circuits made smaller when the TRVM is switched from the X1 range to the X10 range?

*   *   *

A dc signal must be applied to the transistor base circuit regardless of the type of measurement being made. Therefore, to measure an ac test voltage the input circuits must have some means of changing the ac voltage to dc. To do this, a rectifier is connected in the input circuits. When an

ac voltage is applied to the input jacks the rectifier circuit produces a dc voltage which is effectively equal to the peak value of ac.

*   *   *

31. The TRVM, like the VTVM, effectively measures a dc voltage proportional to the peak value of an ac test voltage that is applied at the proper meter input jacks. True or False?

*   *   *

Figure 16 shows a simplified diagram of the ac input circuit for the TRVM of Figure 12.   Assume an ac voltage is being measured. With the function switch set at AC and the range switch set at $\times 10$, the ac voltage being measured is applied to input jacks J_1 and J_2. Capacitor C_1 has low reactance at most frequencies, so the ac test voltage appears across R_{14}, R_{15}, R_{16} and R_{17}.   These resistors act as a voltage divider, reducing the ac voltage applied to the rectifier circuit.

Diode D_1 conducts when the input signal makes J_2 positive with respect to J_1.   Current flows from J_1 through C_1 and R_{14} to the range switch.   It then flows through the range switch (RA_3 and RA_6), C_2, D_1, the function switch (FC_{10} and FC_{11A}), and then to J_2. The circuit is completed through the leads to the source being measured. When D_1 conducts, its resistance is low.   This allows C_2 to charge to the approximate peak value of the ac voltage appearing between contacts RA_6 and FC_{10}. The polarity of this charge is shown in Figure 16. Capacitor C_2 has a high-resistance discharge path when D_1 is not conducting, so it remains almost completely charged. Because of this, D_1 conducts very slightly after the first few negative alternations of the ac input signal.

For all practical purposes, you can consider D_1 out of the circuit when J_1 is more positive than J_2. The positive signal at J_1 adds to the charge of C_2. Thus, a positive dc voltage appears at the junction of C_2 and D_1. This dc voltage is

applied through the function switch (FA_{10}, FA_{11A}, FB_{11A} and FB_{10}) to resistors R_2, R_3 and R_4. The voltage across R_4 causes current to flow in the transistor base circuits. Capacitor C_3 acts to filter the pulsations in the dc voltage.

*   *   *

32. When the TRVM is used to measure a test voltage, capacitor C_3 in Figure 12 acts as a (a) coupling capacitor, (b) filter capacitor to remove the ripple in the rectified signal.

*   *   *

To measure resistance, the TRVM function switch is set at OHMS. With this meter set to measure resistance, a 1.5 volt C cell is connected into the meter input circuit. Depending on the range switch setting, the C cell is connected to one of the resistors, R_{20} to R_{23}, on deck B of the range switch. These resistors are connected into the input circuits for different ranges of resistance measurements.

Figure 17 shows a simplified diagram of the ohms input circuit for the TRVM of Figure 12. Assume you are measuring an unknown resistance and the range switch is set at ×10. When the unknown resistance R_X is connected between input jacks J_1 and J_2, a complete circuit is formed and current flows from the negative terminal of the 1.5 volt C cell through R_X and R_{22} to the positive terminal of the cell. Part of the C cell voltage is across R_X, and the rest is across R_{22}. The voltage across R_{22} causes current to flow through resistors R_4 and R_3 and through P_1, the ohms adjust control. In turn, the voltage across R_4 causes current to flow through R_5 and the transistor amplifier.

The amount of pointer deflection depends on the current flowing in the unknown resistance R_X and the range resistor. If the unknown resistance is small compared to the ohms range resistor, the largest portion of the voltage is across the range resistor. This results in more signal to the amplifier and more current through the meter movement. This

causes a large deflection of the meter pointer. If the un-known resistance is large, there is only a small portion of the voltage across the ohms range resistor, and the meter pointer does not deflect as far.

*   *   *

33. What is the operating principle behind the resistance meas-uring circuit of the TRVM?

*   *   *

The general purpose TRVM of Figure 12 measures direct current in the microampere range without special equipment. For example, the TRVM can be used to measure the base, emitter or collector current of a transistor amplifier in a radio receiver. The TRVM does this by measuring the small voltage drop across low-resistance, high-precision resistors placed in SERIES with a test circuit. Current from the test circuit passing through one of these precision resistors causes a small voltage to appear across it. These special resistors are in the meter and are selected by the range switch.

*   *   *

34. How does the TRVM measure direct current?

*   *   *

To measure current, the function switch is set at μa. In this function switch setting, one of the resistors of deck B on the range switch (R_{24} to R_{27}) is connected into the input circuits. The selection of one of these resistors depends on the setting of the range switch. For proper meter pointer deflection, input jack J_2 must be connected to a less positive point than input jack J_1. There is a complete current path from J_2 through one of the current range resistors to J_1 and the circuit being tested. Resistor R_{27} is in the input circuit for the range switch setting of $\times 1$, while R_{26} is connected

for the ×10 setting, R_{25} is connected for the ×100 setting, and R_{24} is connected for the ×1000 setting.

Figure 18 shows a simplified TRVM dc current input circuit with the function switch set at μa and the range switch set at ×10. Assume the test leads are inserted in series with the collector circuit of a transistor for a collector current measurement. The dc current range resistors are in series with the circuit under test. Test circuit current flows from J_2 through R_{26}, the range switch (RB_9 and RB_{12}), and the function switch (FB_{12}, FB_{11A} and FA_{12}) to J_1, and back to the test circuit.

This transistorized voltmeter operates from a self-contained battery pack. It is ideal for ac voltage measurements in laboratory and production work.

Courtesy Hewlett-Packard Co.

The voltage across R_{26} is the signal applied to the transistor base circuits. This signal is positive at the junction of function switch terminal FB_{12} and resistor R_4, and is applied through R_4 and R_5 to the transistor base circuits. The resulting transistor base current is amplified and causes the meter pointer to deflect.

*   *   *

35. If you want to measure the collector current of a transistor, you should use (a) the vacuum tube voltmeter of Figure 4, (b) the transistorized multimeter of Figure 11.

*   *   *

Operating the Meter

The complete TRVM circuit of Figure 12 is contained in a compact case for easy handling and portability. The external appearance of any commercial meter depends on the

manufacturer's desires. The controls may be located in different positions and they may differ in size and shape.

Figure 11 shows the control panel for the TRVM described in this lesson. The meter movement is mounted on the left side of the control panel. The function switch, range switch, zero adjust control, and ohms adjust control are mounted concentrically to the right of the meter movement. This means that two controls are mounted one over the other. The shaft of one control is hollow and the other control shaft extends through it so either shaft may be turned without turning the other. This is illustrated in Figure 14. Concentrically mounted controls reduce panel size and group the controls conveniently.

The ohms adjust control is mounted concentrically with the range switch and extends through the range switch shaft. The ohms adjust control varies the pointer position at the right side of the meter scale when resistances are measured. It is adjusted to make the pointer rest over the zero mark at the right end of the OHMS scale when the test prods are touched together (zero resistance). The range switch determines the amount of signal applied to the amplifier and meter movement.   It also serves as the on-off switch.   When the range switch is in its maximum counterclockwise position, the transistor circuits are turned off. At any other setting, the meter is turned on and the input voltage divider is connected to the meter circuits.

The zero adjust control is mounted concentrically with the function switch. This control extends through the function switch shaft.   The zero adjust control varies the pointer position on the left side of the meter scale. Before any measurements are made, the zero adjust knob is adjusted so the pointer rests over zero. The function switch changes the internal meter circuits to allow the meter to measure the +dc or -dc voltage, ac voltage resistance, or dc current.   To measure dc current, the function switch is set at its maximum clockwise position. In the fully counterclockwise setting, the meter can check its own power supply.

The input jacks are located below the concentrically mounted controls. Only one set of input jacks is used in this meter, making it unnecessary to change the test leads to different jack positions with every different type of measurement.

This general purpose TRVM uses different colored meter scales. The color of the labeling at each function switch setting is the same color as the associated meter scale. This feature reduces chances of your reading the wrong scale for a particular measurement.

The TRVM shown in Figure 11 has four scales.   The green OHMS scale at the top begins with 0 on the right and ends with ∞ on the left.   This scale is not linear. The major divisions are spaced closer together on the left side of the scale than on the right.   The DC VOLTS scale is used to measure the +dc and -dc voltages.   It is a black, linear scale. The scale divisions are equally spaced and start at the left with 0 and end at the right with 1.0. The DC μA scale, used to measure dc currents, starts at the left with 0 and ends at the right with 50. A red scale, under the dc current scale, is used to measure ac voltages. This scale is non-linear.   The ac voltage scale extends from 0 at the left to 5 at the right and is labeled AC VOLTS.

A green rectangle on the meter face, labeled BATT ADJ, aids in setting the battery supply voltage. When the function switch is set at BATT and the range switch is in any X position, the meter pointer should deflect to the rectangle of the battery adjust scale.   Adjustment is made by varying the battery adjustment control at the rear of the instrument. When you make this adjustment, the pointer should be positioned at the center of the rectangle.

The TRVM also has controls which are used to calibrate the instrument.   The calibration controls are located inside the rear of the case and are adjusted through holes in the case. Calibration is completed by applying a known signal to the meter inputs and adjusting the associated calibration control until the meter pointer rests over the scale value equal to the

known input. Figure 19 shows the location of these controls.

When the function switch is set for a particular setting, an associated calibration control is placed in series with the meter movement.   These controls are variable resistors

Two models of the same meter are pictured above. The portable model is on the left and the rack mounted model is pictured on the right. Typical uses include measuring the outputs of strain gages, thermocouples, bolometers, phototubes and ionization chambers.

Courtesy Keithley Instruments, Inc.

which adjust the meter pointer setting by changing the resistance offered to the current flowing through the meter movement.   The electrical connections of the calibration control are shown in Figures 12 and 13A. An alignment tool or a narrow-bladed screw driver can be used to adjust the calibration controls.

*   *   *

36. How do the calibration controls change the deflection of a meter pointer?

*   *   *

When compensating for changes in battery voltage, it is not necessary to apply an external signal to the meter input. By turning the function switch to BATT, the dc voltage at the battery adjust control, P_3, is applied to the transistors. Figure 20 shows that this voltage also causes current to flow through R_{28}, a 7870 ohm resistor, and the meter movement. Since the meter movement requires 1 ma for full scale deflection, .5 ma through the movement causes half scale deflection. Multiplying 7870 ohms by .5 ma, we find that 3.935 volts (approximately 4 volts) produces half scale deflection. Deflection to the green area of the meter face (BATT ADJ) corresponds to this voltage. Therefore, the calibration control should be adjusted until the meter pointer rests at mid scale in the green area.

SPECIALIZED ELECTRONIC METERS

Most general purpose meters measure ac and dc voltages, resistance, and in some cases dc current. These meters handle most of the common measurements. However, there are times when a specialized meter may be required for measurements beyond the range of a general purpose VTVM or TRVM.

*   *   *

37. Why is it sometimes necessary to use a specialized electronic meter instead of the general purpose VTVM or TRVM?

*   *   *

Specialized electronic meters are similar in their basic operation to the general purpose electronic meters and can be divided into the same sections shown in Figure 1B. These meters use amplifiers, rectifiers, and other circuits to develop a meter deflection proportional to the measured input signal.

THE AUDIO VOLTMETER

The AUDIO VOLTMETER, also called an AC VTVM, gen-

erally uses audio amplifier stages in place of the dc amplifier stages usually found in the general purpose VTVM. The reason for this is to get a relatively large amount of gain from just a few amplifier stages. It is not uncommon to find audio voltmeters which have a full scale deflection of several hundredths of a volt on the lowest range. Another advantage of the meter is its flat response to signal frequencies as high as 600 kHz.

Figure 21 shows the front panel of a typical audio voltmeter. The schematic diagram of the meter circuit is shown in Figure 22. The amplifier section consists of a two stage ac amplifier, V_{1A} and V_{1B}. In operation, the measured ac voltage is passed from the input circuits to the grid of V_{1A}. The amplified ac signal is coupled from the plate of V_{1A} through capacitor C_2 to the grid of V_{1B}. Tube V_{1B} amplifies the test signal even more. The fully amplified signal is coupled by C_3 and R_{15} to the rectifier and meter movement. Resistor R_{15} is a current limiting resistor which protects the meter movement.

*   *   *

38. The amplifier section of Figure 22 consists of a (a) dc balanced amplifier, (b) dc differential amplifier, (c) two stage audio amplifier.

*   *   *

Diodes D_1, D_2, D_3 and D_4 of Figure 22 form a bridge rectifier. When the upper end of the bridge is positive, electrons flow from the negative end of the bridge through D_4, the meter movement (negative to positive), through D_1 to the upper end of the bridge. When the test signal reverses polarity, electrons flow through D_2, the meter movement, and D_3 to the bottom end of the bridge. In this way the amplified ac test voltage is rectified so that current passes through the meter movement from negative to positive on either alternation of ac test voltage.

Part of the amplified ac signal is fed back to resistor R_{11} in the cathode circuit of V_{1A} by a direct connection to the bottom of the rectifier bridge. This is called a **NEGATIVE FEEDBACK LOOP.** The feedback loop stabilizes the amplifier and improves the frequency response. The feedback loop causes a reduction in overall gain of the amplifier, but the advantages of stability and frequency response overshadow the slight loss in gain.

Resistor R_{11} is constructed of high quality material so that its resistance value remains relatively constant. This resistor is adjustable, and the accuracy and sensitivity of the audio meter depends on its setting. Because of its high quality, this resistor can be adjusted and set, once and for all, at the factory or in your shop.
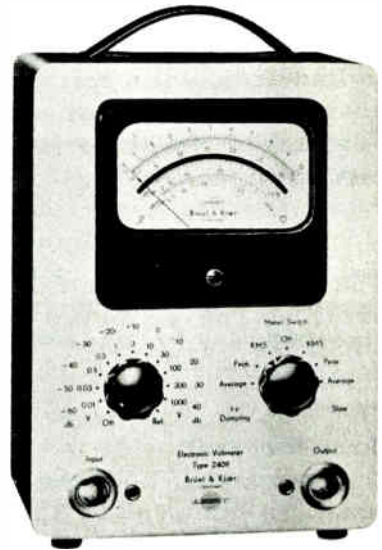
This audio voltmeter has a frequency response from 2 to 200,000 Hz. This meter has linear voltage scales which minimize error in scale reading and allow direct readings in db for convenient measurements.

Courtesy Bruel and Kjaer Instruments, Inc.

Shown in the lower portion of Figure 22, the audio voltmeter power supply consists of a full wave rectifier (D_5 and D_6) and filter (capacitors C_{4A} and C_{4B} and resistors R_{16} and R_{17}). To stabilize the power supply output, gas diode V_2 is added to the output of the filter network.

The gas diode is used as a voltage regulator. When the gas inside the tube ionizes, the voltage drop across the diode remains constant even when the current through it changes. In this way, the voltage at the output of the power supply remains the same even when different values of current are needed by the other meter circuits.

Because the audio voltmeter is only required to measure ac

voltages, it does not require the elaborate switching circuits found in the input of a general purpose VTVM or TRVM. The input circuit in Figure 22 includes input jacks J_1 and J_2, coupling capacitor C_1, range resistors R_1 through R_9, and range switch S_1.

The ac test signal is applied to input jacks J_1 and J_2. Input capacitor C_1 blocks any dc voltage and passes the ac test signal. C_1 has a low reactance for a wide range of frequencies. From C_1, the test signal is applied to the range resistors. A portion of the test signal is passed from the range resistors to the grid of V_{1A}. The portion of the test signal applied to the grid of V_{1A} depends on the setting of the range switch.

The audio voltmeter is used in the same manner as the general purpose VTVM or TRVM. To measure the voltage across a component, the range switch is set to a suitable range, and the meter test leads are placed across the component. The ac voltage is then read from the meter scale in the usual manner.

Because of its voltage range, often from .001 volt to about 300 volts, this type of meter can be used to determine the voltage gain of an amplifier stage. This can be done by measuring and comparing the input and output voltages of that stage. Meters of this type can also be used to determine the amount of ac voltage appearing in the output of a dc power supply. Its sensitivity allows this meter to be used in audio design work, maintenance, installation, or whereever low ac voltages are to be measured.

*   *   *

39. In most cases, what type of electronic meter would you use
     to measure the gain of a voltage amplifier in a stereo phono-
     graph system?

*   *   *

ACCESSORY EQUIPMENT

Almost all electronic meters can be adapted to use different accessories. The most common are cable assemblies, probes, and shunts. Cable assemblies come in many different lengths and have many types and combinations of terminal devices (for example, banana plugs or alligator clips). For working in high frequency circuits, the cable assemblies are shielded. Probes are devices which can be added to the meter inputs to extend the normal operating range.

Figure 23A shows the simplest meter probe, the resistance probe. Resistance probes can be used to extend the voltage range of a voltmeter. To extend the range of an electronic meter that has an input impedance of 10 megohms by a factor of 100, a resistance of 990 megohms is used in a test probe. This resistance is connected in series with the input circuit.

Resistances as high as 12,000 megohms may be used in test probes designed for high voltage use. High voltage probes are usually longer than other resistance probes. They are constructed to prevent arcover or flash-over and possible shock to the user. A typical

This r-f voltmeter makes accurate low level radio frequency voltage measurements. Below the meter is a 50 ohm adapter and a high impedance probe which includes a full wave rectifier circuit.

Courtesy Boonton Electronics Corp.

high voltage probe is shown in Figure 23B. Notice the special construction used to insure safety to the user.

Diode probes are used to rectify high frequency signals before they are fed through the cable to the meter input. This prevents signal losses that would occur if the high frequencies

were passed through a long cable. Figure 24 shows a typical diode probe. Here, a solid state diode is used in the test probe. The ac test signal is applied to the probe after the ground clip has been connected to the test circuit. When the signal at the collector or anode is positive, effectively no signal is applied to the meter. When the collector is negative, a signal equal to the voltage from ground to the diode collector is applied to the meter. By using rectifier probes, a dc voltmeter can measure ac voltages. Do not exceed the voltage rating of the probe.

It is possible to extend the current range of the TRVM of Figure 12 by means of external shunt resistors. By means of these shunts, currents up to 5 amperes may safely be measured by the meter. This greatly extends the usefulness of the TRVM. The shunt is placed in parallel with the input circuit. A current shunt is illustrated in Figure 25. In use, the shunt is inserted into the meter jacks and the test leads are connected to the shunt. This automatically places the shunt resistance across the input circuit.

*   *   *

40. What type of probe would you use with a VTVM having a 10 megohm input impedance to measure the voltage (about 15KV dc) of the high voltage rectifier section in a color TV receiver?

*   *   *

SUMMARY

Both electric and electronic meters are used to measure voltage, current and resistance. An electric meter used to measure these quantities loads the test circuit to a certain extent. This loading effect caused by the meter changes the test circuit operation and can result in incorrect measurements. The electronic meter was developed to overcome the disadvantages of loading the circuit under test.

An electronic meter has an amplifier and power supply in addition to the meter movement and input circuits, which

are similar for both types of meters.

The heart of the electric meter is the meter movement, which uses test circuit current to cause the pointer to deflect. In an electronic meter, the current for the meter movement is supplied by the amplifier and power supply sections. The amplifier in an electronic meter increases the meter input impedance, increases meter sensitivity, offers overload protection, and makes it possible to measure a wider range of frequencies than can be measured by an electric meter.

The VTVM and TRVM are multi-purpose meters which measure more than one quantity. A specialized meter, such as an audio voltmeter, is designed to measure one particular quantity.

Many types of accessory equipment are available for use with meters. An important accessory is the meter probe. It contains an element used to isolate the meter from the test circuit, rectify an ac signal, or block a dc signal. Another very important meter accessory is the current shunt. These shunts extend the current ranges of meters such as the TRVM. The shunt places a current dividing resistance in parallel with the input circuit.

IMPORTANT DEFINITIONS

AC VTVM - See AUDIO VOLTMETER.

AUDIO VOLTMETER - An electronic meter used to measure low values of ac voltage in the audio frequency range. Also called an AC VTVM.

BALANCED AMPLIFIER - An amplifier in which the output is taken from two tubes or transistors. In a VTVM, it is an amplifier arranged into a bridge circuit so an equal voltage exists across each branch.

BRIDGE CIRCUIT - A measuring circuit consisting of four arms, with a variable resistance or impedance in one or more of the arms. Any change in the variable element causes the bridge to be unbalanced, and a resultant difference of potential can be used to operate a meter movement.

D'ARSONVAL METER MOVEMENT - [DAHR son vahl] - A type of direct current meter movement in which a light weight wire coil, supported on jewel bearings between the poles of a permanent magnet, is rotated by the effects of an electric current in the coil.

DIFFERENTIAL AMPLIFIER - [dif er EN sh'l] - In a transistorized meter, a circuit whose output signal is proportional to the difference in emitter current flowing through two transistor amplifiers whose no-signal emitter currents cause the meter to read zero.

ELECTRIC METER - A meter that consists simply of a meter movement and the input circuits necessary to measure various electrical quantities.

IMPORTANT DEFINITIONS (Continued)

ELECTRONIC METER - A meter that includes vacuum tube or transistor circuits, with the necessary power supplies, in addition to the meter movement and input circuits of an electric meter.

FUNCTION SWITCH - In a multiple function meter, the switch that selects the proper circuitry for the type of measurement desired.

INPUT IMPEDANCE - In an electronic meter, the total opposition offered to the flow of test circuit current. The combined resistance and reactance of the input circuit and amplifier input.

INPUT RESISTANCE - In an electric meter, the total resistance offered to the flow of test circuit current.

LOADING - The action of a meter using current from the circuit it is measuring.

MULTIPLIER - A resistor connected in series with the meter movement to increase the range of a voltmeter.

RANGE RESISTOR - A general term used to describe a resistor used to increase the range of a meter.

RANGE SWITCH - In a multiple range meter, the switch that selects the resistor or combination of resistors to give the desired range of readings.

SHUNT - A resistance connected in parallel with the meter movement or test circuit to effectively reduce the total resistance and increase the current measuring range.

IMPORTANT DEFINITIONS (Continued)

TRANSISTORIZED METER - An electronic meter which uses a transistor amplifier to provide the current for the meter movement.

VACUUM TUBE VOLTMETER - An electronic meter which uses a vacuum tube amplifier to provide the current for the meter movement.

STUDENT NOTES

STUDENT NOTES

WIRE
COVERING

MULTIPLIER
RESISTANCE
CARTRIDGE

PROBE
TIP

INSULATED
HANDLE

PROBE TIP

A

LEAKAGE BARRIER
INSULATED HANDLE
INSULATION SLEEVE

GROUNDED
FLASHOVER
SHIELD

SHIELDED
CABLE

TEST
INPUT
PLUG

INPUT
GROUND
PLUG

SAFETY GROUND
CLIP

B

FIGURE 23

INSULATED HANDLE

COUPLING CAPACITOR

WIRE
COVERING

TO GROUND
CLIP

SOLID STATE DIODE
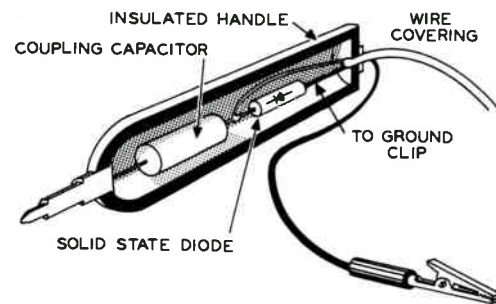
FIGURE 24

FIGURE 25

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question, as illustrated in the example below.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

Example: A fish is

LESSON CODE
2203A

A ☐
B ☐
C ☐
D ■

(A) a bird.   (B) a mineral.   (C) a vegetable.   (D) an animal.

1.
A ☐ B ☐ C ☐ D ☐
The primary advantage of an electronic voltmeter over an electric voltmeter is its ability
(A) to increase loading effects.   (B) to decrease loading effects.   (C) to change, as much as possible, a circuit's operating conditions.   (D) to produce ABSOLUTELY NO change in a circuit's operating conditions.

2.
A ☐ B ☐ C ☐ D ☐
The high input impedance of an electronic meter is supplied by
(A) the function switch.   (B) the input and amplifier sections.   (C) the meter movement.
(D) the power supply.

3.
A ☐ B ☐ C ☐ D ☐
Most general purpose VTVM's measure
(A) dc voltage and ac current.   (B) dc and ac voltages and resistance.   (C) ac voltage and dc current.   (D) ac current and resistance.

4.
A ☐ B ☐ C ☐ D ☐
A typical general purpose VTVM makes use of
(A) a power amplifier.   (B) an ac audio amplifier.   (C) a transistor circuit.   (D) a balanced amplifier.

5.
A ☐ B ☐ C ☐ D ☐
The TRVM of Figure 12 has an advantage over most general purpose VTVM's because it can measure
(A) dc voltage.   (B) ac voltage.   (C) dc current.   (D) resistance.

6.
A ☐ B ☐ C ☐ D ☐
The TRVM of Figure 12 uses
(A) a power amplifier.   (B) a transistor differential amplifier.   (C) a vacuum tube bridge circuit.   (D) an audio amplifier.

7.
A ☐ B ☐ C ☐ D ☐
The meter movement of the TRVM in Figure 12 measures the
(A) sum of the emitter currents of Q_2 and Q_3.   (B) collector currents of Q_1 and Q_4.   (C) difference in the emitter currents of Q_2 and Q_4.   (D) base currents of Q_1 and Q_4.

8.
A ☐ B ☐ C ☐ D ☐
A specialized electronic meter that measures low ac voltage from 20 to 20,000 cps is called
(A) a multimeter.   (B) an audio voltmeter.   (C) an electric meter.   (D) a radio frequency voltmeter.

9.
A ☐ B ☐ C ☐ D ☐
The audio voltmeter of Figure 22 is stabilized by
(A) using a balanced amplifier network.   (B) a negative feedback loop.   (C) varying the range switch.   (D) measuring only dc voltages.

10.
A ☐ B ☐ C ☐ D ☐
The type of accessory equipment which is normally used to extend the VOLTAGE range of an electronic meter is a
(A) diode probe.   (B) special resistor probe.   (C) cable assembly.   (D) meter shunt.

PRACTICE EXERCISE SOLUTIONS

1. electric meters and electronic meters

2. Both use a meter movement and input circuits to extend the range of measurements the meter can make.

3. (b) less -- The electronic meter uses only small current from a test circuit to develop a signal for the meter amplifier.

4. (b) the power supply and amplifier section.

5. True

6. (a) internal resistance

7. True

8. When the same amount of voltage is applied to two branches of a bridge circuit whose branches have equal resistance, the current flowing through these branches will be equal. This is referred to as balance in a bridge circuit.

9. (c) resistor. -- The internal resistance of the tube decreases or increases as the signal drives the grid of V_1 positive or negative.

10. Reference tube V_2 in Figure 3C is used to make up for any change in V_1 tube conduction during warm-up or as the tube ages.

11. The zero adjust control is a variable resistor which is adjusted to make up for any small differences in the resistances of the branches so a zero meter reading can be obtained.

12. The power supply section of the electronic meter, since it furnishes the voltage and current for the operation of the bridge circuit.

13. (b) a balanced bridge circuit. -- The arrangement of the amplifier and meter movement of Figure 5 is similar to the bridge circuit shown in Figure 3C.

14. The voltage at point X becomes more positive than the voltage at point Y.

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FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

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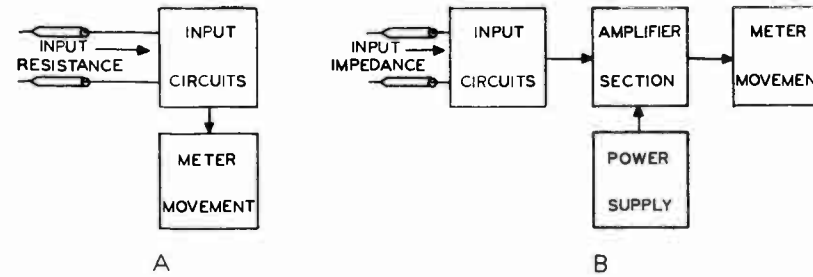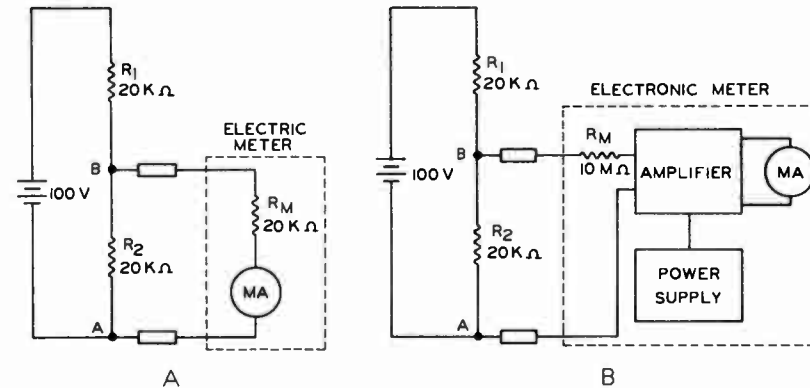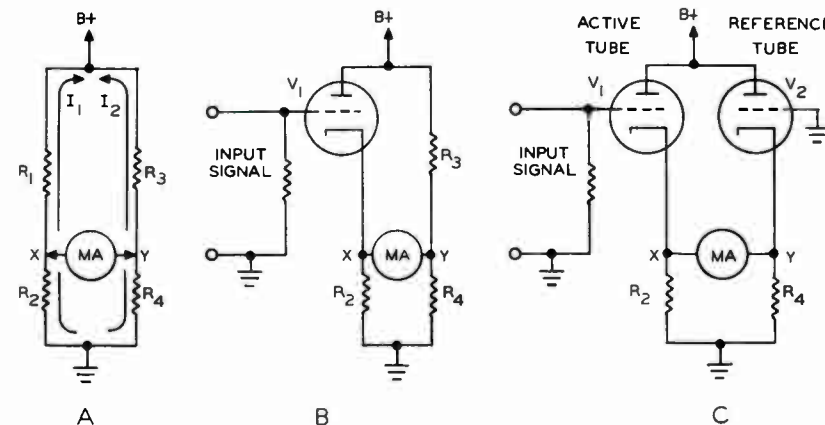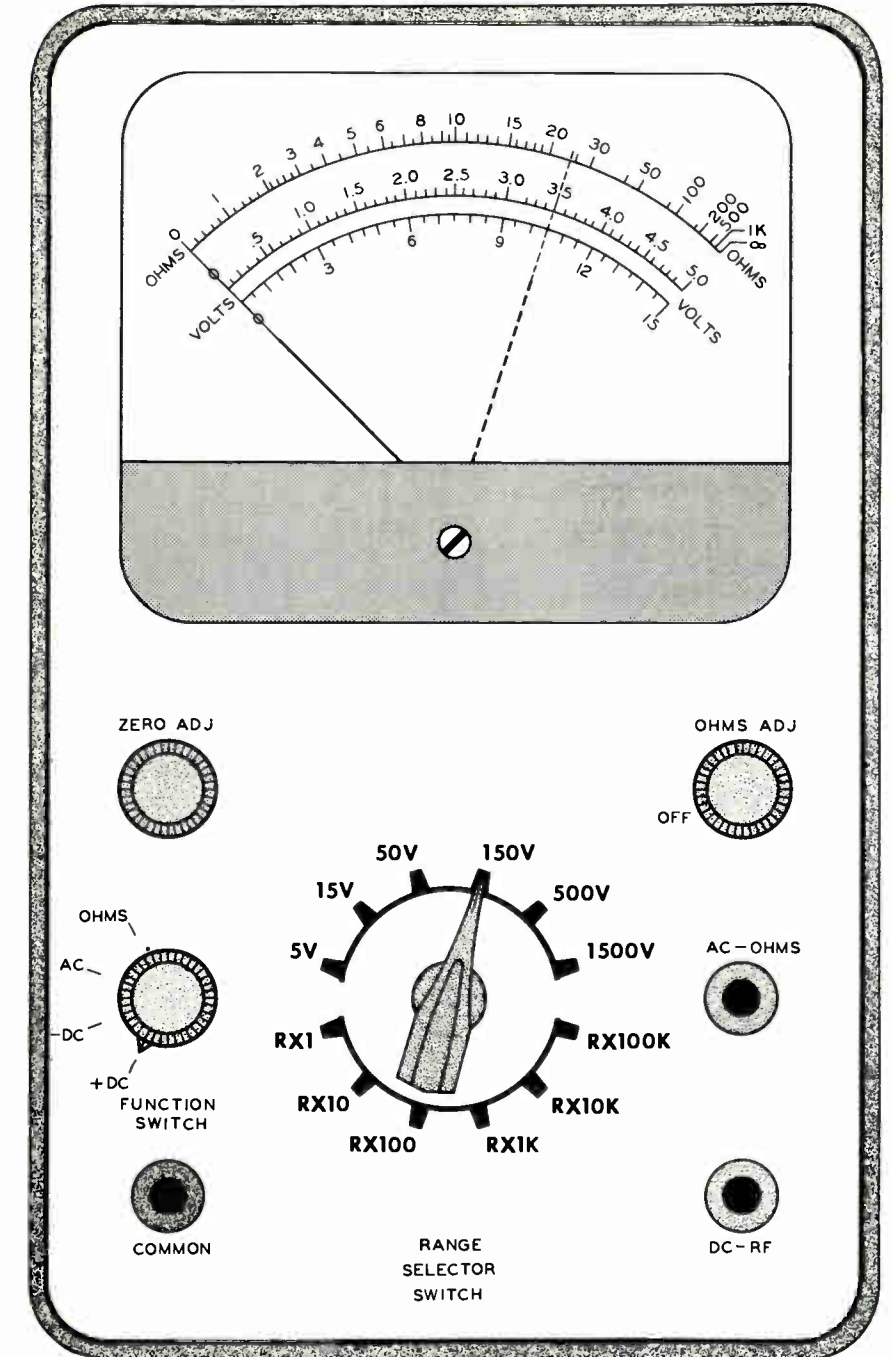
FIGURE 5

PRACTICE EXERCISE SOLUTIONS (Continued)

15. from X to Y -- The voltage at point X of Figure 6A decreases, and the voltage at point Y becomes more positive than the voltage at point X causing current to flow from point X through R_C and R_M to point Y.

16. (a) capacitor C_4. -- The voltage across capacitor C_4 divides between resistors R_{24}, R_{25}, and R_{26}; therefore the total B+ to B- voltage cannot appear across any one of these three resistors.

17. The function switch.

18. Most general purpose VTVM's use dc amplifiers to supply the dc for the meter movement. Therefore, the input circuits must have a rectifier to change the incoming ac test signal into a dc signal.

19. The ac balance control is adjusted so the plate of V_{2A} is set at a slightly more negative potential than the V_{2A} cathode. This prevents the small amount of plate current that might otherwise flow in the tube even when no ac test signal is being measured.

20. The FUNCTION switch should be set at AC and the RANGE switch should be set at 150V in order to measure a 100V ac test voltage.

21. (b) 105 volts. -- Since the function switch is at +DC, you use one of the voltage scales. With the range switch set to 150V, you read the 0-15 scale, and multiply all values by 10. The dashed line pointer is on the 10.5 mark, so the voltage is 10.5 × 10, or 105 volts.

22. True -- A known voltage is applied to the meter input circuits and the corresponding calibration control is adjusted until the meter pointer indicates the known voltage.

23. True -- Because of its low power requirements, the TRVM has self contained batteries which make it more portable than most VTVM's.

24. current -- Both the VTVM and TRVM can measure ac or dc voltage and resistance.
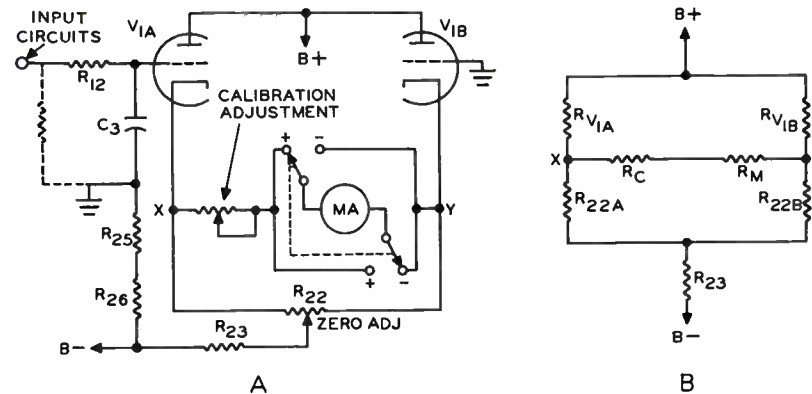
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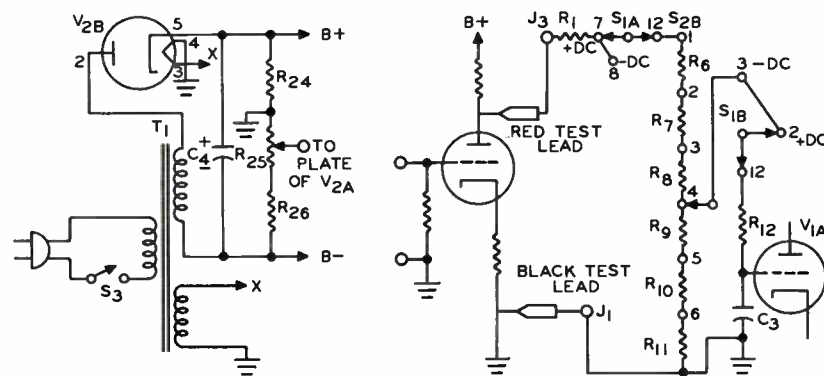
FIGURE 7 FIGURE 8

FIGURE 9

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FIGURE 10

FIGURE 11

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FIGURE 12

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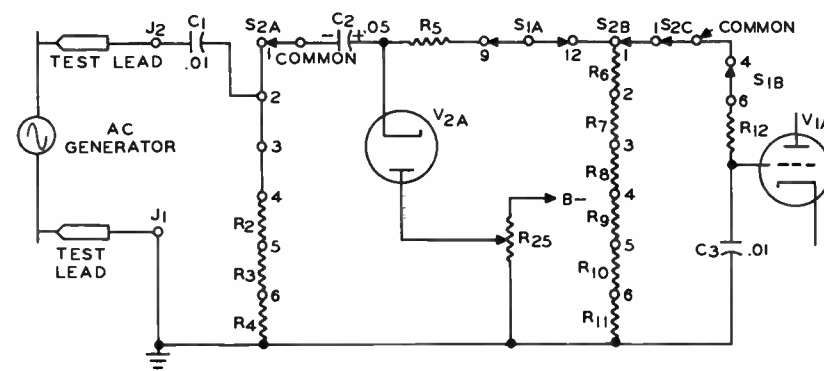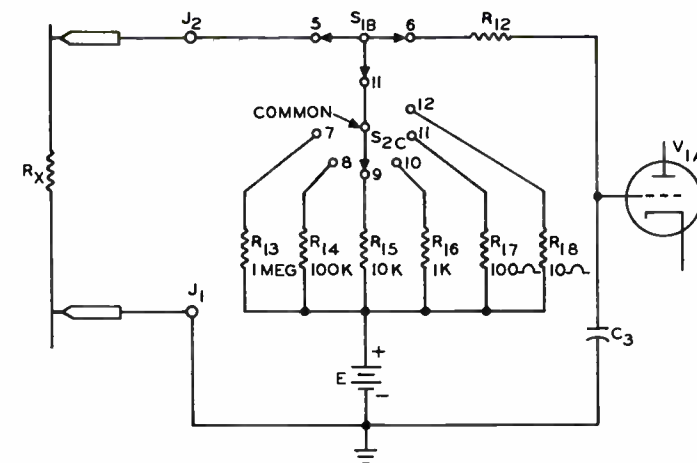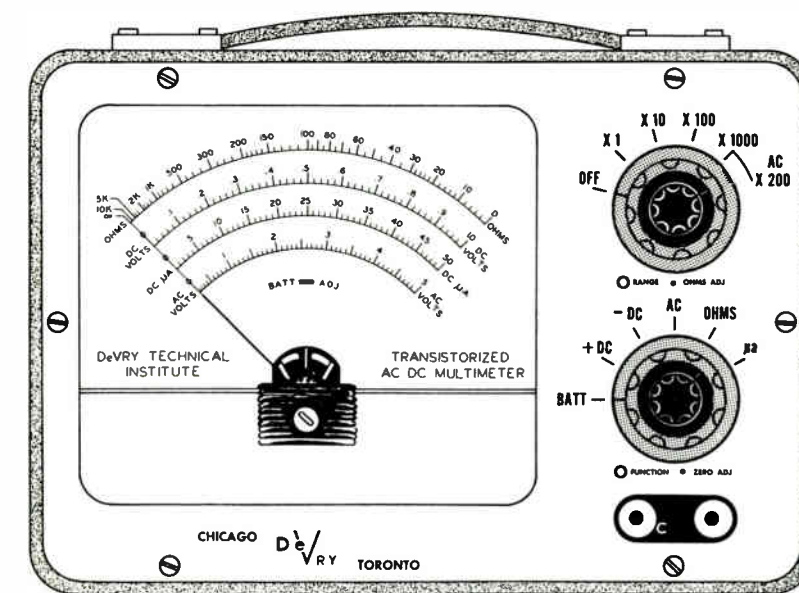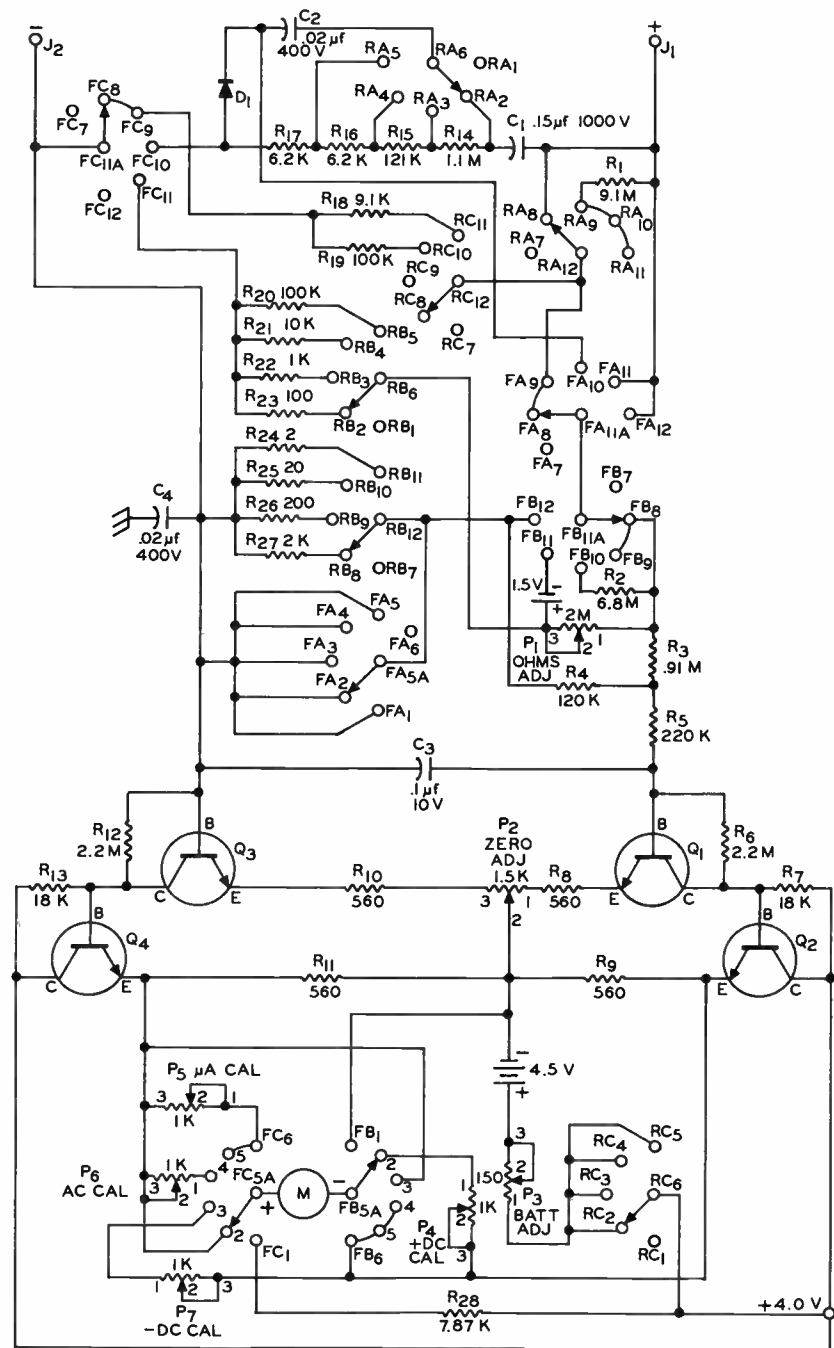
PRACTICE EXERCISE SOLUTIONS (Continued)

25. True -- The base-to-emitter bias on any transistor determines the amount of current flowing through the transistor.

26. No -- Both arms are active. As one arm decreases in value, the other arm increases in value.

27. The setting of P_3 allows greater usable cell life and reduces the number of times the cells must be changed while keeping the collector voltage of each transistor at about 4 volts.

28. There are no tube filaments or other circuit elements that require any warm-up.

29. (b) the same -- The function switch determines what type of measurement can be made by the meter while the range switch determines the magnitude of the measurement.

30. The signal to the transistor circuits is reduced because R_1 is now connected into a series circuit with R_3 and R_4. With an additional resistor in this circuit, the voltage across R_4 is decreased and a smaller signal is passed to the transistors.

31. True

32. (b) filter capacitor

33. The TRVM resistance measuring circuit operates on the basic principle that a voltage divides between two series resistors in proportion to their resistance values. In this case the voltage divides between a known and an unknown resistance, and the voltage across the known resistance is the signal applied to the transistor amplifier.

34. The TRVM measures direct current by measuring the voltage dropped across low-resistance, high-precision resistors placed in series with the circuit being measured. This voltage is proportional to the current through the resistors.

35. (b) the transistorized multimeter of Figure 11. -- The VTVM of Figure 4 can only measure + or - dc voltage, ac voltage, and resistance.
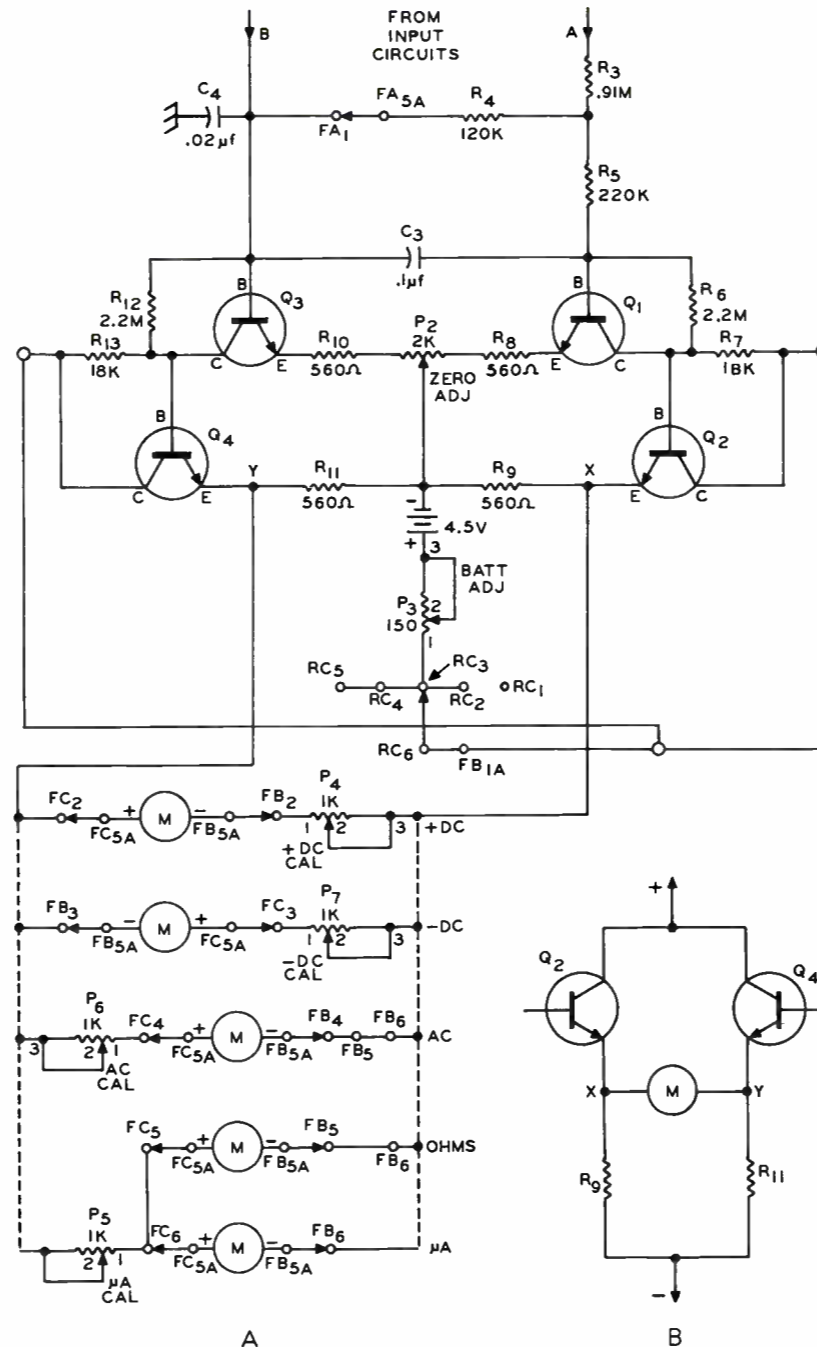
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FIGURE 13

FIGURE 14

FIGURE 15

FIGURE 16

2203
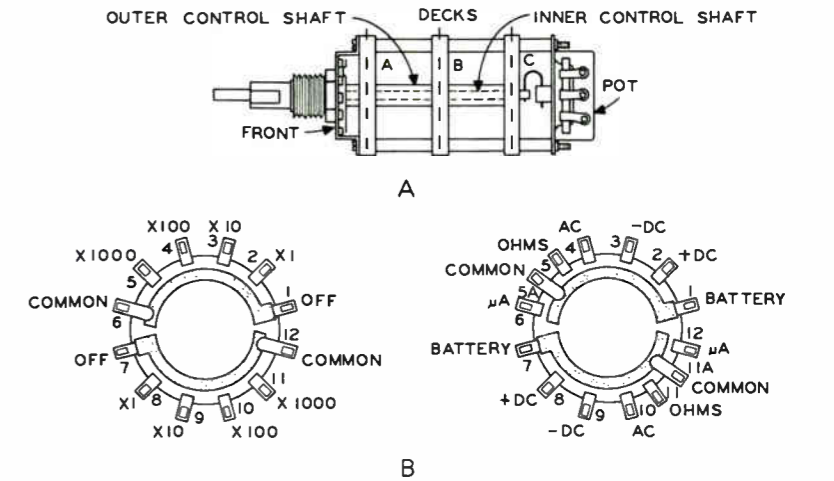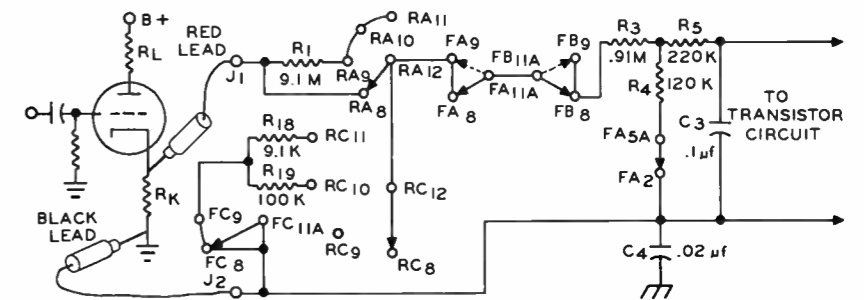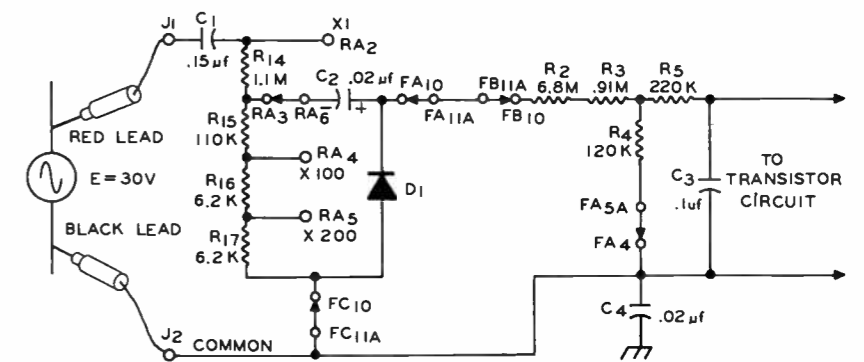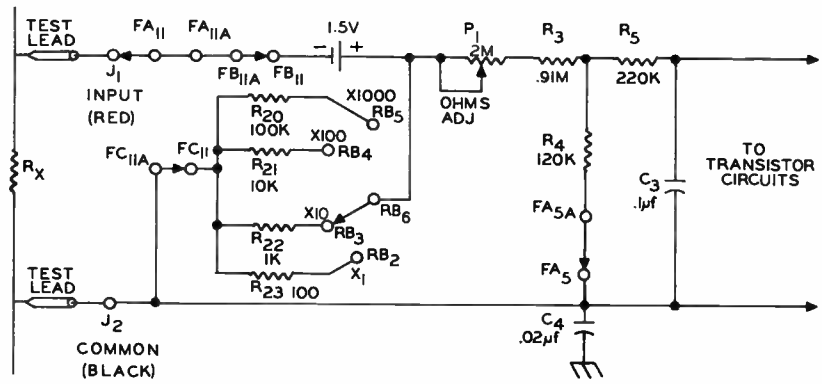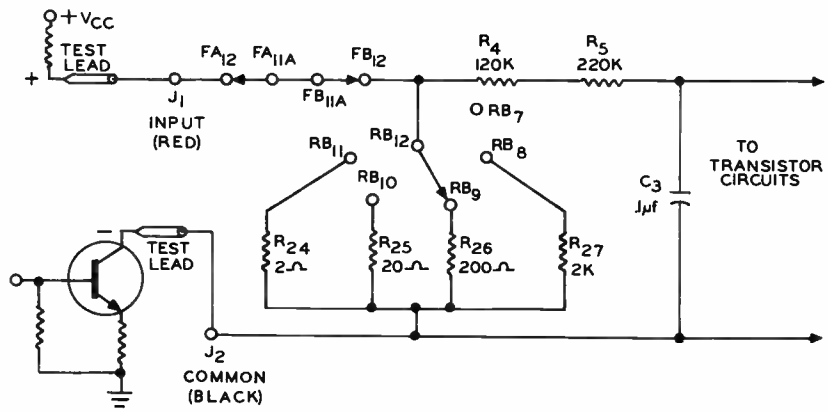
FIGURE 17

FIGURE 18

PRACTICE EXERCISE SOLUTIONS (Continued)

36. The calibration controls are adjusted to change the resistance offered to the flow of current in the meter movement circuit.

37. Specialized meters are used to aid the operator in making measurements beyond the range of a general purpose VTVM or TRVM.

38. (c) two stage audio amplifier.

39. In most cases, an audio voltmeter would be the best electronic meter to use in measuring audio amplifier gain.

40. A high voltage resistance probe should be used. This probe would extend the range of the meter and would protect you because it would not break down or arc over.
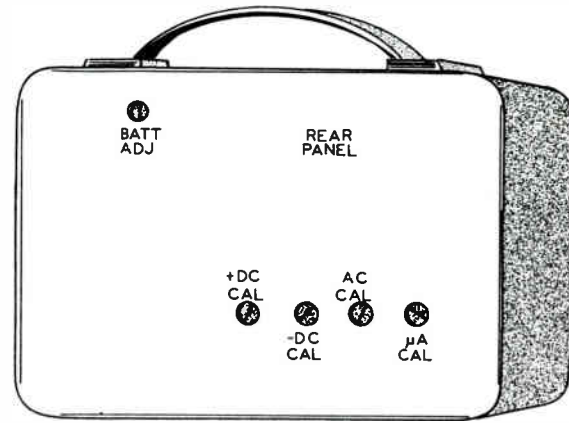
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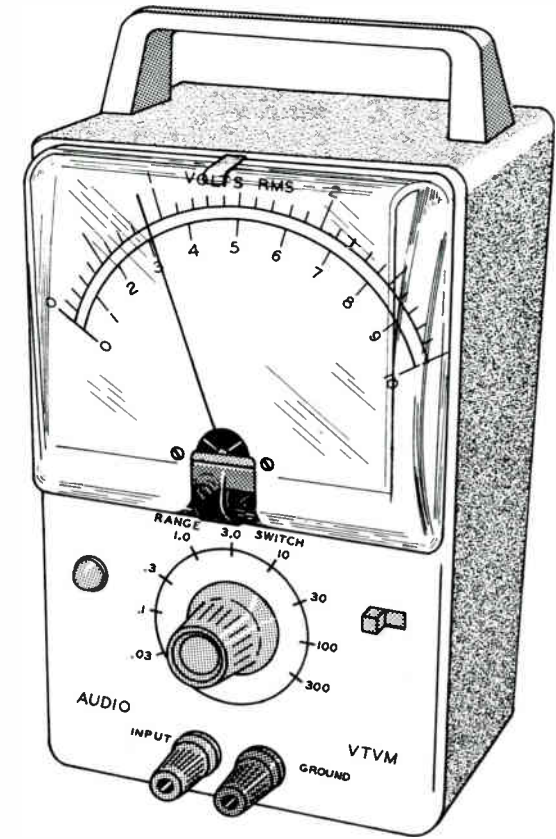
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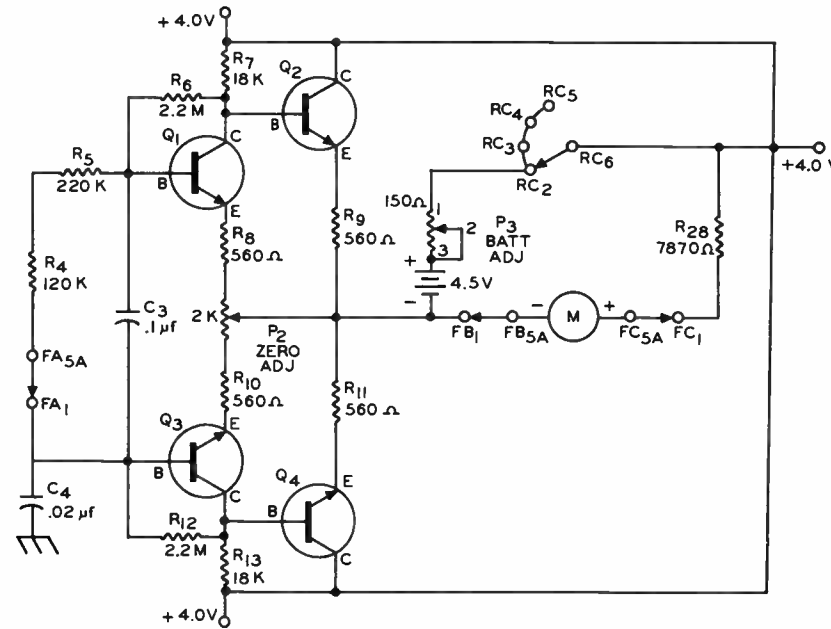
FIGURE 21

AMPLIFIER

J_1 J_2 C_1

R_1 R_2 R_3 R_4 R_5 R_6 R_7 R_8 R_9

S_1
RANGE SW

INPUT CIRCUITS

V_{1A} C_2 V_{1B} C_3 R_{15}

D_1 D_2

MA

D_3 D_4

R_{13} X Y

R_{10} CALIBRATE R_{11} R_{12} R_{14}

METER
MOVEMENT
AND RECTIFIER

TO 117 AC T_1 D_5 R_{16} R_{17} R_{18}

S_2 C_5 D_6 C_{4A} C_{4B}

C_6 Y V_2

R_{19} PL_1

F_1 R_{20} X

POWER SUPPLY

FIGURE 22

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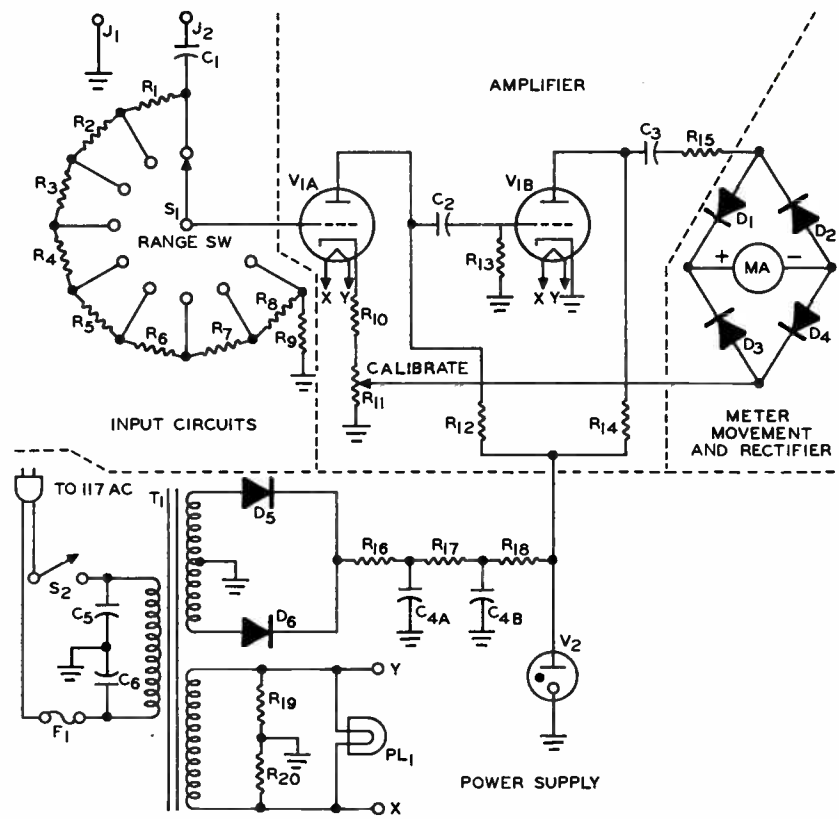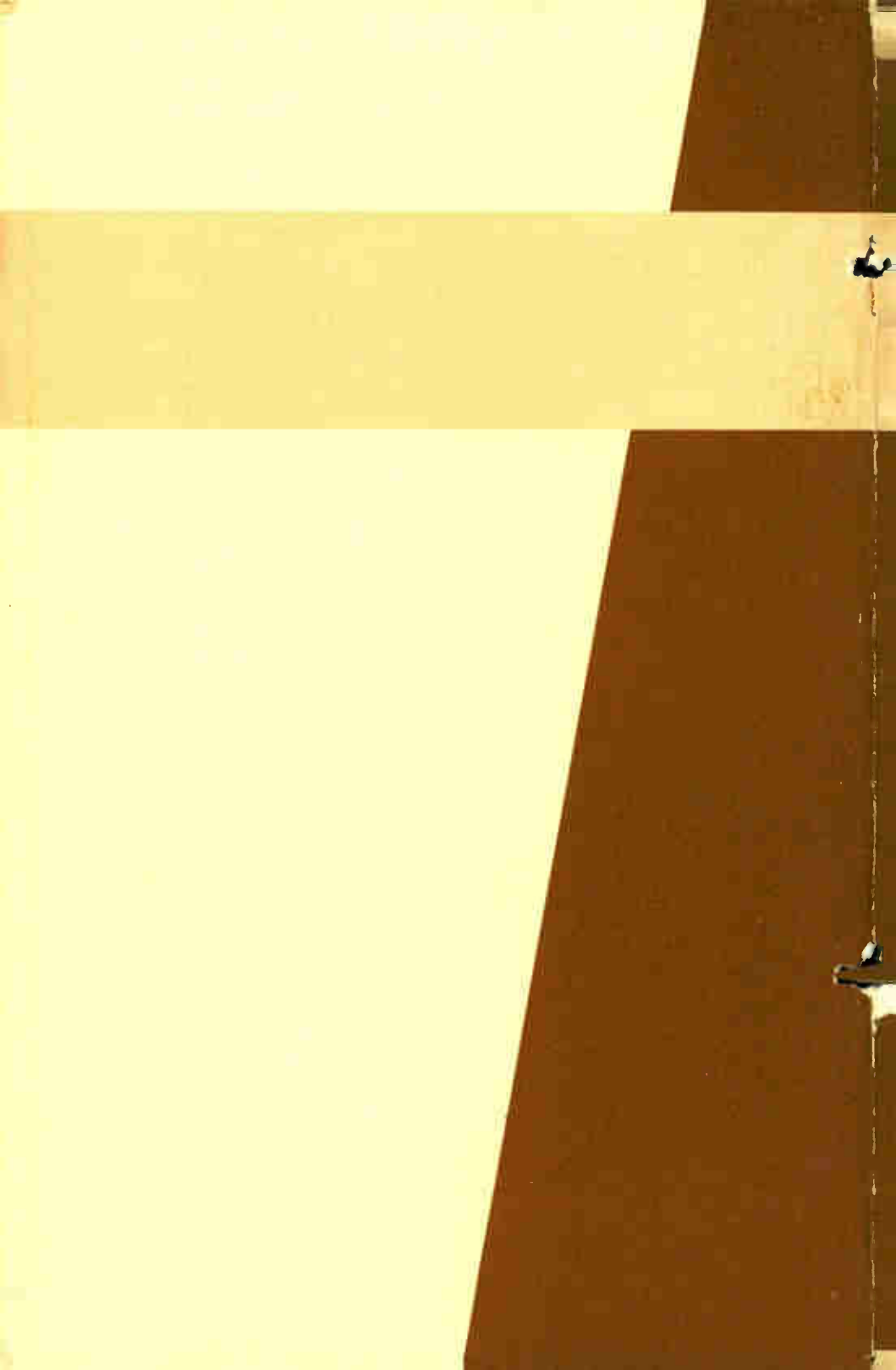
VOLTAGE, CURRENT
AND RESISTANCE

Lesson 1012A

DeVRY Technical Institute

CHICAGO   TORONTO

MAKE YOUR OWN BREAKS

Breaks are nothing more than captured opportunities. If opportunity comes our way, we have the choice of taking full advantage of it. If it goes the other way, we still have the choice of creating a new opportunity.

A perfect example was the immortal Paderewski, who aspired to become a great pianist. He practiced at the piano until his fingers bled. He became a mighty genius, the man he aspired to be, not because of the "breaks" but because he had a purpose and applied himself to that end with every ounce of energy he had.

Men become great as a result of effort—not through gifts of heritage.

—Texas Outlook

VOLTAGE, CURRENT
AND RESISTANCE

Revised 1966

OPPORTUNITY
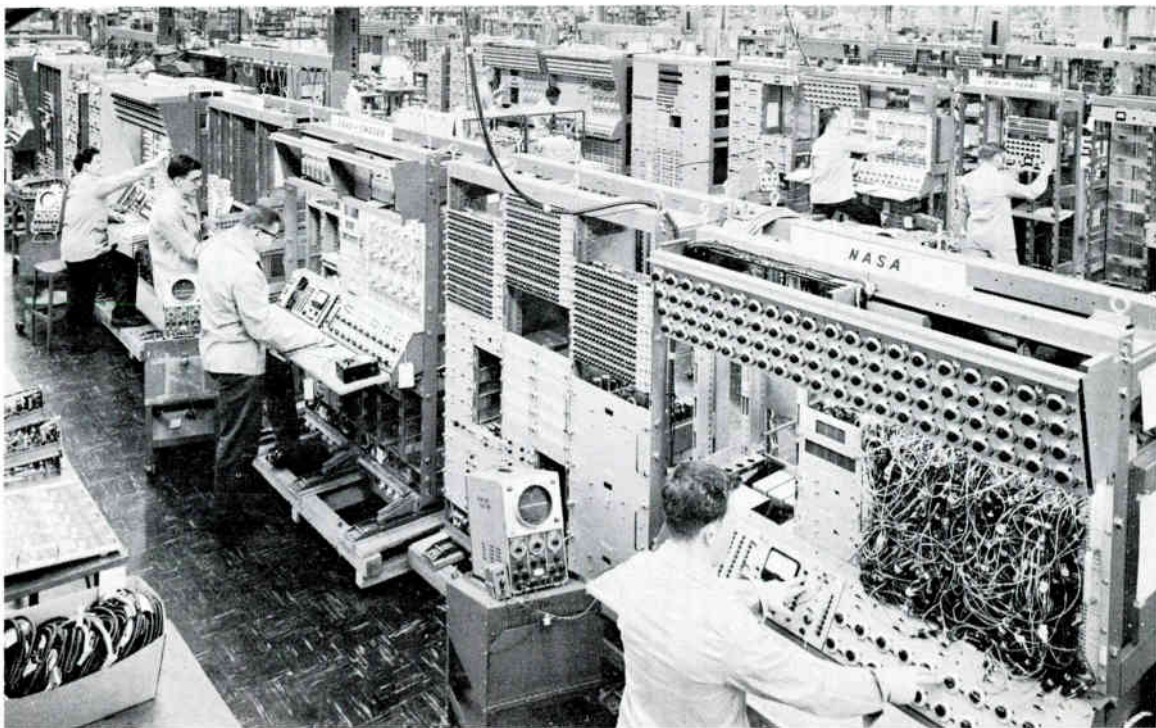
Analog computers are thoroughly tested to be certain that all circuits are operating properly. Voltage and current measurements give accurate indications of circuit operation.

Courtesy Electronic Associates, Inc.

VOLTAGE, CURRENT AND RESISTANCE

CONTENTS

***

Three things are good in little measure
and evil in large; yeast, salt and hesi-
tation.

--Talmud

VOLTAGE, CURRENT
AND RESISTANCE

The key to working with electricity and electronics is the ability to identify the basic electric properties, and to determine how these properties are related to each other. In the very early days of electricity, experimenters found they could predict how the current would be affected if the voltage or resistance was changed. This was an important milestone because present day electricity and electronics rely greatly on these same relationships.

Another important factor in the progress of electronics has been the use of standard units. In the early days of electrical experimentation, before basic units were used, standard measurements were impossible. There was no way for an experimenter to describe exactly what happened when he tried some change in the circuit. Today, we can measure the voltage, current and resistance in standard units, and we can study these values to learn just what is going on in the circuit. Every new circuit involves predictions based on these same quantities and their effects.

STANDARD UNITS

The standard units are named in honor of the men who have contributed so much to the progress of electronics. The unit of current, or rate of electron flow, is the AMPERE. This unit is named in honor of the French physicist, Andre Ampere, who discovered certain relationships between electricity and magnetism. The unit of electric pressure, or voltage, is the VOLT. This unit is named after Allesandro Volta, an Italian physicist, who is credited with developing the voltaic cell, or battery. The unit of resistance, or opposition to electron flow, is the OHM, named for Dr. Ohm, the German scientist who discovered the

relationships between voltage, current and resistance.

* * *

1. Current, or rate of electron flow, is measured in (a) volts, (b) amperes, (c) ohms, (d) circular mils.

2. Voltage, or electric pressure, is measured in (a) volts, (b) amperes, (c) ohms, (d) circular mils.

3. Resistance, or opposition to current, is measured in (a) volts, (b) amperes, (c) ohms, (d) circular mils.

* * *

The properties represented by these three units are related. Therefore, a convenient way to identify the standard units for voltage, current and resistance is to compare them to each other.

VOLT - the electric pressure required to produce one ampere of current in a circuit having one ohm of resistance.

AMPERE - the current that exists when a pressure of one volt is applied to a circuit having a resistance of one ohm.

OHM - the resistance required to limit the current to one ampere when a pressure of one volt is applied.

* * *

4. An electric pressure of one __volt__ causes a current of one __Ampere__ in a complete circuit which has a resistance of one __Ohm__ .

* * *

To help us in the measurement of electric quantities,

several instruments are employed. One of these is the
VOLTMETER, which measures the electric pressure (emf)
or potential difference between any two points in a circuit.
The use of the voltmeter is quite simple, requiring only
two connections between the voltmeter and the circuit.

Suppose, for example, that you wish to investigate a circuit
consisting of a battery as the
voltage source and a resistor
as the load. Figure 1A shows
one way in which the two com-
ponents can be connected.
Rather than connect the resis-
tor directly across the battery
terminals, the two resistor
leads are connected to sepa-
rate tie points. Lengths of
hook-up wire are then connec-
ted from the battery terminals
to the tie points. In practically
all electronic equipment, the
resistors and other compo-
nents are physically attached
to some sort of tie points.
Wire is then connected be-
tween the various tie points

Meters such as this dc voltmeter are used by
technicians in all fields of electronics to make
voltage measurements.

Courtesy Daystram, Inc.,
Weston Instruments Div.

to complete the circuit. Where permanent connections are
desired, the tie points are soldered.

For convenience, the circuit of Figure 1A is represented
by the schematic diagram of Figure 1B. Here, we have
also indicated the direction of current (by the arrows) and
the polarity of the voltage across the resistor (by the plus
and minus signs).

A resistor has no polarity of its own. However, when we
connect a resistor into a circuit, the current through it
produces a voltage across the resistor. The direction of
the current through the resistor determines the polarity of
the voltage across the resistor. The end of the resistor

which the electron current enters is negative; the end which the current leaves is positive.

To measure the voltage across the resistor, a voltmeter is connected across the resistor as shown in Figure 2A. Notice that the positive terminal of the voltmeter is connected to the positive end of the resistor, and the negative terminal of the voltmeter is connected to the negative end of the resistor.

*   *   *

5.   The polarity of the voltage across a resistor is determined by the direction of the _current_ through the resistor.

*   *   *

Figure 2A is represented by the schematic diagram of Figure 2B. Here, current is from the negative battery terminal to the lower end of the resistor, up through the resistor and over to the positive battery terminal. The current through the resistor causes a voltage across it which has the polarity indicated. The voltmeter is connected directly across the resistor, with the polarity indicated.

Notice that the circuit of Figure 2B is identical to the circuit of Figure 1B. The addition of the voltmeter in Figure 2B does not affect the basic operation of the circuit, and the voltmeter can be removed without changing the basic circuit action.

Notice, also, in Figures 2A and 2B that the only separations between the voltmeter leads and the battery terminals are two lengths of wire. Electrically, then, the voltmeter is connected across the battery as well as across the resistor, and indicates that the same voltage is across both components. This is the case when a single voltage source is connected into a circuit with a single load -- the voltage across the load is the source voltage.

*   *   *

6.   In a complete circuit, such as Figure 2B, what instrument
      would you use to measure the electromotive force (emf) of
      the source?   *Volt meter*

*   *   *

Another very useful instrument is the AMMETER, which
measures the electric current in a circuit. The ammeter
is also very simple to use, as only two connections are
required between it and the circuit. However, the method
of connecting the ammeter is different than the method of
connecting the voltmeter.

To measure the current in the circuit of Figure 1, an am-

meter is connected so the
circuit appears as in Figures
3A and 3B. Here, the path
for current is from the neg-
ative battery terminal through
the resistor, to the negative
ammeter terminal, through
the ammeter and back to the
positive battery terminal. In
Figure 3A, notice particularly
the manner in which the am-
meter is connected. The am-
meter is a part of the complete
circuit and current must flow
through it. If the ammeter is

The scale of an ammeter used to measure cur-
rents from 0 to 100 amperes.
Courtesy General Electric Co.

removed from the circuit, the circuit is incomplete and
there is no path for current.

When any device or component, such as an ammeter, is
connected so the circuit current must pass through it, it
is said to be connected in SERIES with the other parts of
the circuit. A voltmeter, on the other hand, is connected
across or in PARALLEL with another component.

*   *   *

7.   In the circuit of Figure 3B, the meter being used to measure
      current is an _Ammeter_ .

*   *   *

VOLTAGE AND CURRENT

We have mentioned that a definite relationship exists be-
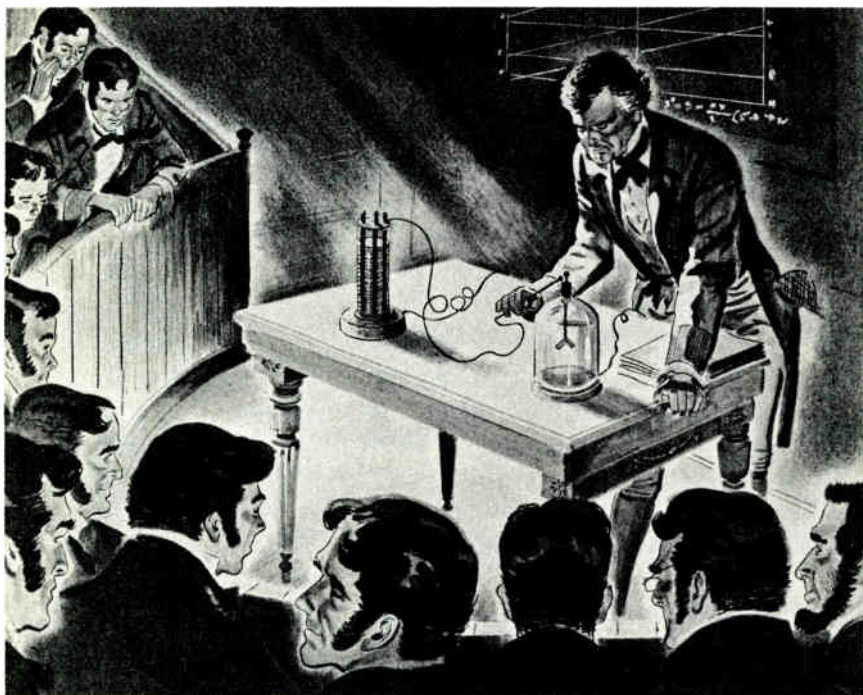
Dr. Georg Simon Ohm (1787-1854) discovered the fundamental relationship between voltage,
current and resistance. Ohm's Law, a simple statement of a great electrical truth, ranks in impor-
tance with the greatest physical laws of history.

Courtesy Ohmite Manufacturing Co.

tween voltage, current and resistance in an electric cir-
cuit. This relationship was discovered by Dr. Ohm, who

learned that the current in a circuit can be varied by
changing either the amount of voltage applied to the circuit
or the amount of circuit resistance. He also found that the
current changes in exactly the same proportion as the
change in voltage or resistance. However, a change in
voltage has exactly the opposite effect on the current as a
change in resistance. If the source voltage is increased,
the current increases; but if the resistance is increased,
the current decreases.

If we stop to think about this relationship, we find that it is
a very logical one. The voltage is the electric pressure
that causes the flow of electrons or current, and if we sup-
ply more pressure, we expect the current to increase.
Using the same reasoning, resistance is the opposition to
the electron flow, and if there is a greater amount of op-
position, we expect the current to decrease.

                    *   *   *

8.   In a complete circuit, such as Figure 3B, what happens to the
     current when the voltage is increased?   *Current is
     increased*.
                    *   *   *

By understanding this relationship, we can predict what is
going to happen in a circuit when a certain combination of
values is used. To simplify matters, let's study just two
of the three quantities at a time.

Figure 4A is the pictorial diagram of a simple circuit in
which a battery is the source voltage and a resistor is the
load. We will assume the resistance of the resistor is 1
ohm. Included in the circuit are an ammeter for measur-
ing current and a voltmeter for measuring voltage. The
schematic diagram of this circuit is shown in Figure 4B.
According to the definitions of the standard units, a battery
voltage of 1 volt produces a current of 1 ampere in this
circuit. If the voltage is increased to 2 volts, the current
increases to 2 amperes, so long as the resistance is held

constant. With the same 1 ohm of resistance, the current increases to 20 amperes if the voltage is increased to 20 volts. In fact, increasing or decreasing the voltage by any amount causes the current to vary by that same amount, as long as the resistance is kept at the same value. This relationship between voltage and current is referred to as a DIRECT PROPORTION, since any change in voltage causes the current to change in exactly the same manner.

Since the current exactly follows the voltage, the relationship between voltage and current can be stated as follows: IN AN ELECTRIC CIRCUIT, WHEN THE RESISTANCE IS HELD CONSTANT, THE CURRENT IS DIRECTLY PROPORTIONAL TO THE VOLTAGE.

    *   *   *

9. In Figure 4B, if the resistance is 1 ohm and the battery supplies 4 volts, how much current is in the circuit? 4 $Amps$

10. The phrase "directly proportional to" means an increase of one quantity causes (a) an increase of another quantity, (b) a decrease of another quantity, (c) no change of another quantity.

    *   *   *

RESISTANCE AND CURRENT

In the previous example, we held the resistance constant and varied the voltage to produce a change in current. However, as explained earlier, the current varies also with a change in resistance. To study the relationship between resistance and current, let's again use the circuit of Figure 4B, but this time assume that the voltage is held constant.

If the battery voltage in Figure 4B is 1 volt and the resistance is 1 ohm, the current is 1 ampere. If the resistance is now increased to 2 ohms, there is twice as much opposition to the electron flow. Doubling the opposition reduces

the current to one half its original value. Therefore, with
1 volt applied to the circuit, and the resistance increased
to 2 ohms, the current is only $\frac{1}{2}$ ampere.

On the other hand, a decrease in resistance means that the
opposition to electron flow has decreased, and the current
increases accordingly. Thus, if the voltage is still 1 volt,
and the resistance is decreased to half an ohm, the current
increases to 2 amperes. This type of relationship is re-
ferred to as an INVERSE PROPORTION, and we can use
the results of this example to form the general statement:
IN AN ELECTRIC CIRCUIT, WHEN THE VOLTAGE IS
HELD CONSTANT, THE CURRENT IS INVERSELY PRO-
PORTIONAL TO THE RESISTANCE.

*   *   *

11. In a complete circuit, what happens to the current when the
resistance is increased? The current decreases.

*   *   *

Practical examples of this inverse relationship between
current and resistance are the ordinary light bulbs used in
the home. When you switch on a lamp that contains a 100
watt light bulb, you are completing a circuit as shown in
Figure 5A. When you switch on a lamp that contains a 200
watt light bulb, you are completing a circuit as shown in
Figure 5B. In both circuits, the line voltage is the source
of electric pressure and is about 120 volts. Both circuits
have a switch and both circuits have wiring to form a
complete path for the current. This leaves the light bulbs
as the only difference in the two circuits.

We can see that a 200 watt light bulb gives off more light
and therefore must use more electric energy than a 100 watt
light bulb. This observation leads to the conclusion that a
200 watt light bulb allows more current in its circuit than
does a 100 watt light bulb. Since the voltage is the same in
both circuits, the resistance of the light bulbs must be the

difference in the circuits. They are, in fact, designed so a 100 watt bulb has about 150 ohms of resistance during normal operation and a 200 watt bulb has about 75 ohms of resistance.

*   *   *

12. In the circuit of Figure 5A, if a 300 watt light bulb were substituted for the 100 watt light bulb, would the circuit current increase or decrease?   *Increase*

13. In the circuit of Figure 5B, if the 200 watt bulb is replaced with one that has a resistance of 60 ohms, what happens to the current?   *It would increase*

*   *   *
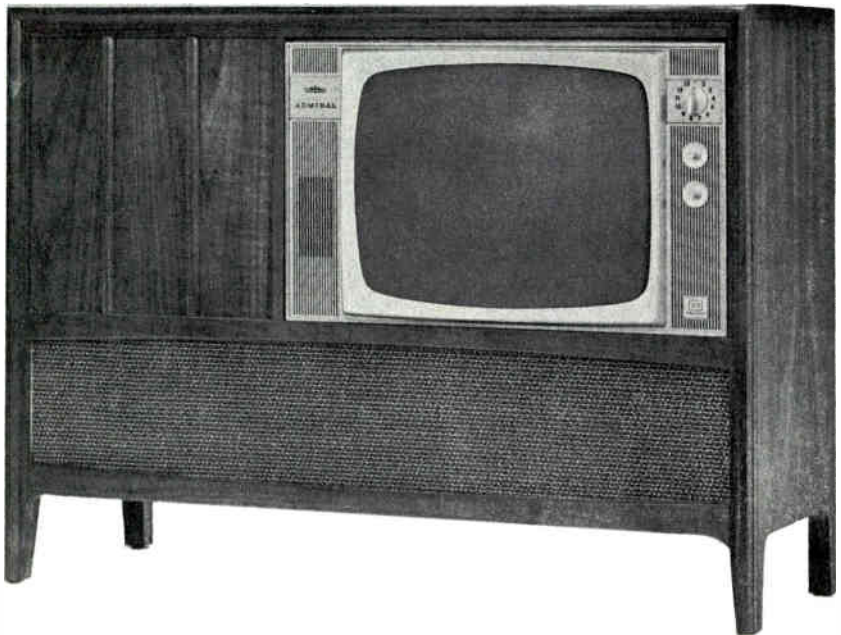
Modern television receivers include many circuits which require different amounts of voltage and current. The voltages vary from a fraction of a volt to several thousand volts; currents vary from less than a milliampere to several amperes.

Courtesy Admiral Corporation

OHM'S LAW

The relationship between voltage and current can be combined with the relationship between resistance and current to form OHM'S LAW. This law may be stated as follows: IN AN ELECTRIC CIRCUIT, THE CURRENT IS DIRECTLY PROPORTIONAL TO THE SOURCE VOLTAGE AND INVERSELY PROPORTIONAL TO THE CIRCUIT RESISTANCE. Technicians in all types of electrical and electronics work make use of this relationship.

In working with electricity, we want to know exactly how much the current changes if the voltage or resistance is changed by a certain amount. Ohm's Law is a valuable tool in this respect, since it allows us to determine in advance the circuit current when certain amounts of voltage and resistance are used. This expression is basic to almost every calculation made in electricity and electronics. In practice, the Ohm's Law relationship is expressed by a simple formula or "equation" that is written like this:

$$Current = Voltage \div Resistance$$

This equation shows that you can find current by simply dividing voltage by resistance. Suppose the source voltage in Figure 6 is 20 volts and the resistance is 2 ohms. If you divide the voltage by the resistance, you can quickly and easily find the current:

$$Current = Voltage \div Resistance$$
$$Current = 20 \div 2$$
$$Current = 10 \text{ Amperes}$$

Let's try another example. Suppose the voltage is 100 volts and the resistance is 25 ohms. To find the current, just divide the voltage by the resistance:

$$Current = Voltage \div Resistance$$
$$Current = 100 \div 25$$
$$Current = 4 \text{ Amperes}$$

*   *   *

14. In the circuit of Figure 6, if you replaced the 20 volt battery with a 40 volt battery, the current would change from 10 amperes to (a) 5 amperes, (b) 20 amperes, (c) 40 amperes.

15. In the same circuit (Figure 6), if you replaced the 20 volt battery with a 10 volt battery, the current would change from 10 amperes to (a) 5 amperes, (b) 8 amperes, (c) 20 amperes.

*   *   *

Thus, the current can be found for any combination of voltage and resistance. For convenience, the standard letter symbols E, I and R usually are inserted in place of the terms "voltage", "current" and "resistance". Then the equation becomes:

$$I = E \div R$$

In working with equations, it is customary to indicate division by placing the values one above the other and using a "bar" between them to show that the value above the bar is divided by the value below the bar. The usual way of expressing Ohm's Law is then as follows:

$$I = \frac{E}{R} \tag{1}$$

In applying Ohm's Law, the voltage, in volts, is inserted in place of the E. The resistance, in ohms, is inserted in place of the R. The current, expressed in amperes, then appears in place of the I.

*   *   *

16. Ohm's Law simply states that, in a complete circuit, the current is equal to the _voltage_ divided by the _Resistance_

17. What is the current in a circuit when the voltage is 300 volts
     and the resistance is 100 ohms?

     *   *   *

There may be times when you know the current, and you
want to find the voltage or resistance.   If so, you can re-
arrange the Ohm's Law equation to find the desired quan-
tity. WHEN YOU KNOW ANY TWO of the three quantities,
you can determine the remaining one. If you know the cur-
rent and resistance, and you want to find the voltage, just
multiply the current by the resistance:

$$\text{Voltage} = \text{Current} \times \text{Resistance}$$
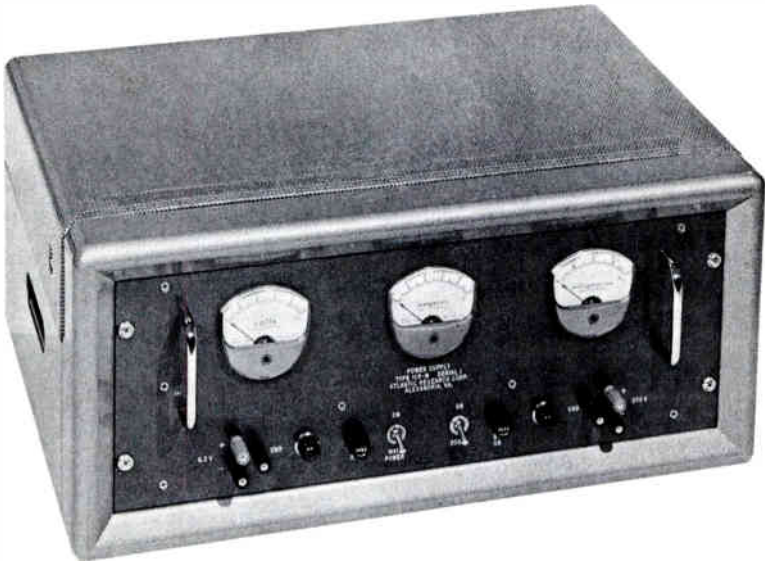
The meters in this power supply are connected permanently to internal circuits and constantly indi-
cate the amount of voltage and current being delivered to an external load.

Courtesy Atlantic Research Corp.

Using the standard symbols for convenience, the equation
becomes:

$$E = IR \qquad\qquad (2)$$

Notice that the multiplication sign (X) is omitted between I and R. When symbols are written next to each other, without a sign of any kind between them, the values represented by these symbols are to be multiplied by each other.

To illustrate this form of the Ohm's Law equation, the circuit of Figure 7 indicates that a particular load has 120 ohms of resistance with a current of 2 amperes through it. The voltage then is found by multiplying the current by the resistance:

$$E = IR$$
$$E = 2 \times 120$$
$$E = 240 \text{ volts}$$

Whether the source voltage is ac or dc, the current is multiplied by the resistance to determine the voltage. If the source voltage is ac, the current is ac; if the source voltage is dc, the current is dc.

*   *   *

18. How many volts is the source voltage when the circuit current is 4 amperes and the circuit resistance is 20 ohms? *80v*

19. In Figure 7, assume that the load is an electric heater which has 12 ohms of resistance and requires 10 amperes of current to operate properly. How much voltage must the source provide for normal operation? *120v*

*   *   *

There are many instances where it is desirable to determine the resistance of a circuit when the voltage and current are known. The Ohm's Law equation which enables you to do this is

Resistance = Voltage ÷ Current

Again using standard symbols, the equation becomes:

$$R = \frac{E}{I} \tag{3}$$

For example, in Figure 8, a source voltage of 20 volts is
indicated while the meter shows 2 amperes of current in
the circuit.   The resistance is then found by dividing the
voltage by the current:

$$R = \frac{E}{I}$$
$$R = \frac{20}{2}$$
$$R = 10 \text{ ohms}$$

*   *   *

20. What is the circuit resistance when the source voltage is 120
     volts and the circuit current is 4 amperes? $30\,\Omega$

21. The space suit of an astronaut is heated by a voltage source
     forcing current through a heating element in the space suit.
     If the source voltage is 24 volts and the current through the
     heating element is 6 amperes, what is the resistance of the
     heating element? $4\,\Omega$

22. Which of the following are forms of Ohm's Law?   (a) $E = IR$,
     (b) $R = \frac{E}{I}$, (c) $I = \frac{E}{R}$ all

*   *   *

MILLIAMPERES AND MICROAMPERES

A color television set may be designed so it draws 3 amps
(amperes) of current when connected across a 120 volt ac
source.   Inside this color television set, however, there
are a number of circuits which use the electric energy.
One group of circuits produces sound from the speaker; a
second group of circuits produces a picture on the picture
tube; another group of circuits determines the size of the
picture in the vertical direction; another group determines

how large the picture is in the horizontal direction; and still other circuits must perform various jobs in order that the television set functions properly.

With a little thought, we realize that each of these individual circuits uses less electric energy than the entire television set uses. As a result, we find many electronic circuits that require less than 1 amp of current for normal operation. To keep from specifying current values in fractions of an ampere, it is common practice to use units that are smaller than an ampere.

A very interesting and useful test instrument is the oscilloscope. Voltages and currents are converted into visual patterns which can be studied.

Courtesy Tektronix, Inc.

One of these units is the **MIL-LIAMPERE** (ma), which is one-thousandth of an ampere. Keep in mind that a milliampere is ONE THOUSAND TIMES SMALLER than an ampere, and that 1000 milliamperes equal 1 ampere.

*   *   *

23. How many milliamperes (ma) are in one ampere? *1000*

*   *   *

To gain a better understanding of how the milliampere is used, let's examine some circuits.

In the circuit of Figure 9A, the source voltage is 1 volt and the load resistance is 1 ohm. Using Ohm's Law to determine the current we get

$$I = \frac{E}{R}$$

$$I = \frac{1}{1} \text{ ampere}$$
$$I = 1 \text{ ampere}$$

In the circuit of Figure 9B, the source voltage is still 1 volt, but the load resistance is 1K (1000) ohms. Again using Ohm's Law to determine the current, we get

$$I = \frac{E}{R}$$
$$I = \frac{1}{1000} \text{ ampere} \;\text{---}\; 1000\overline{)1.000}^{\;.001}$$
$$I = .001 \text{ ampere}$$

To convert amperes to milliamperes (ma), it is necessary to move the decimal point three places to the right as follows:

$$I = .001 \text{ ampere}$$
$$I = .001 \text{ ma}$$
$$I = 1 \text{ ma}$$

In the middle step above, the curved arrow shows the decimal point being moved three places to the right. Also, milliampere (ma) is substituted for ampere.

In some types of aircraft, electric energy is supplied to the various pieces of radio equipment by a voltage source which is 24 volts dc. Since some of the circuits in this equipment require relatively small amounts of current, they can be represented by the circuit of Figure 9C in which the source voltage is 24 volts and the load resistance is 2K (2000) ohms. Using Ohm's Law to determine the current, and converting amperes to milliamperes, we get

$$I = \frac{E}{R}$$
$$I = \frac{24}{2000} \text{ ampere} \;\text{---}\; 2000\overline{)24.000}^{\;.012}$$

$$I = .012 \text{ ampere}$$
$$I = .\underline{012} \text{ ma}$$
$$I = 12 \text{ ma}$$

The vacuum tubes found in many types of electronic equip-
ment contain elements that are used solely to produce heat.
When functioning normally, the heating element in many
types of tubes has a resistance of 40 ohms and requires a
source voltage of 6 volts as shown in Figure 9D. To deter-
mine the amount of current in the circuit, use Ohm's Law
and convert amperes to milliamperes as follows:

$$I = \frac{E}{R}$$

$$I = \frac{6}{40} \text{ ampere} \;\text{---}\; 40\overline{\smash{\big)}6.00}\;^{.15}$$

$$I = .15 \text{ ampere}$$
$$I = .\underline{150} \text{ ma}$$
$$I = 150 \text{ ma}$$

In the fourth step above notice that it was necessary to add
a zero after the .15 in order to move the decimal point
three places to the right.

*   *   *

24. Convert the following to milliamperes (ma): .25 ampere,
    .037 ampere, 1.6 ampere, .005 ampere.   250 milla
    37 milla   1600 milla   5 milla
25. In a circuit where the source voltage is 600 volts and the
    total resistance is 15,000 (15K) ohms, what is the circuit
    current in ma?   150 = .00
                          40 milla

*   *   *

When working with electric circuits, it often happens that
you know the resistance and current and wish to determine
the voltage. To find the voltage, use the E = IR form of
Ohm's Law. Make sure all quantities are in basic units.
That is, E is in volts, I is in amperes and R is in ohms. As

explained, the current in many circuits is less than 1 am-
pere and is specified in mil-
liamperes for convenience.
For example, the final ampli-
fier circuit which provides
energy for the speaker in a
transistor radio, may have a
total resistance of 500 ohms
with 18 ma of current in the
circuit. To find out how many
volts are necessary for proper
operation, use Ohm's Law
and substitute in the equation
as follows:

The three-gun color picture tube for color
television receivers requires a variety of volt-
ages and currents. The high voltage needed
is about 22,000 volts dc while the beam cur-
rent for each gun is less than 1 milliampere.
Courtesy Sylvania Electric Products, Inc.

$$E = IR$$
$$E = 18 \text{ ma} \times 500$$

Since Ohm's Law requires
the current to be in amperes,
you must convert milliamperes to amperes. To do this,
move the decimal point three places to the left as follows:

$$E = 18 \text{ ma} \times 500$$
$$E = .018. \text{amp} \times 500$$
$$E = .018 \text{ amp} \times 500$$
$$E = .018 \times 500$$
$$E = 9 \text{ volts}$$

Notice in the second step above, a zero was added to the
left of the number 18 in order that the decimal point could
be moved three places to the left.

Regardless of what type of circuit or equipment is involved,
milliamperes are converted to amperes by moving the deci-
mal point three places to the left.

*   *   *

26. Convert the following to amperes (amps): 150 ma, 45 ma,
370 ma, 6500 ma, 8 ma, 80 ma, 800 ma, 8000 ma

27. In the circuit of Figure 10, if the resistance is 200 ohms and
the current is 45 ma, how many volts is the battery supplying?

*   *   *

Another unit of current commonly used in electronics is the
MICROAMPERE (μa) which is one-millionth of an ampere.
A microampere is such a small amount of current that it
takes one million of them to make an ampere. To convert
from amperes to microamperes, you move the decimal
point six places to the right. For example, let us deter-
mine the current in the circuit of Figure 11. Using Ohm's
Law, we get

$$I = \frac{E}{R}$$

$$I = \frac{10}{2,000,000} \text{ ampere} \quad \text{---} \quad 2,000,000 \overline{\smash{)}10.000000} \quad .000005$$

$$I = .000005 \text{ ampere}$$

Converting amperes to microamperes, we get

$$I = .000005 \text{ ampere}$$

$$I = .000005 \text{ microamperes}$$

$$I = 5 \text{ microamperes}$$

*   *   *

28. Convert the following to microamperes (μa): .072 ampere,
.0025 ampere, .000043 ampere, .0007 ampere
29. In the circuit of Figure 11, if the 10 volt battery is replaced
with a 160 volt battery, what is the circuit current in μa?

*   *   *

Sometimes it is necessary to convert microamperes to
amperes, and this is done by moving the decimal point six
places to the left as follows:

$$8 \ \mu a = \quad ? \quad amp$$
$$8 \ \mu a = .000008 \quad amp$$
$$8 \ \mu a = .000008 \ amp$$

In the middle step above, zeros were placed to the left of the number 8 so the decimal could be moved six places to the left.

*   *   *

30. Convert the following to amperes: $2 \ \mu a$, $25 \ \mu a$, $147 \ \mu a$

,000002 amp   ,000025 amp   .000147 amp

*   *   *

For your convenience, the chart of Figure 12 summarizes the conversion of amps to ma, amps to μa, ma to amps, and μa to amps.

SUMMARY

In an electric circuit, there is a definite relationship between voltage, current and resistance. This relationship is known as Ohm's Law.

According to Ohm's Law, the current in a circuit is directly proportional to the voltage applied to the circuit, and inversely proportional to the circuit resistance. Thus, the current increases when the voltage is increased, and the current decreases when the resistance is increased.

Whenever two of the three quantities E, I and R are known, one of the three Ohm's Law equations is used to calculate the unknown quantity. These equations are $I = E/R$, $E = IR$, and $R = E/I$.

The basic unit for measurement of current is the ampere. When the circuit current is stated in ma or μa, the value is converted to amperes when using it in Ohm's Law.

IMPORTANT DEFINITIONS

AMMETER - An instrument used to measure the electric
current in a circuit.

AMPERE - [AM pier] - The basic un⁺⁺ of current in an
electric circuit.

DIRECT PROPORTION - A relationship by which a change
in one quantity produces exactly the same change in
another quantity. If doubling one quantity causes
the other quantity to be doubled, the two quantities
are said to be directly proportional.

INVERSE PROPORTION - A relationship by which a change
in one quantity produces exactly the opposite change
in another quantity. If doubling one quantity causes
the other quantity to decrease to one half its origi-
nal value, the two quantities are said to be inversely
proportional.

MICROAMPERE (μa)- [MIGH kroh AM pier) - A unit of cur-
rent equal to one-millionth of an ampere. (1 μa =
.000001 ampere)

MILLIAMPERE (ma) - [MIL i AM pier] - A unit of current
equal to one-thousandth of an ampere. (1 ma = .001
ampere)

OHM - [oam] - The basic unit of resistance in an electric
circuit.

OHM'S LAW - A law which describes the relationship be-
tween voltage, current and resistance in an electric
circuit. In an electric circuit, the current is directly
proportional to the voltage, and inversely propor-
tional to the resistance.

IMPORTANT DEFINITIONS (Continued)

VOLT - [vohlt] - The basic unit of electric pressure, or voltage, in an electric circuit.

VOLTMETER - An instrument used to measure the electric pressure, or the potential difference between any two points in a circuit.

ESSENTIAL SYMBOLS AND EQUATIONS

E -   voltage   (volts)

I -   current   (amperes)

R - resistance   (ohms)

$$I = \frac{E}{R} \qquad (1)$$

$$E = IR \qquad (2)$$

$$R = \frac{E}{I} \qquad (3)$$

STUDENT NOTES

STUDENT NOTES

STUDENT NOTES

PRACTICE EXERCISE SOLUTIONS

1. (b) amperes.

2. (a) volts.

3. (c) ohms.

4. volt, ampere, ohm

5. current

6. a voltmeter

7. ammeter

8. the current increases -- Current is directly proportional to voltage.

9. 4 amperes -- With 1 ohm of resistance in a circuit, the numerical value of current is the same as the numerical value of voltage.

10. (a) an increase of another quantity.

11. the current decreases -- Current is inversely proportional to resistance.

12. increase -- The higher wattage bulb has less resistance and thus carries a greater current.

13. the current increases -- The replacement bulb has only 60 ohms of resistance, which is less than the resistance (75 ohms) of the 200 watt bulb.

14. (b) 20 amperes. -- Doubling the voltage doubles the current.

15. (a) 5 amperes. -- Halving the voltage halves the current.

16. voltage, resistance

17. 3 amperes -- $I = E/R$; therefore, I equals 300 divided by 100.

18. 80 volts -- $E = IR$; therefore, E equals 4 times 20.
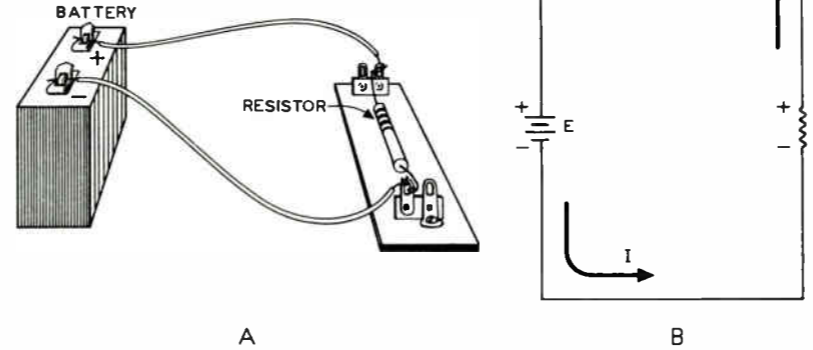
FIGURE 1
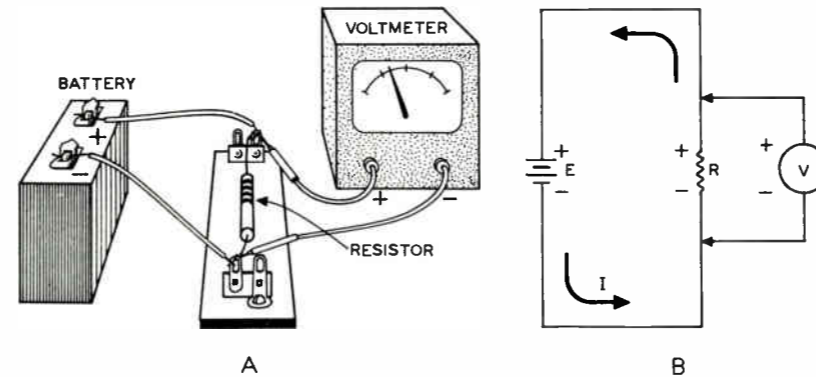
FIGURE 2
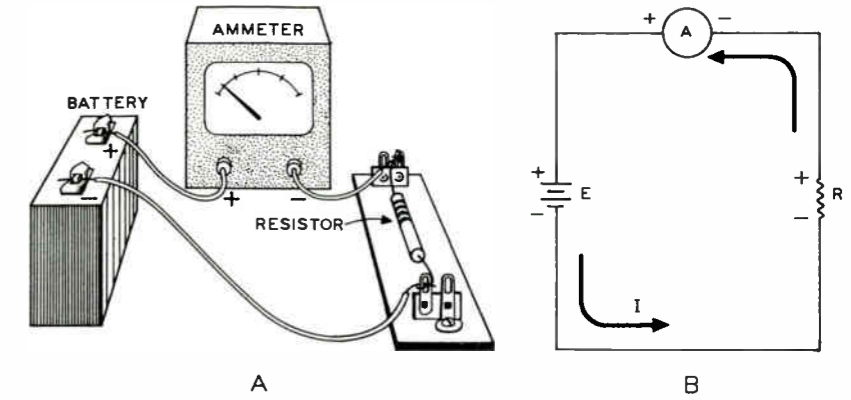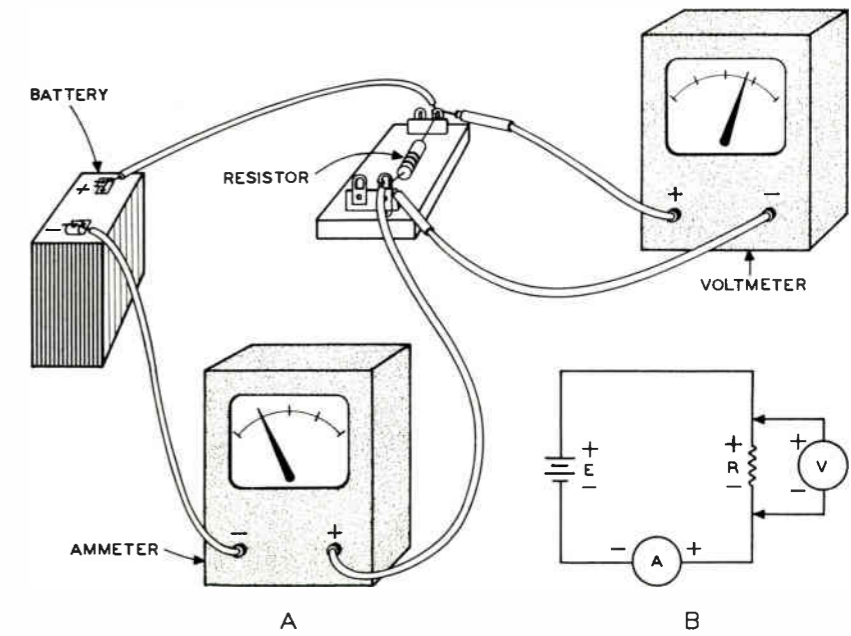
FIGURE 3

FIGURE 4

1012

1012

FIGURE 5

FIGURE 6

FIGURE 7

FIGURE 8

1012
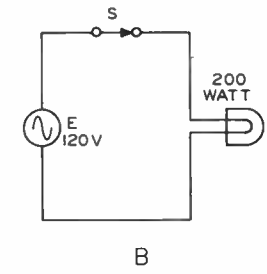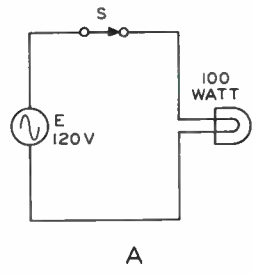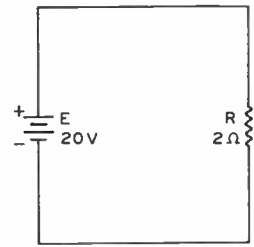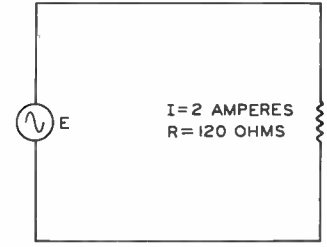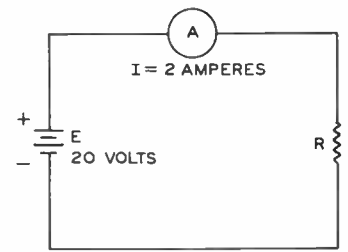
PRACTICE EXERCISE SOLUTIONS (Continued)

19. 120 volts -- E = IR; therefore, E equals 10 times 12.

20. 30 ohms -- R = E/I; therefore, R equals 120 divided by 4.

21. 4 ohms -- R = E/I; therefore, R equals 24 divided by 6.

22. All three are forms of Ohm's Law.

23. There are 1000 milliamperes in 1 ampere.

24. 250 ma, 37 ma, 1600 ma, 5 ma

25. 40 ma -- $I = \dfrac{E}{R} = \dfrac{600}{15,000} = .04$ ampere. Converting amperes to milliamperes by moving the decimal point three places to the right gives .04 amp = 40 ma.

26. .15 amp, .045 amp, .37 amp, 6.5 amps, .008 amp, .08 amp, .8 amp, 8 amps

27. 9 volts -- $E = IR = .045 \times 200 = 9$

28. 72,000 μa, 2500 μa, 43 μa, 700 μa

29. 80 μa -- $I = \dfrac{E}{R} = \dfrac{160}{2,000,000} = .00008$ ampere = 80 μa

30. .000002 ampere, .000025 ampere, .000147 ampere
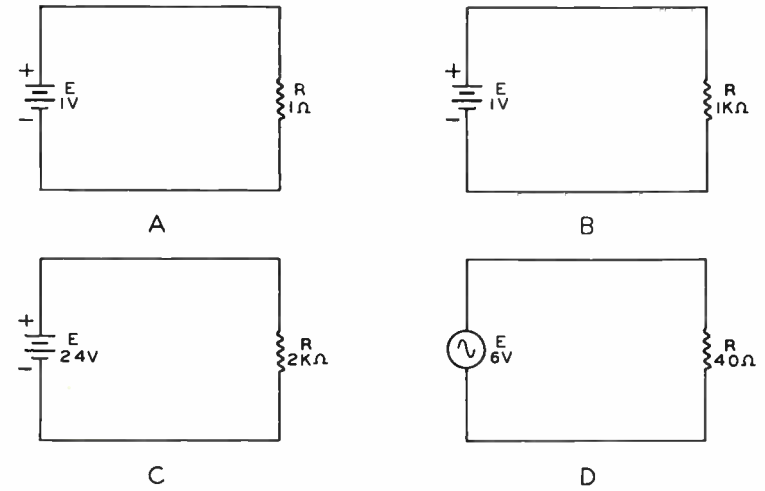
FIGURE 9
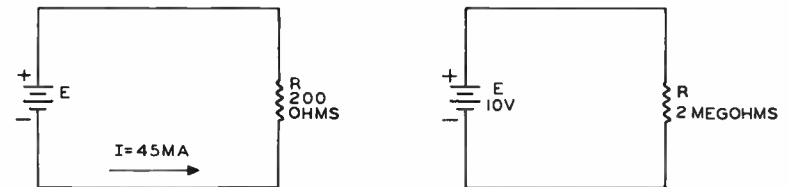
FIGURE 10   FIGURE 11

TO CONVERT		MOVE DECIMAL POINT	EXAMPLE
FROM	TO		
AMPS	MA	3 PLACES TO RIGHT	.43 AMP = .430 = 430 MA
AMPS	UA	6 PLACES TO RIGHT	.000055 AMP = .000055 = 55 UA
MA	AMPS	3 PLACES TO LEFT	68 MA = 068. = .068 AMP
UA	AMPS	6 PLACES TO LEFT	235 UA = 000235. = .000235 AMP

FIGURE 12

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question, as illustrated in the example below.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

Example: A thermometer measures

LESSON CODE

1012 A

A ■
B
C
D

(A) temperature. (B) speed. (C) time. (D) distance.

1.
A
B ■
C
D

Voltage and current are
(A) measured in the same units. (B) directly proportional. (C) inversely proportional. (D) always larger than the resistance.

2.
A
B ■
C
D

Resistance and current are
(A) measured in the same units. (B) inversely proportional. (C) directly proportional. (D) always smaller than the voltage.

3.
A
B ■
C
D

If the voltage applied to a circuit is doubled, and the resistance remains the same, the current
(A) remains the same. (B) is doubled. (C) is halved. (D) decreases in proportion.

4.
A
B
C
D ■

In an electric circuit, when the voltage and resistance are known, which form of the Ohm's Law equation is used to directly find the current?

(A) $E = IR$ (B) $R = \frac{E}{I}$ (C) $R = IR$ (D) $I = \frac{E}{R}$

5.
A
B
C ■
D

In an electric circuit, if the current is 20 amperes and the source voltage is 400 volts, the circuit resistance is
(A) 8000 ohms. (B) 420 ohms. (C) 20 ohms. (D) 380 ohms.

6.
A
B ■
C
D

In an electric circuit, if the current is 25 milliamperes (.025 ampere) and the resistance is 5000 ohms, the source voltage is
(A) 200 volts. (B) 125 volts. (C) 1250 volts. (D) 5 volts.

7.
A
B
C
D ■

In an electric circuit, if the voltage is 100 volts and the resistance is 25K ohms (25,000 ohms), the current is
(A) 25 ma. (B) 25 amps. (C) 40 amps. (D) 4 ma.

8.
A
B
C
D

A MILLIAMPERE is
(A) one thousand times larger than an ampere. (B) one thousand times smaller than an ampere.
(C) one million times smaller than an ampere. (D) one million times larger than a micro-ampere.

9.
A
B
C
D ■

When using any form of Ohm's Law, how many values must be KNOWN?
(A) three, (B) none, (C) one, (D) two.

10.
A
B ■
C
D

Ohm's Law is used
(A) only when the source voltage is dc. (B) when the source voltage is dc or ac. (C) only when the source voltage is ac. (D) only when the source voltage is greater than 10 volts.
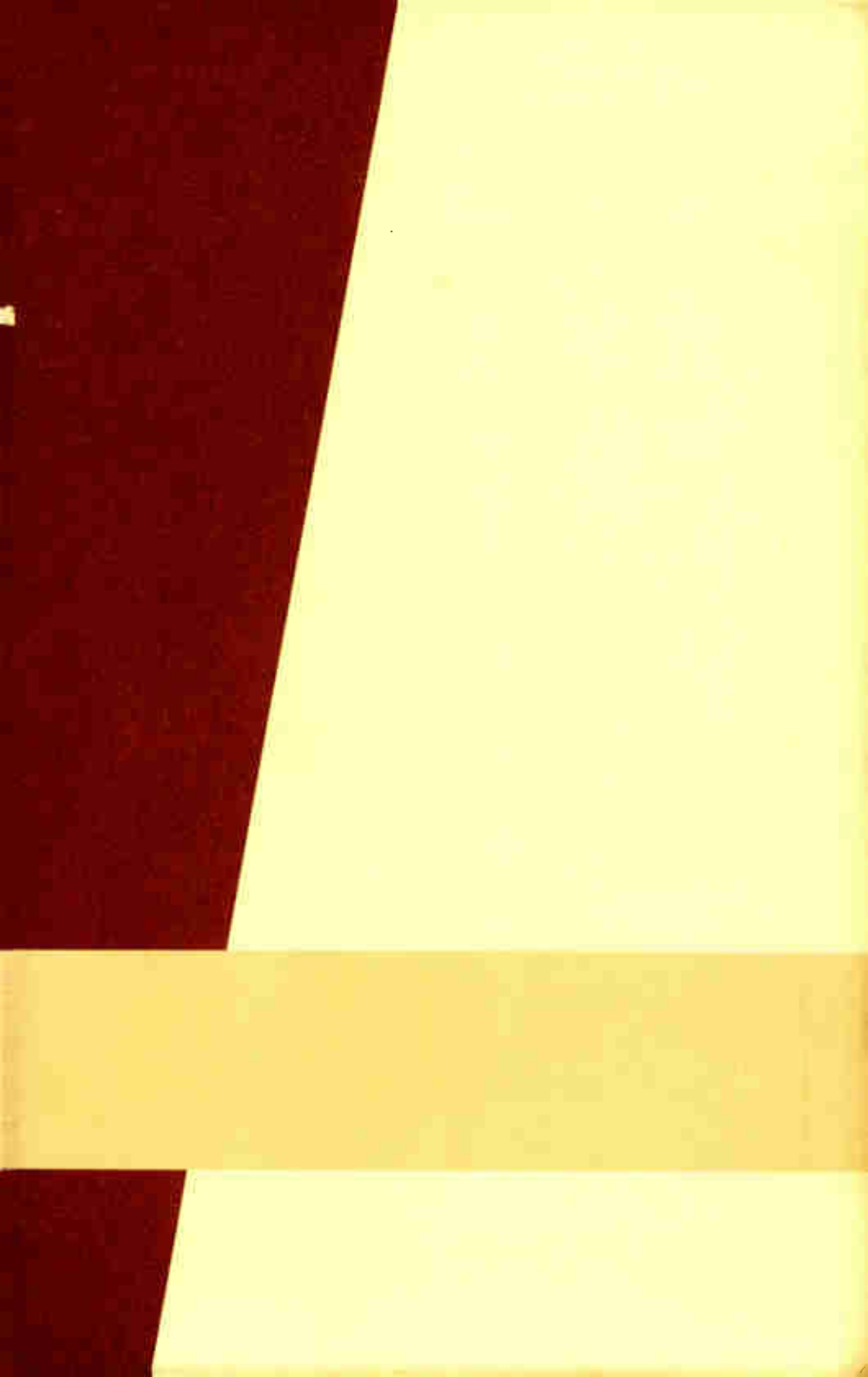
ELECTRIC CIRCUITS

Lesson 1015A

DeVRY Technical Institute

CHICAGO   TORONTO

YOUR TIME IS PRECIOUS

If time be of all things most precious, wasting time must be the greatest prodigality, since lost time is never found again; and what we call time enough always proves little enough. Let us then be up and doing, and doing to a good purpose; so by diligence shall we do more with less perplexity.

—Franklin

ELECTRIC CIRCUITS

Revised 1966

OPPORTUNITY

The voltages and currents in an analog computer are adjusted to simulate specific conditions such as the flight of an airplane. In the lower, right hand section of the computer are a number of rack-mounted amplifiers which must be connected properly to the computer voltage source.

Courtesy Donner Scientific Co.

ELECTRIC CIRCUITS

CONTENTS

****

I don't think much of a man
who is not wiser today than
he was yesterday.
          --Abraham Lincoln

ELECTRIC CIRCUITS

In order to do useful work, electricity must flow in some
type of circuit. The complete circuit may be as simple as
that of a flashlight, or it may be as elaborate as that of a
modern electronic computer. However, certain basic
properties are common to all circuits, no matter how sim-
ple or elaborate the circuits may be. In this lesson we will
consider the basic rules that govern all electric circuits,
and which form the basis for the entire field of electronics.

SUBSCRIPTS

The ability to read schematic diagrams is important in all
branches of electronics. Very simple circuits of course
have very simple schematic diagrams and there is not much
of a problem in tracing out current paths or identifying
parts. For example, Figure 1 is the schematic diagram of
a circuit containing a battery as the voltage source and a
resistor as the load. Here, no identification problem
exists. Any reference to a voltage or a resistance must
necessarily mean the only battery or the only resistor in
the circuit.

In most electronic devices, however, more than one resis-
tor is supplied with voltage and current at the same time.
A common circuit is shown in Figure 2A, where two resis-
tors are the load for the source. Immediately, a problem
arises of identifying one resistor from the other. Of
course, we could identify one resistor by saying "the re-
sistor which has one end connected to the positive terminal
of the battery", and the other resistor could be identified
by saying "the resistor which has one end connected to the
negative terminal of the battery". Even this lengthy descrip-
tion might be acceptable if there were only two or three
resistors in a circuit. However, a modern transistor
radio receiver may contain over 60 parts while a color
television receiver requires more than 300 parts. Because

of the large number of components in electronic equipment, a system of positive identification must be used to distinguish one component from another.

Figure 2B illustrates the system of component identification used in the electronics industry. Instead of labeling the resistors with a plain R and the battery with a plain E, a number is placed to the right of, and slightly below, each letter symbol. Thus, the two resistors in Figure 2B are labeled R_1 and R_2, while the battery is labeled E_1. Since the identifying numbers are placed slightly below the letter designations, the numbers are called SUBSCRIPTS and the system is called SUBSCRIPT NOTATION.

Figure 2C is another example of the use of subscripts. Notice in Figures 2B and 2C that the resistance values of the resistors have no bearing on the subscript numbers. In Figure 2B, R_1 has less resistance than R_2, while in Figure 2C, R_1 has more resistance than R_2.

*   *   *

1.   When subscripts are used to identify resistors, the resistor with the least resistance is always labeled R_1. True or False?

*   *   *

Subscripts are used to identify all types of components used in electric circuits. In the schematic diagram of Figure 3, we show a circuit with three resistors and two batteries. By using subscript notation, we can distinguish between the resistors, and also between the batteries. Now, to describe the effects of E_2 on the circuit, we simply say, "Electric current is from the negative terminal of E_2, through R_3, through R_2, and back to the positive terminal of E_2." Just try to think of a way to say this without using subscripts to identify the components.

*   *   *

2.   Subscripts are used to help identify (a) only the resistors in a circuit, (b) only the batteries in a circuit, (c) all components in a circuit.

*   *   *

REFERENCE POINTS

Often, the phrases POSITIVE VOLTAGE and NEGATIVE VOLTAGE are used rather loosely. A battery, for example, produces neither a positive voltage nor a negative voltage. It does produce a voltage between its two terminals so that the plus terminal is positive with reference to the minus
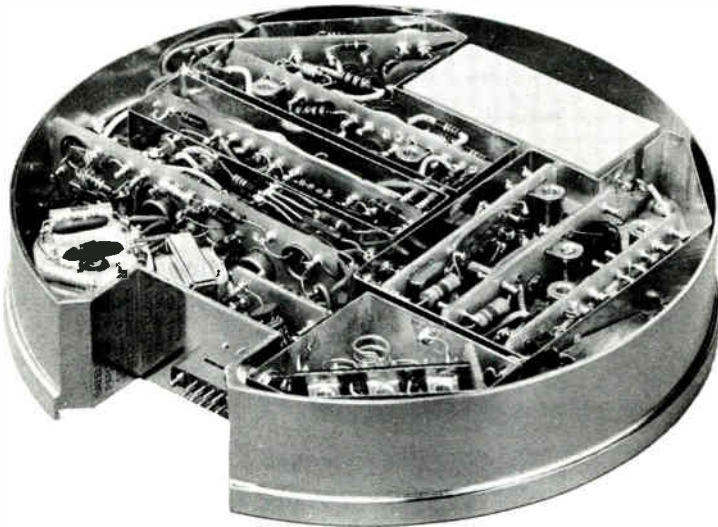
This unit is the radio receiver used in a complete satellite command control system. Notice that many of the components are ordinary resistors. These resistors are part of ordinary series and parallel circuits.

Courtesy AVCO Corp.
Electronics and Ordnance Div.

terminal, and the minus terminal is negative with reference to the plus terminal.

*   *   *

3.   The voltage produced by a battery is (a) a positive voltage,
      (b) a negative voltage, (c) a voltage between the positive and
      negative terminals.

*   *   *

Notice that the voltage is specified as being positive, or
negative, with reference to another point. The concept of
voltage being between two points also applies to complete
circuits.   Referring to Figure 4, we see a 6 ohm resistor,
R_1, connected across a 6 volt battery, E_1. Also, a 12 ohm
resistor, R_2, is connected across a 12 volt battery, E_2.
Since E_1 and R_1 are connected as a complete circuit, E_1
forces current through R_1 and the resultant voltage across
R_1 is 6 volts positive at point A with reference to point B.

A similar situation exists in the circuit containing E_2 and
R_2, and the resultant voltage across R_2 is 12 volts positive
at point C with reference to point D.

Since the circuit containing E_1 and R_1 is completely inde-
pendent of the circuit containing E_2 and R_2, a point in one
circuit cannot be compared with a point in the other circuit.
That is, we cannot say that the voltage at point A is positive
with reference to point D.

*   *   *

4.   Concerning Figure 4, which of the following statements are
      correct? (a) Point A is positive with reference to point B.
      (b) Point A is positive with reference to point D.   (c) Point
      D is positive with reference to point C. (d) Point C is positive
      with reference to point D.

*   *   *

In order to compare point A with either point C or D, it is
necessary for the two circuits to have something in com-

.mon. This is illustrated in Figure 5, where points B and
D are connected together. Now, the voltage at point A is
6 volts positive with reference to points B and D. Also,
the voltage at point C is 12 volts positive with reference to
points B and D.

In most equipment there are several circuits which have a
common connection. This common connection is indicated
in some schematic diagrams by a wide, dark line, as in
Figure 5. It is common practice to use the metal chassis
as a common connecting line. The schematic diagram
usually indicates this condition by adding a GROUND sym-
bol to the common connecting line, as in Figure 5.

The word ground does not necessarily mean "earth ground".
Any point used as a common reference point in a circuit
may be called ground.

                    *   *   *

5.   In Figure 5, points B and D are common reference points.
     True or False?

6.   The schematic diagram of a television receiver has many
     points terminated with the ground symbol of Figure 5.   This
     means that all these points probably are (a) connected directly
     together with hook-up wire, (b) connected to the metal chassis,
     (c) electrically independent of each other.

                    *   *   *

The schematic diagram of Figure 6 illustrates a method of
connecting resistors that is found in almost all electric or
electronic equipment. Here, the circuit is arranged so the
source voltage is divided between three resistors. Each
resistor has 20 ohms of resistance, so the source voltage
divides equally between them. Since the source voltage is
12 volts, there is 4 volts across each resistor.

Notice that the ground symbol in Figure 6 is different than

the one used in Figure 5. We show this symbol because it, as well as the symbol of Figure 5, is used to indicate a common reference point.

Let's take another look at Figure 6. With point A connected directly to the positive battery terminal, and point D connected directly to the negative battery terminal, the voltage between points A and D is 12 volts. Also, point A is 12 volts positive with reference to point D.

Suppose we use point D, or ground, as the common reference point. Then point A is 12 volts positive, point B is 8 volts positive, and point C is 4 volts positive. Keep in mind that a voltage exists BETWEEN TWO POINTS. When someone says a particular point in a circuit is positive (or negative), he usually means the point is positive (or negative) with respect to a reference point in the circuit.

*   *   *

7. In Figure 6, what is the voltage between points A and B? Between points B and C? Between points A and C?
    $4v._{,}$ $7v._{,}$ $3v.$
    *   *   *
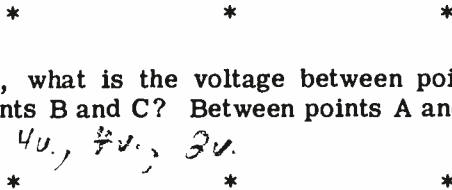
The schematic diagram of Figure 7 is almost identical to that of Figure 6. The only difference is that the ground point in Figure 7 is at point C, whereas the ground point in Figure 6 is at point D. Nothing else is changed. There is still 4 volts across each of the three resistors.

In Figure 6, we said that point C was 4 volts positive when using ground as the reference point. In Figure 7, point C is ground and there is zero voltage between point C and ground. Since the ground point has been changed, the voltages at all other points in the circuit change with reference to ground. Point A is now 8 volts positive, point B is 4 volts positive, and point D is 4 volts negative. Again, all of these voltages are with reference to ground, or point C.

*   *   *

8.   Referring to Figure 7 and using ground as a reference, what
      is the voltage at point D?
                              4 ...l/s negative

      *   *   *

Referring to Figure 8, we see a circuit which is identical
to Figures 6 and 7 except that the ground point has been
changed to point A.   Point A is still 12 volts positive with
reference to point D, but it is no longer 12 volts positive
with reference to ground.   In Figure 8, point D is 12 volts
negative, point C is 8 volts negative, and point B is 4 volts
negative, all with reference to ground.

This idea of putting the reference point at different places
is very common in the design and manufacture of transis-
torized equipment. Depending on the types of transistors
used and the designer's preference, the common reference
point (ground) may be the most negative point in the circuit
(as in Figure 6) or the most positive point in the circuit (as
in Figure 8).   In some cases it may even be at some in-
between point (as in Figure 7).

                  *   *   *

9.   Ground is always the most negative point in any circuit. True
      or False?

                  *   *   *

SERIES CIRCUITS

Simple circuits such as shown in Figure 9A are easy to
analyze. With switch S_1 open, there is no complete path
for current. Thus, there is no voltage across R_1 and no
current through R_1. To prove this, we could connect an
ammeter and a voltmeter into the circuit as shown in Fig-
ure 9B. With S_1 open, there is no complete path, and both
meters read zero.

When switch S_1 is closed, as shown in Figure 9C, the circuit is completed and current flows in the circuit. Starting
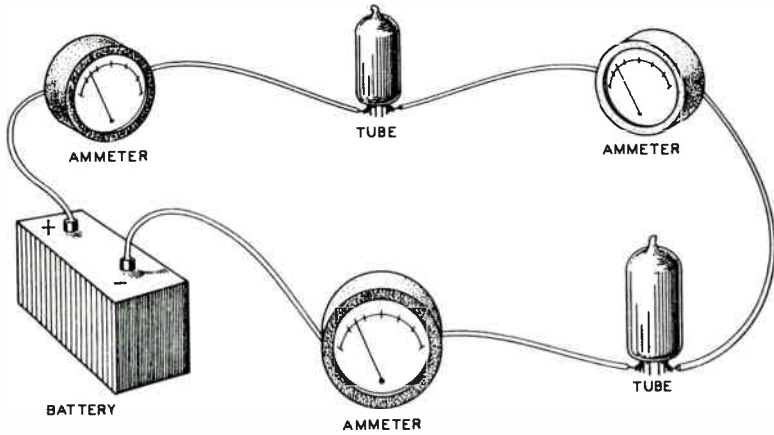
An example of a series circuit, using ammeters to show that the current is the same in all parts of the circuit.

from the negative terminal of voltage source E_S, current (I_1) flows through switch S_1, resistor R_1, and ammeter A_1. It continues on to the positive terminal of source E_S. With a 50 volt source and 10 ohms of resistance in the circuit, the circuit current is 5 amperes (50 ÷ 10), as indicated by ammeter A_1. Also, with 5 amperes of current through resistor R_1, the voltage across R_1 is 50 volts, as indicated by voltmeter V_1.

*   *   *

10. In Figure 9B, which of the following statements are true and which are false? (a) The circuit current I_1 is zero. (b) The voltage E_1 across the load resistance, R_1, is zero. (c) The source voltage E_S is 50 volts.

$(A)T$, (B) ·

*   *   *

In Figure 9C, if we change R_1 from 10 ohms to 50 ohms the circuit current changes to 1 ampere (50 volts ÷ 50 ohms).

However, with only one resistor in the circuit, the voltage across R_1 would still be equal to the source voltage, or 50 volts. Whenever a single resistor is the only component connected in a circuit with a voltage source, the full source voltage is developed across the resistor. If the resistance of the resistor is changed, the current through it changes but the voltage across it remains equal to the source voltage.

*   *   *

11. Assume that you have the circuit of Figure 9C set up and you change the load resistance, R_1, from 10 ohms to 5 ohms. What changes occur in the values of I_1 and E_1? *I_1 doubles*

E_1 stays the same

*   *   *

In most electronic equipment, one voltage source supplies electric energy to a number of loads. One way that these loads are connected is shown in Figure 10A. We call this a **SERIES CIRCUIT** because the components are connected one after another and there is only a single current path through all of the parts. As in Figure 9A, when S_1 is open there is no complete path for current and there is no voltage across resistors R_1 and R_2.

When switch S_1 is closed the circuit is completed and the conditions of Figure 10B exist. The circuit of Figure 10B is the same as Figure 10A except that we have added an ammeter (A_1) to measure the current, and two voltmeters $(V_1$ and $V_2)$ to measure the voltages across R_1 and R_2.

Ammeter A_1 of Figure 10B indicates 5 amperes of circuit current, while the voltmeters $(V_1$ and $V_2)$ indicate 25 volts across each of the resistors R_1 and R_2. These readings enable us to make some conclusions about a series circuit. First, the voltages across the individual resistors when added together equal the source voltage. Second, the voltage across each resistor is equal to the current through it multiplied by the resistance of that resistor. Thus, the

voltage across R_1 is

$$E_1 = I_1 R_1$$
$$E_1 = 5 \times 5 = 25 \text{ volts},$$

and the voltage across R_2 is

$$E_2 = I_1 R_2$$
$$E_2 = 5 \times 5 = 25 \text{ volts}.$$

Third, the voltage across each resistor in series is directly proportional to the resistance of that resistor. That is, the resistor with the largest resistance value will have the greatest share of the source voltage. Since R_1 and R_2 are equal in Figure 10, the voltages across them are equal.

Finally, we can arrive at a conclusion concerning the total resistance in a series circuit. Ohm's Law states that $R = E/I$. Therefore, the total resistance, R_T, is

$$R_T = \frac{E_S}{I_1} = \frac{50}{5} = 10 \text{ ohms}.$$

With R_1 and R_2 equal to 5 ohms each, we see that the total
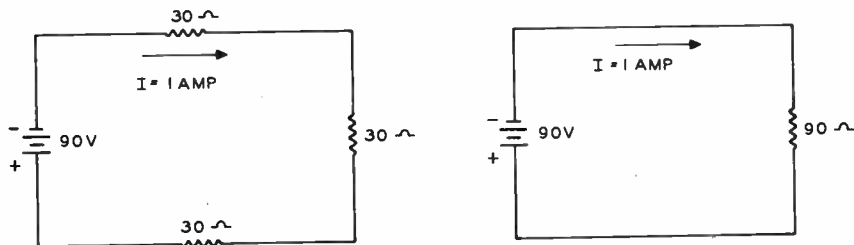
So for as circuit current is concerned, three 30 ohm resistors in series offer the some oppasition os o single 90 ohm resistor.

circuit resistance, R_T, is equal to the sum of the individual resistances.

If we chose to do so, we could connect ammeter A_1 between R_1 and R_2, or on either side of S_1, or at any place in the

circuit and it would indicate 5 amperes of current. This leads to the conclusion that, in a series circuit the current is the same at all points in the circuit.

Figure 11 is another example of a series circuit containing two resistors. Since a switch and the various meters are not essential to the operation of the circuit, they have been omitted. Notice, also, that the current is labeled I_T. With only one current in the complete circuit, it must be the total current from the source and it is common practice to label the total current I_T.

To analyze the circuit the first thing to do is inspect the circuit and see which things are known and which are unknown. Here, we know the supply voltage and we know the resistance of each resistor. We don't know the current, or the voltage across each resistor, or the total resistance. To calculate the voltage across a resistor, you must know the resistance of the resistor and the current through it. Since we don't know the circuit current, I_T, we cannot calculate the voltage across the resistors.

We do know, however, that the total resistance, R_T, is equal to the sum of $R_1 + R_2$:

$$R_T = R_1 + R_2$$
$$R_T = 20 + 25$$
$$R_T = 45 \text{ ohms}$$

Now, knowing R_T, we can calculate the circuit current, I_T:

$$I_T = \frac{E_S}{R_T}$$

$$I_T = \frac{90}{45}$$

$$I_T = 2 \text{ amps}$$

Knowing the circuit current, I_T, and the resistance of each resistor, we can calculate the voltage across each resistor.

The voltage across R_1 is

$$
\begin{aligned}
E_1 &= I_T R_1 \\
E_1 &= 2 \times 20 \\
E_1 &= 40 \text{ volts.}
\end{aligned}
$$

The voltage across R_2 is

$$
\begin{aligned}
E_2 &= I_T R_2 \\
E_2 &= 2 \times 25 \\
E_2 &= 50 \text{ volts.}
\end{aligned}
$$

*   *   *

12. In the circuit of Figure 11, change R_1 from 20 ohms to 65 ohms. What is the total resistance R_T? What is the current I_T? What are the voltages E_1 and E_2?

$90\,\Omega$, 1 amp. $E_1 = 65\ v$ $E_2 = 25\ v$

*   *   *

Figure 12 is another example of a series circuit in which we know the source voltage E_S and the resistance of the load resistors R_1 and R_2. To calculate R_T, we take the sum of R_1 and R_2:

$$
\begin{aligned}
R_T &= R_1 + R_2 \\
R_T &= 2000 + 1000 \\
R_T &= 3000 \text{ ohms}
\end{aligned}
$$

To calculate I_T, we divide the source voltage by the total resistance:

$$
I_T = \frac{E_S}{R_T} = \frac{30}{3000} = .01 \text{ ampere or 10 milliamperes}
$$

The voltage across R_1 is

$$
\begin{aligned}
E_1 &= I_T R_1 \\
E_1 &= .01 \times 2000 \\
E_1 &= 20 \text{ volts.}
\end{aligned}
$$

The voltage across R_2 is

$$E_2 = I_T R_2$$
$$E_2 = .01 \times 1000$$
$$E_2 = 10 \text{ volts}.$$

*   *   *

13. In the circuit of Figure 12, change R_1 to 500 ohms. Calculate R_T, I_T, E_1 and E_2.

*   *   *

When a series circuit contains more than two resistors, as in Figure 13A, the same general methods are used to analyze the circuit. The total resistance, R_T, is found by adding the resistances of the series resistors as follows:

$$R_T = R_1 + R_2 + R_3$$
$$R_T = 10 + 20 + 30$$
$$R_T = 60 \text{ ohms}$$

The total current, I_T, is found by dividing the source voltage by the total resistance:

$$I_T = \frac{E_S}{R_T} = \frac{60}{60} = 1 \text{ ampere}$$

The voltage across each resistor is directly proportional to its resistance. Their voltages are calculated as follows:

$$E_1 = I_T R_1 = 1 \times 10 = 10 \text{ volts}$$
$$E_2 = I_T R_2 = 1 \times 20 = 20 \text{ volts}$$
$$E_3 = I_T R_3 = 1 \times 30 = 30 \text{ volts}$$

Notice, also, that the sum of the individual voltages is equal to the source voltage. That is,

$$E_S = E_1 + E_2 + E_3 = 10 + 20 + 30 = 60 \text{ volts}.$$

*   *   *

/

14. In Figure 13A, change R_1 to 70 ohms. What is total resistance, R_T? What is the current I_T? What are the voltages E_1, E_2 and E_3? $120\overline{V_0f}$
    $RT \cdot 120\Omega$
    $I_1 = 500$ mills ☆

$E_1 = 35V$ $E = 10v$ $E_3 = 15V$.

*   *

The direction of current in Figure 13A, as indicated, is from the negative terminal of the source through R_3, R_2 and R_1, and back to the positive terminal of the source. The plus and minus signs close to the resistors indicate the polarity of the voltage across each resistor as it is connected in this circuit. In this particular figure the top end of each resistor is positive with reference to its bottom end, because the battery polarity is such that the current passes upward through the resistors.

Figure 13B is the same as Figure 13A except that no values have been assigned to the various components. We do this so we can make some general rules that will apply to all series circuits. These general rules are:

1. THE CURRENT IS THE SAME AT ALL POINTS IN A SERIES CIRCUIT.

2. THE SUM OF THE VOLTAGES ACROSS THE INDIVIDUAL COMPONENTS IN A SERIES CIRCUIT IS EQUAL TO THE SOURCE VOLTAGE.

3. THE TOTAL RESISTANCE IN A SERIES CIRCUIT IS EQUAL TO THE SUM OF THE INDIVIDUAL RESISTANCES.

Rule number 2 can be written as this equation:

$$E_S = E_1 + E_2 + E_3 \ldots + etc. \qquad (1)$$

Rule number 3 can be written as this equation:

$$R_T = R_1 + R_2 + R_3 \ldots + etc. \qquad (2)$$

The series circuit rules and the methods of analyzing series
circuits are the same regardless of whether the voltage
source is ac or dc. Figure 14 is a series circuit like Fig-
ure 13A except that the voltage source is 120 volts ac
rather than 60 volts dc. The total resistance, R_T, is found
by adding together the individual resistances:

$$R_T = R_1 + R_2 + R_3$$
$$R_T = 10 + 20 + 30$$
$$R_T = 60 \text{ ohms}$$

The circuit current is determined by dividing the source
voltage by the total resistance:

$$I_T = \frac{E_S}{R_T} = \frac{120}{60} = 2 \text{ amperes}$$

The voltage across each resistor is found by multiplying
the circuit current by the value of that resistor:

$$E_1 = I_T R_1 = 2 \times 10 = 20 \text{ volts}$$
$$E_2 = I_T R_2 = 2 \times 20 = 40 \text{ volts}$$
$$E_3 = I_T R_3 = 2 \times 30 = 60 \text{ volts}$$

Adding together the individual voltage drops, we find that
they total 120 volts. This is also the source voltage.

The direction of current flow and the voltage polarities are
not shown for this ac circuit because they are constantly
reversing.

*   *   *

15. The rules for series circuits apply (a) only when the source
     voltage is ac, (b) only when the source voltage is dc, (c) when
     the source voltage is either ac or dc.

*   *   *

The simple rules for series circuits are used in various

ways and at almost every level of electric or electronic work. Assume that you must develop 20 volts across a 2K ohm resistor, using only a 50 volt source. Figure 15 shows a solution to this problem. Since the voltage source is 50 volts, it becomes necessary to connect another resistor (which we shall call R_2) in series with the 2K ohm resistor R_1 and have 30 volts across R_2. Thus, the voltage E_2 must be 30 volts.
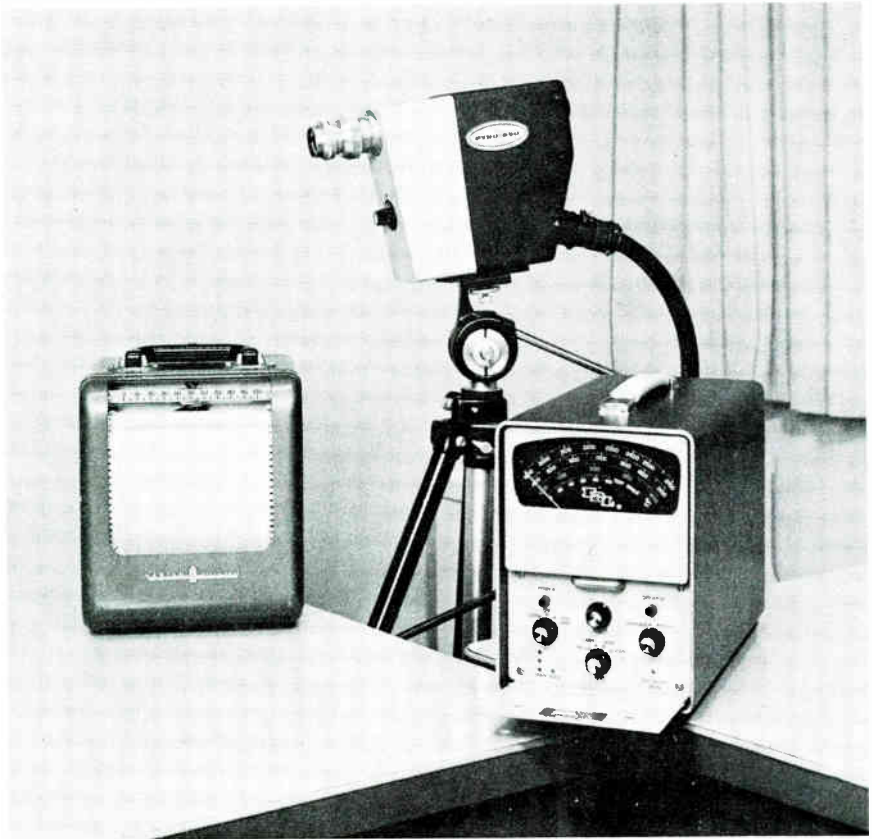
This special equipment is designed to continuously measure and control high and ultra-high temperatures. Many series and parallel resistance networks help to make this equipment function properly.
Courtesy Instrument Development Laboratories, Inc.

In order to have 20 volts across the 2K ohm resistor R_1,

the current through it must be

$$I_T = \frac{E_1}{R_1} = \frac{20}{2000} = .01 \text{ amp.}$$

Since the current through R_1 and R_2 must be the same, the current through R_2 is also .01 amp. Knowing the current through R_2 and the voltage across R_2, the resistance of R_2 is determined by Ohm's Law as follows:

$$R_2 = \frac{E_2}{I_T} = \frac{30}{.01} = 3000 \text{ ohms}$$

*   *   *

16. In Figure 15, the current through R_1 is equal to (a) the source voltage (E_S) divided by the resistance of R_1, (b) the voltage across R_1 (E_1) divided by the resistance of R_1, (c) the voltage across R_2 (E_2) divided by the resistance of R_1.

*   *   *

The same type of analysis is applied to a series circuit where more than two resistors are involved. In Figure 16, for example, it is necessary to determine the resistance of R_2 and the voltage of the source. To make use of Ohm's Law, two of the three quantities (I, E and R) must be known.

R_1 is the only component about which two of these factors are known. Knowing that the resistance of R_1 is 10K ohms and the voltage across it (E_1) is 20 volts, the current can be found:

$$I_T = \frac{E_1}{R_1} = \frac{20}{10,000} = .002 \text{ amp}$$

We also know that the current is the same in all parts of a series circuit. Therefore, the current through R_2 and R_3 is also .002 ampere. Knowing the current through R_2 and the voltage across R_2, the resistance of R_2 can be found:

$$R_2 = \frac{E_2}{I_T} = \frac{60}{.002} = 30,000 \text{ ohms}$$

The voltage across R_3 is determined by

$$E_3 = I_T R_3 = .002 \times 5000 = 10 \text{ volts}.$$

Finally, the source voltage, E_S, is determined by taking the sum of the individual voltages:

$$E_S = E_1 + E_2 + E_3 = 20 + 60 + 10 = 90 \text{ volts}$$

*   *   *

17. In a series circuit, such as Figure 16, the current through R_1 is one-half the current through R_3. True or False?

18. In a series circuit, such as Figure 16, the sum of the voltages across the individual resistors is equal to the source voltage. True or False?

*   *   *

An important thing to notice about Figure 16 is the relationship between the voltages across the resistors and the resistances of the resistors. The 5K ohm resistor R_3 has only 10 volts across it. R_1 is 10K ohms, or twice the resistance of R_3, and it has twice as much voltage across it as R_3 has. R_2 is 30K ohms, or six times the resistance of R_3, and it has six times as much voltage across it as R_3 has.

*   *   *

19. In a series circuit, such as Figure 16, the voltage across each resistor is inversely proportional to the resistance of each resistor. True or False?

*   *   *

PARALLEL CIRCUITS

Many practical electric circuits are arranged so that several
devices requiring the same amount and type of voltage may
be operated from one voltage source. Also, the arrangement
permits one or more of the devices to be turned on and off
without affecting the operation of the others. A typical ex-
ample of this arrangement is the average home in which the
electric circuits are wired so that lights, fans, radio and
television receivers, and other devices operate from the
same voltage source, yet may be turned on and off separately.

To provide for such operation, a **PARALLEL CIRCUIT** must
be employed. As a general definition, a parallel circuit is
an arrangement of two or more components such that each
provides a separate current path from one point to another.

The simplest arrangement of a parallel circuit is illustrated
by the schematic diagram of Figure 17. For the moment
disregard resistor R_2. The 50 volt battery and the 10 ohm
resistor R_1, are connected as in the basic circuit of Figure
9A. The current through resistor R_1, which we shall call
I_1, is found the same way as it was in Figure 9A as follows:

$$I_1 = \frac{E_S}{R_1} = \frac{50}{10} = 5 \text{ amperes}$$

With only one resistor in the circuit (still disregarding R_2),
there is only one path for current. The total current, I_T,
is the same as I_1.

When the second 10 ohm resistor, R_2 is connected in paral-
lel with R_1, as shown in Figure 17, it provides an additional
path for current. Since R_2 is connected across the source
voltage, just as R_1 is, the source voltage forces a current
which we shall call I_2 through R_2. The value of I_2 is found
as follows:

$$I_2 = \frac{E_S}{R_2} = \frac{50}{10} = 5 \text{ amperes}$$

With two paths for current, the total current being supplied by the source is the sum of the two currents. That is,

$$I_T = I_1 + I_2 = 5 + 5 = 10 \text{ amperes.}$$

$*$ $*$ $*$

20. In the parallel circuit of Figure 17, the voltage across R_2 is (a) one-half the voltage across R_1, (b) the same as the voltage across R_1 and is equal to E_S.

$*$ $*$ $*$

In Figure 17, adding R_2 in parallel with R_1 causes the total current to increase from 5 amperes to 10 amperes. Since the total resistance of an electric circuit is equal to the source voltage divided by the total current, the addition of R_2 causes the total resistance to decrease. The total resistance with both resistors in parallel is only 5 ohms compared to the 10 ohms of either resistor alone.

Each current path of a parallel circuit is called a branch of the circuit. Since THE SOURCE VOLTAGE IS APPLIED ACROSS EACH BRANCH OF A PARALLEL CIRCUIT, branch current I_1 flows through branch resistance R_1, and branch current I_2 flows through branch resistance R_2 in Figure 17.

Each time a branch is added to a parallel circuit, the total current increases and the total resistance decreases. In Figure 18, we have added branch resistance R_3 in parallel with branch resistances R_1 and R_2. The entire source voltage is across R_3, so branch current I_3 is

$$I_3 = \frac{E_S}{R_3} = \frac{50}{5} = 10 \text{ amperes.}$$

We have already found that branch currents I_1 and I_2 are 5 amperes each. The total current supplied by the source is equal to the sum of the branch currents. Thus,

$$I_T = I_1 + I_2 + I_3 = 5 + 5 + 10 = 20 \text{ amperes.}$$

The total resistance in the circuit, R_T, is

$$R_T = \frac{E_S}{I_T} = \frac{50}{20} = 2.5 \text{ ohms.}$$

*   *   *

21. In the parallel circuit of Figure 18, the total resistance is (a) the sum of the branch resistances, (b) independent of the branch resistances, (c) less than any of the branch resistances.

22. In the parallel circuit of Figure 18, the total current is (a) the sum of the branch currents, (b) divided equally among the branches, (c) less than any of the branch currents.

*   *   *

At this point, let's analyze our findings concerning Figures 17 and 18, and make some general rules about parallel circuits as follows:

1. THE VOLTAGE ACROSS EACH BRANCH OF A PARALLEL CIRCUIT IS THE SAME AS THE SOURCE VOLTAGE.

2. THE TOTAL CURRENT IN A PARALLEL CIRCUIT IS EQUAL TO THE SUM OF THE BRANCH CURRENTS.

3. THE TOTAL RESISTANCE IN A PARALLEL CIRCUIT IS LESS THAN THE RESISTANCE OF ANY BRANCH.

Rule number 2 can be written as the equation:

$$I_T = I_1 + I_2 + I_3 \ldots + \text{etc.} \qquad (3)$$

Figure 19A is a typical arrangement of various loads which are connected in parallel across a voltage source. We know

that the voltage is the same across each of the branch re-
sistances.   To find the current in each branch, we divide
the source voltage by the resistance of each branch as fol-
lows:

$$I_1 = \frac{E_S}{R_1} = \frac{120}{120} = 1 \text{ ampere}$$

$$I_2 = \frac{E_S}{R_2} = \frac{120}{60} = 2 \text{ amperes}$$

$$I_3 = \frac{E_S}{R_3} = \frac{120}{40} = 3 \text{ amperes}$$

*   *   *

23. In the parallel circuit of Figure 19, the current through each
     branch (a) is the same as that through the other branches,
     (b) is inversely proportional to the branch resistance, (c) is
     directly proportional to the branch resistance.

*   *   *

We find the total circuit current in Figure 19A by

$$I_T = I_1 + I_2 + I_3 = 1 + 2 + 3 = 6 \text{ amperes.}$$

The total resistance is

$$R_T = \frac{E_S}{I_T} = \frac{120}{6} = 20 \text{ ohms.}$$

Let's see what you could expect to measure in this circuit.
Figure 19B is the same circuit as Figure 19A with meters
connected.   Appropriate voltmeters (V_1, V_2 and V_3) are
connected across the branch resistances, and each of them
will show a reading of 120 volts.

Ammeter A_1 is connected so the total current, I_T, must
flow through it. From our previous calculations we know

that A_1 will show a reading of 6 amperes. At junction point
W , the current divides, with I_1 flowing through A_2 and R_1,
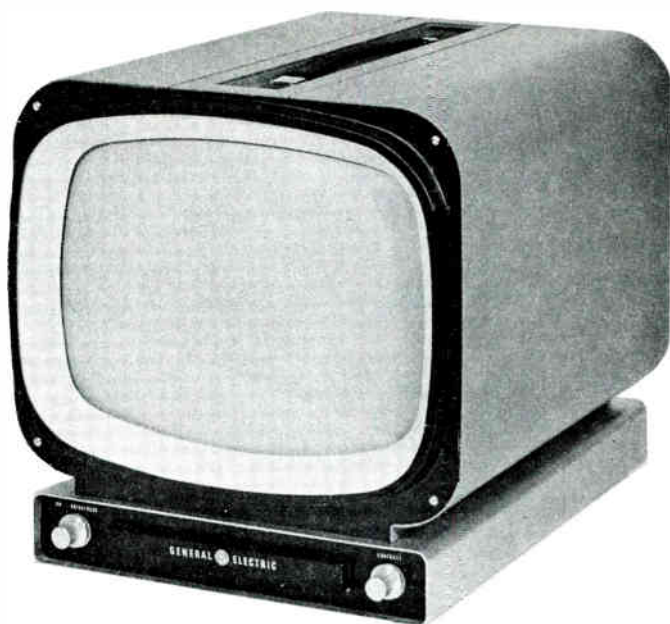
A closed circuit TV monitor is a highly specialized viewing device for commercial, industrial,
military and educational applications. Each tube, with its associated components, in this unit is
connected in parallel with a dc voltage source.

Courtesy General Electric Company

and the remainder of the current continuing on through A_3.
Since I_1 is 1 ampere, the remaining 5 amperes flows through
A_3.   At junction point X, the current again divides, with 2
amperes flowing through A_4 and R_2, and 3 amperes flowing
through A_5 and R_3.

The 3 amperes of branch current I_3 approaches junction
point Y and combines with the 2 amperes of branch current
I_2. The sum of I_2 and I_3 leaves junction point Y and ap-
proaches junction point Z.   The sum of I_2 and I_3 combines
with the 1 ampere of branch current I_1 at junction point Z.
Thus, the sum of I_1, I_2 and I_3 leaves junction point Z and
continues to the voltage source.

There is a very definite reason for going into detail con-
cerning the current arriving at a junction point and the cur-
rent leaving a junction point. In all cases, the current ar-
riving at a junction point is exactly equal to the current
leaving that junction point. It doesn't matter how many
paths lead to the junction or how many paths lead away
from the junction; THE CURRENT ARRIVING AT A JUNC-
TION AND THE CURRENT LEAVING A JUNCTION ARE
ALWAYS EQUAL TO EACH OTHER.

For example, in Figure 19B, the current arriving at junc-
tion point X is 5 amperes. The current leaving is I_2 (2 am-
peres) and I_3 (3 amperes), the sum of which is also 5 am-
peres. The current arriving at junction point Z is 5 amperes
from junction point Y and 1 ampere from R_1. The current
leaving junction point Z is the total current of 6 amperes.

*   *   *

24. In Figure 19B, how much current is arriving at junction W?
    How much is leaving junction W?
         6 amps, 6 amps
25. In Figure 19B, how much current is arriving at junction Y?
    How much is leaving junction Y?
         5 amps, 5 amps
                              *   *

Another important point to notice in parallel circuits is the
relationship of the branch currents to the branch resistances.
The current through each branch is inversely proportional
to the resistance of the branch. In Figure 19B, the branch
with the most resistance (R_1) has the least current; the
branch with the least resistance (R_3) has the most current.

*   *   *

26. In the parallel circuit of Figure 19, if R_2 is changed to a 120
    ohm resistor, what happens to the current through R_2? What
    happens to the total current?
         current decreases, decreases
              *   *   *

Practically all electrical devices have circuits where the various loads are in parallel. Often it is not convenient to measure the resistance of a device or the current through it. Yet, it may be necessary to know these details. Figure 20 represents such a situation. Here, the things we know are: the source voltage is 120 volts, the total current is 6 amperes, the current through R_1 is .5 ampere, and R_2 is 30 ohms. Using Ohm's Law and the basic rules for parallel circuits, we can calculate the remaining quantities.
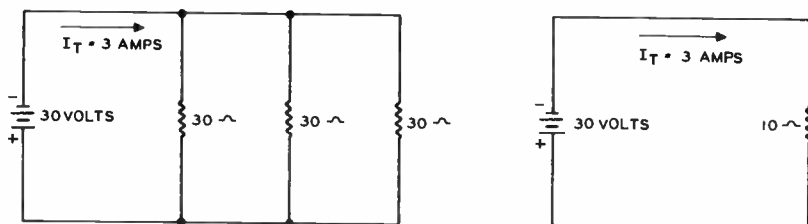
So far as the total circuit current I_T is concerned, three 30 ohm resistors in parallel offer the same opposition as one 10 ohm resistor.

Knowing the source voltage and the resistance of R_2, the current through R_2 is

$$I_2 = \frac{E_S}{R_2} = \frac{120}{30} = 4 \text{ amperes.}$$

Since the sum of I_1 (.5 ampere), I_2 (4 amperes), and I_3 must be equal to I_T (6 amperes), we can calculate the value of I_3. The sum of I_1 and I_2 is 4.5 amperes. Subtracting this amount from the total current of 6 amperes leaves 1.5 amperes for I_3.

Now that we know all of the currents and the source voltage, we can determine R_1 and R_3 by dividing the source voltage by each branch current:

$$R_1 = \frac{E_S}{I_1} = \frac{120}{.5} = 240 \text{ ohms}$$

$$R_3 = \frac{E_S}{I_3} = \frac{120}{1.5} = 80 \text{ ohms}$$

The total resistance of the circuit is found by dividing the source voltage by the total current:

$$R_T = \frac{E_S}{I_T} = \frac{120}{6} = 20 \text{ ohms}$$

Notice that the total resistance R_T is less than the smallest branch resistance, which is always the case in parallel circuits.

*   *   *

27. In Figure 20, is the total resistance less than or greater than the resistance of R_2?

*   *   *

It is often helpful to quickly determine the total resistance of parallel resistors. This is particularly true of two re- sistances in parallel, because such an arrangement is com- mon in electrical or electronic equipment. Figure 21 shows such a circuit. The total resistance of this circuit, or any circuit having two parallel resistors, can be quickly found by using the following equation:

$$R_T = \frac{R_1 R_2}{R_1 + R_2} \qquad (4)$$

In this equation notice that the two values of resistance are first multiplied together and placed above the division bar. Next, the same values of resistance are added together and placed below the division bar. Because of this arrange- ment, the equation is usually called the "product over the sum" equation.

To see how this equation works, let's assume some values for E_S, R_1 and R_2. Assume E_S to be 10 volts, R_1 to be 10 ohms and R_2 to be 10 ohms. Using the "product over the sum" equation:

$$R_T = \frac{R_1 R_2}{R_1 + R_2}$$

$$R_T = \frac{10 \times 10}{10 + 10} = \frac{100}{20} = 5 \text{ ohms}$$

We can check this answer with the method used earlier. Using our previous methods, we find the current through each resistor:

$$I_1 = \frac{E_S}{R_1} = \frac{10}{10} = 1 \text{ ampere}$$

$$I_2 = \frac{E_S}{R_2} = \frac{10}{10} = 1 \text{ ampere}$$

The total current I_T is equal to the sum of I_1 and I_2:

$$I_T = I_1 + I_2 = 1 + 1 = 2 \text{ amperes}$$

The total resistance R_T is

$$R_T = \frac{E_S}{I_T} = \frac{10}{2} = 5 \text{ ohms.}$$

Thus, we see that the same value of total resistance for the circuit of Figure 21 can be determined by either method.

                    *   *   *

28. In Figure 21, assume that R_1 is 4 ohms and R_2 is 12 ohms. What is the value of R_T? $\frac{4 \cdot 12}{4+12}$ $\frac{48}{16} = 3$

29. In Figure 21, assume that both resistors are 20,000 ohms. What is the value of R_T? $\frac{20,000 \times 20,000}{20,000 + 20,000}$ $\frac{40,000}{4} = 10K$

                    *   *   *

In the circuit of Figure 21, or in any electric circuit, the amount of source voltage does not affect the circuit resist-

ance. Remember, the resistance of a resistor is deter-
mined by how it is made and not by the voltage or current
in a circuit. Therefore, you can always assume a voltage
and use it to calculate the re-
sistance by the longer Ohm's
Law method. If you prefer, the
"product over the sum" equa-
tion can be used when you are
concerned only with the total
resistance in a parallel circuit
containing two resistors.

When more than two resistors
are connected in parallel, as
in Figure 22, the "product over
the sum" equation is no longer
directly used. Referring back
to Figure 18, the total resist-
ance is determined by finding
the current in each branch,
adding the branch currents to-
gether to find the total current,

A signal generator of this type is used to align
and troubleshoot color television receivers.
To make use of its signals, the generator output
terminals are connected in parallel with the
antenna input terminals of the receiver.
Courtesy Precision Apparatus Co., Inc.

and finally by dividing the source voltage by the total current.

Keep in mind that the source voltage determines the cur-
rent through a resistor but does not determine the resist-
ance of a resistor. If the source voltage is changed, the
current in a circuit changes proportionally but the resist-
ance remains constant. Therefore, in Figure 22, to find
the total resistance we can assume any value of source
voltage. For example, let's assume that E_S is 80 volts.
In this case, the assumed currents are:

$$I_1 = \frac{E_S}{R_1} = \frac{80}{80} = 1 \text{ ampere}$$

$$I_2 = \frac{E_S}{R_2} = \frac{80}{80} = 1 \text{ ampere}$$

$$I_3 = \frac{E_S}{R_3} = \frac{80}{40} = 2 \text{ amperes}$$

The total circuit current is

$$I_T = I_1 + I_2 + I_3 = 1 + 1 + 2 = 4 \text{ amperes.}$$

The total resistance is

$$R_T = \frac{E_S}{I_T} = \frac{80}{4} = 20 \text{ ohms.}$$

If we had assumed that the source voltage was 240 volts, we would have found the currents and the total resistance as follows:

$$I_1 = \frac{E_S}{R_1} = \frac{240}{80} = 3 \text{ amperes}$$

$$I_2 = \frac{E_S}{R_2} = \frac{240}{80} = 3 \text{ amperes}$$

$$I_3 = \frac{E_S}{R_3} = \frac{240}{40} = 6 \text{ amperes}$$

$$I_T = I_1 + I_2 + I_3 = 3 + 3 + 6 = 12 \text{ amperes}$$

$$R_T = \frac{E_S}{I_T} = \frac{240}{12} = 20 \text{ ohms}$$

For either value of assumed source voltage, the total resistance turns out to be 20 ohms.

For convenience, it is best to assume a source voltage which is a multiple of the branch resistances. If we assume a source voltage of 45 volts for Figure 22, the total resistance is still 20 ohms, but the arithmetic contains decimals and is more difficult to handle.

*   *   *

30. In Figure 22, let R_1 be 30 ohms, R_2 be 45 ohms, and R_3 be 90 ohms. What is the value of R_T ?

31. In Figure 22, let the three resistors be 66 ohms each. What
    is the value of R_T?

                              $22\ \Omega$

    *   *   *

There is another method for determining the total resist-
ance of a parallel circuit regardless of the number of re-
sistors in the circuit. This method is called the "recipro-
cal" method of solving parallel circuits and is thoroughly
explained in the appendix at the end of this lesson. Whether
you use the "reciprocal" method of the appendix or the volt-
age and current method explained in the regular portion of
the text is a matter of personal preference.   Both methods
are good and both methods give identical results.

SUMMARY

Subscripts are small numbers (or letters) used with letter
symbols to identify the various components and quantities
in electric circuits.

Voltage, or potential, is always measured between two
points. When a voltage at a certain point is specified as
being positive or negative, it is with reference to a pre-
viously stated common reference point in the circuit.

The following general rules apply to series resistance cir-
cuits:

1. The current is the same at all points in a series circuit.

2. The sum of the voltages across the individual components
   in a series circuit is equal to the source voltage.

3. The total resistance in a series circuit is equal to the
   sum of the individual resistances.

The following general rules apply to parallel resistance
circuits:

1. The voltage across each branch of a parallel circuit is the same as the source voltage.

2. The total current in a parallel circuit is equal to the sum of the branch currents.

3. The total resistance in a parallel circuit is less than the resistance of any branch.

4. In a parallel circuit, the current through each branch is inversely proportional to the resistance of the branch.

IMPORTANT DEFINITIONS

GROUND - Any point in an electric circuit which is used as a common reference point.

NEGATIVE VOLTAGE - A voltage which is negative with reference to a common reference point.

PARALLEL CIRCUIT - A circuit in which two or more components provide two or more separate current paths from one point to another.

POSITIVE VOLTAGE - A voltage which is positive with reference to a common reference point.

SERIES CIRCUIT - One in which the components are connected one after another so there is only one current path.

SUBSCRIPT - A small identifying number or letter written slightly to the right of and below the quantity being identified.

SUBSCRIPT NOTATION - An identification system using subscripts.

ESSENTIAL SYMBOLS AND EQUATIONS

I_1, I_2, etc. -- current through R_1, R_2, etc.   (amperes)

I_T -- total current   (amperes)

R_1, R_2, etc. -- individual resistors of a circuit   (ohms)

R_T -- total resistance   (ohms)

E_1, E_2, etc. -- voltage across R_1, R_2, etc.   (volts)

E_S -- source voltage   (volts)

$$E_S = E_1 + E_2 + E_3 \ldots + \text{etc.} \tag{1}$$

$$R_T = R_1 + R_2 + R_3 \ldots + \text{etc.} \tag{2}$$

$$I_T = I_1 + I_2 + I_3 \ldots + \text{etc.} \tag{3}$$

$$R_T = \frac{R_1 R_2}{R_1 + R_2} \tag{4}$$

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots + \text{etc.}} \tag{5}$$

APPENDIX

CALCULATING TOTAL RESISTANCE OF PARALLEL CIRCUITS

A rule for finding resistance in parallel circuits, regardless of the number of resistors in the circuit is: THE TOTAL RESISTANCE OF ANY PARALLEL CIRCUIT IS EQUAL TO THE RECIPROCAL OF THE SUM OF THE RECIPROCALS OF THE SEPARATE BRANCH RESISTANCES. This rule is stated in the form of an equation as:

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots + \text{etc.}} \qquad (5)$$

To illustrate the application of this "reciprocal" equation, the resistances of Figure 22 may be substituted in the equation to calculate the total resistance as follows:

$$R_T = \frac{1}{\frac{1}{80} + \frac{1}{80} + \frac{1}{40}}$$

First, the fractions are changed to a common denominator:

$$R_T = \frac{1}{\frac{1}{80} + \frac{1}{80} + \frac{2}{80}}$$

Next, the fractions are added together and reduced:

$$R_T = \frac{1}{\frac{4}{80}} = \frac{1}{\frac{1}{20}}$$

Finally, the number 1 above the main division bar is divided by the fraction below the main division bar. To divide by a

APPENDIX (Continued)

fraction, invert the fraction and multiply as follows:

$$R_T = \frac{1}{\dfrac{1}{20}} = 1 \times \frac{20}{1} = 20 \text{ ohms}$$

For a second example, the resistances of Figure 23 may be substituted into the "reciprocal" equation as follows:

$$R_T = \frac{1}{\dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3} + \dfrac{1}{R_4}}$$

$$R_T = \frac{1}{\dfrac{1}{20} + \dfrac{1}{5} + \dfrac{1}{10} + \dfrac{1}{20}}$$

Again, the fractions are rewritten using a common denominator:

$$R_T = \frac{1}{\dfrac{1}{20} + \dfrac{4}{20} + \dfrac{2}{20} + \dfrac{1}{20}}$$

Next, the fractions are added together and reduced:

$$R_T = \frac{1}{\dfrac{8}{20}} = \frac{1}{\dfrac{2}{5}}$$

Finally, invert the fraction below the main division bar and multiply:

$$R_T = \frac{1}{\dfrac{2}{5}} = 1 \times \frac{5}{2} = \frac{5}{2} = 2.5 \text{ ohms}$$

PRACTICE EXERCISE SOLUTIONS

1. False -- The subscript numbers usually do not refer to the resistance values. The resistance values differ according to the requirements of the circuit.

2. (c) all components in a circuit.

3. (c) a voltage between the positive and negative terminals.

4. (a) and (d) are correct.

5. True

6. (b) connected to the metal chassis.

7. 4 volts;   4 volts;   8 volts

8. Point D is 4 volts negative with reference to ground.

9. False -- Other points in a circuit may be negative with reference to ground (more negative than the ground point).

10. All are true. -- With switch S_1 open, the circuit is incomplete so there is no current through R_1 and no voltage across R_1. The battery voltage, however, remains 50 volts whether S_1 is open or closed.

11. I_1 increases from 5 amperes to 10 amperes; E_1 remains 50 volts.

12. R_T = 90 ohms; I_T = 1 amp; E_1 = 65 volts; E_2 = 25 volts. These values are found as follows:

$$R_T = R_1 + R_2 = 65 + 25 = 90 \text{ ohms}$$

$$I_T = \frac{E_S}{R_T} = \frac{90}{90} = 1 \text{ amp}$$

$$E_1 = I_T R_1 = 1 \times 65 = 65 \text{ volts}$$

$$E_2 = I_T R_2 = 1 \times 25 = 25 \text{ volts}$$
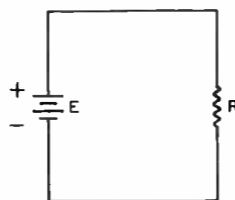
FIGURE 1
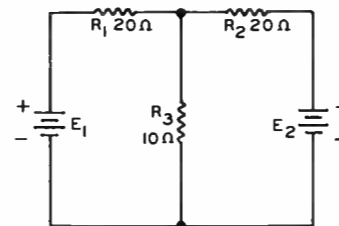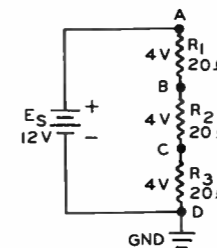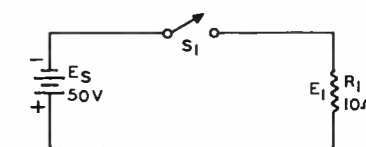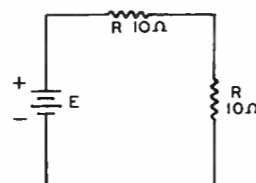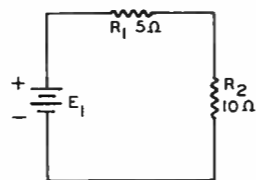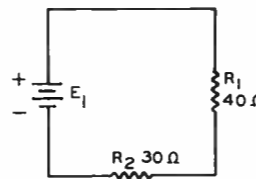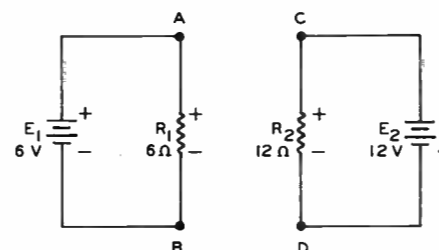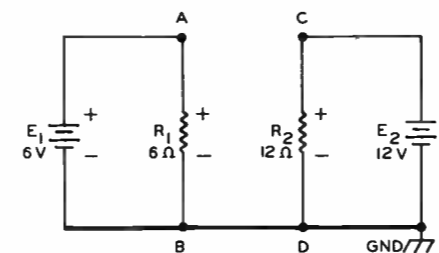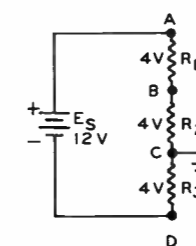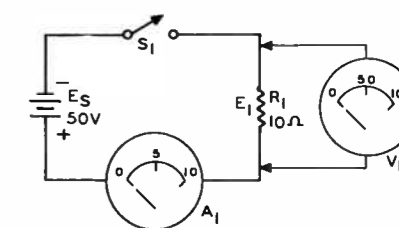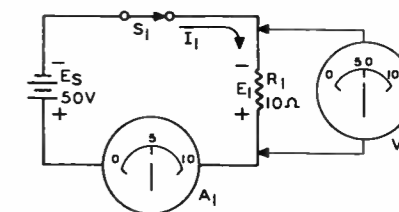
A

B

C

FIGURE 2

FIGURE 3

FIGURE 4

FIGURE 5

FIGURE 6

FIGURE 7

FIGURE 8

A

B

C

FIGURE 9

A

FIGURE 10

FIGURE 11

FIGURE 12

FIGURE 13

1015
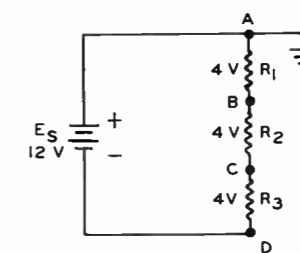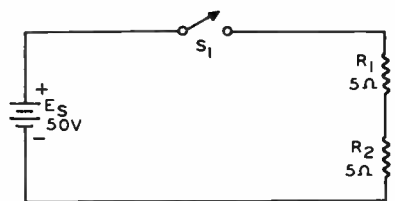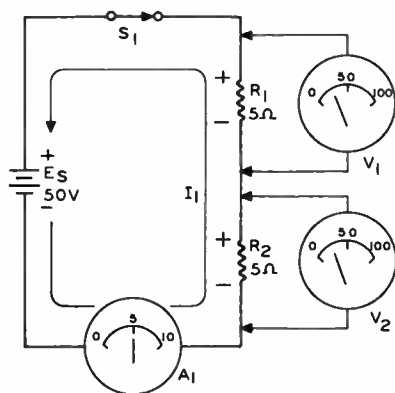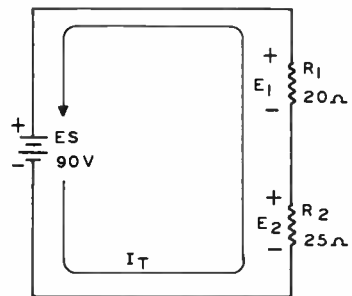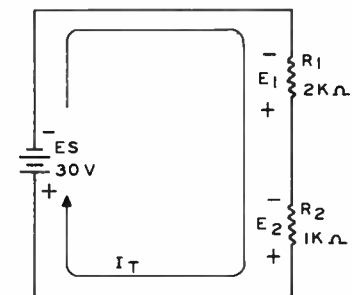
PRACTICE EXERCISE SOLUTIONS (Continued)

13. R_T = 1500 ohms; I_T = 20 ma; E_1 = 10 volts; E_2 = 20 volts.
These values are found as follows:

$$R_T = R_1 + R_2 = 500 + 1000 = 1500 \text{ ohms}$$

$$I_T = \frac{E_S}{R_T} = \frac{30}{1500} = .02 \text{ ampere or } 20 \text{ ma}$$

$$E_1 = I_T R_1 = .02 \times 500 = 10 \text{ volts}$$

$$E_2 = I_T R_2 = .02 \times 1000 = 20 \text{ volts}$$

14. R_T = 120 ohms; I_T = .5 amp; E_1 = 35 volts; E_2 = 10 volts; E_3 = 15 volts.
These values are found as follows:

$$R_T = R_1 + R_2 + R_3 = 70 + 20 + 30 = 120 \text{ ohms}$$

$$I_T = \frac{E_S}{R_T} = \frac{60}{120} = .5 \text{ amp}$$

$$E_1 = I_T R_1 = .5 \times 70 = 35 \text{ volts}$$

$$E_2 = I_T R_2 = .5 \times 20 = 10 \text{ volts}$$

$$E_3 = I_T R_3 = .5 \times 30 = 15 \text{ volts}$$

15. (c) when the source voltage is either ac or dc.

16. (b) the voltage across R_1 (E_1) divided by the resistance of R_1.
--The current through any resistor is always equal to the voltage across it divided by its resistance.

17. False -- In a series circuit, the current is the same in all parts of the circuit.

18. True -- In a series circuit, the source voltage divides between the individual components in proportion to their resistance values.

19. False -- In a series circuit, the voltage across each resistor is directly proportional to the resistance of each resistor.
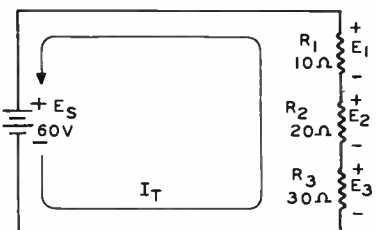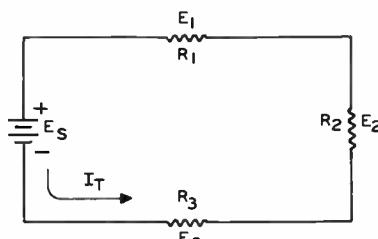
PRACTICE EXERCISE SOLUTIONS (Continued)

20. (b) the same as the voltage across R_1 and is equal to E_S. -- In a parallel circuit, the voltage is the same across all components.

21. (c) less than any of the branch resistances.

22. (a) the sum of the branch currents.

23. (b) is inversely proportional to the branch resistance.

24. 6 amperes arriving and leaving. The current arriving at a junction and the current leaving the same junction are equal.

25. 5 amperes arriving and leaving. The current arriving at a junction and the current leaving a junction are equal.

26. Both the current through R_2 and the total current decrease. --Increasing the resistance of a branch decreases the current through that branch. When the current through R_2 decreases, the total current also decreases.

27. The total resistance is less than the resistance of R_2. -- In a parallel circuit, R_T is less than the resistance of any branch.

28. 3 ohms

$$R_T = \frac{R_1 R_2}{R_1 + R_2} = \frac{4 \times 12}{4 + 12} = \frac{48}{16} = 3 \text{ ohms}$$

29. 10,000 ohms

$$R_T = \frac{R_1 R_2}{R_1 + R_2} = \frac{20,000 \times 20,000}{20,000 + 20,000} = \frac{400,000,000}{40,000} = 10,000 \text{ ohms}$$

Notice that, when two resistors of equal resistance are connected in parallel, the total resistance is equal to one-half the resistance of either resistor.
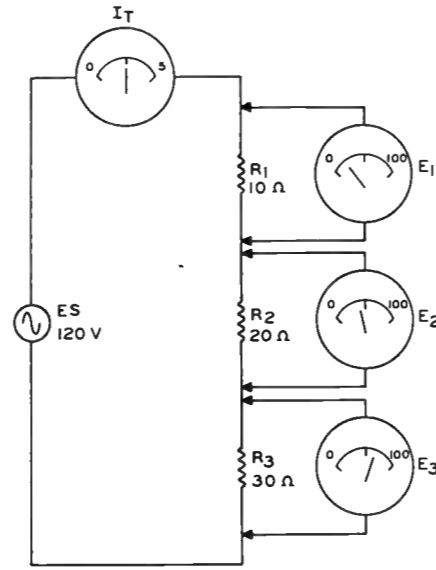
FIGURE 14

FIGURE 15

FIGURE 16

FIGURE 17

FIGURE 18

A

B
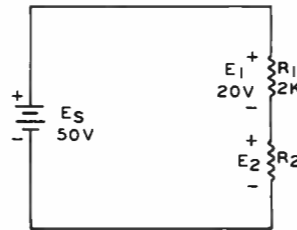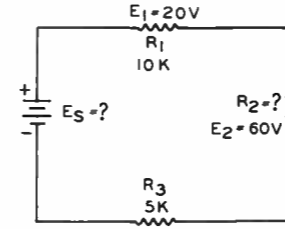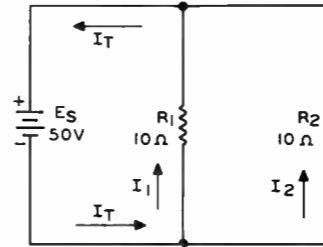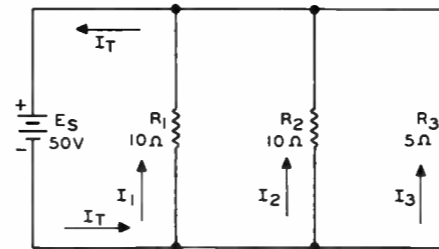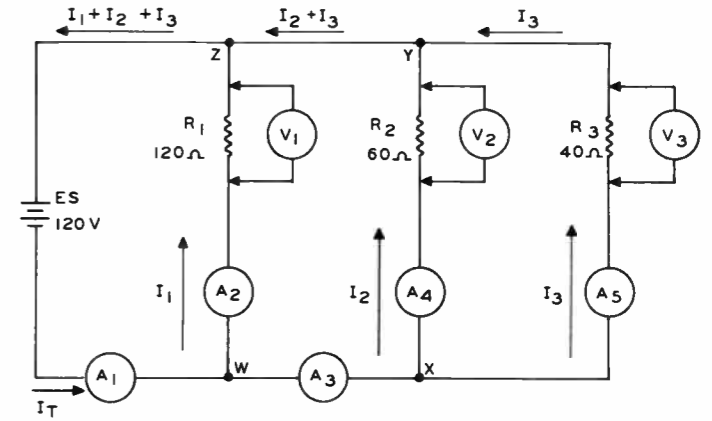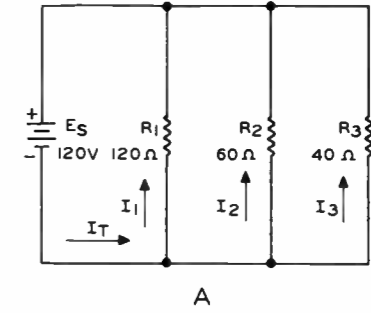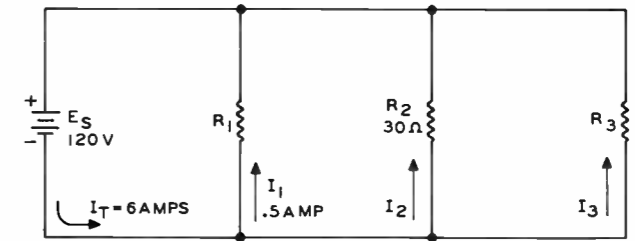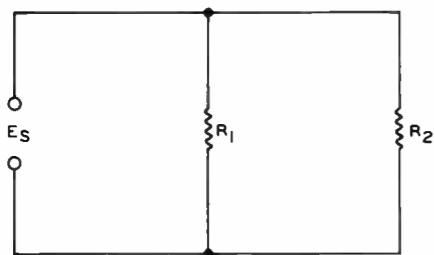
FIGURE 19
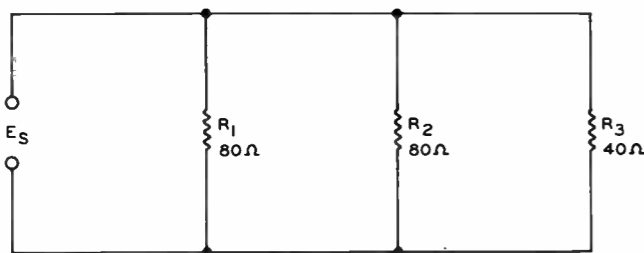
FIGURE 20
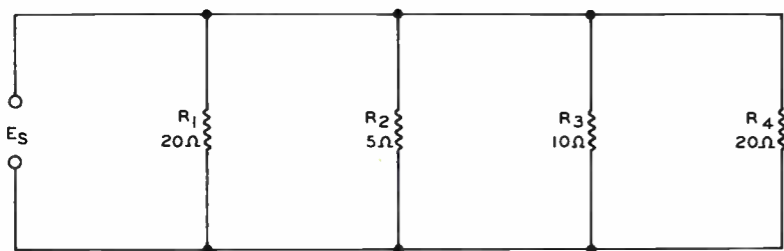
FIGURE 21

FIGURE 22

FIGURE 23

PRACTICE   EXERCISE   SOLUTIONS (Continued)

30. 15 ohms -- Assume a source voltage of 90 volts.   Solve for the branch currents, the total current and the total resistance as follows:

$$I_1 = \frac{E_S}{R_1} = \frac{90}{30} = 3 \text{ amperes}$$

$$I_2 = \frac{E_S}{R_2} = \frac{90}{45} = 2 \text{ amperes}$$

$$I_3 = \frac{E_S}{R_3} = \frac{90}{90} = 1 \text{ ampere}$$

$$I_T = I_1 + I_2 + I_3 = 3 + 2 + 1 = 6 \text{ amperes}$$

$$R_T = \frac{E_S}{I_T} = \frac{90}{6} = 15 \text{ ohms}$$

Remember, any source voltage can be assumed. The circuit currents will change but the resistance will be the same.

31. 22 ohms -- Assume a source voltage of 66 volts.   Solve for the branch currents, the total current and the total resistance as follows:

$$I_1 = \frac{E_S}{R_1} = \frac{66}{66} = 1 \text{ ampere}$$

$$I_2 = \frac{E_S}{R_2} = \frac{66}{66} = 1 \text{ ampere}$$

$$I_3 = \frac{E_S}{R_3} = \frac{66}{66} = 1 \text{ ampere}$$

$$I_T = I_1 + I_2 + I_3 = 1 + 1 + 1 = 3 \text{ amperes}$$

$$R_T = \frac{E_S}{I_T} = \frac{66}{3} = 22 \text{ ohms}$$

Whenever all of the resistors in a parallel circuit are the same resistance, the total resistance of the circuit is equal to the resistance of one resistor divided by the number of resistors.

1015

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question, as illustrated in the example below.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

LESSON CODE

1015A

Example: A young cat is called a

A
B
C ■
D

(A) pup. (B) kitten. (C) cub. (D) chick.

1. When a voltage is indicated at some point in a circuit, the actual meaning is
(A) always the voltage between that point and the positive terminal of the source. (B) the voltage WITHOUT reference to any other point. (C) the voltage between that point and a reference point. (D) the voltage between that point and ANY other point.

2. In electronics, subscripts are used
(A) to identify the components in a circuit. (B) to indicate subordinate parts which are not important to the operation of a circuit. (C) to indicate the resistance of each resistor. (D) only in parallel circuits.

3. In a series circuit, the current is
(A) greater in the high resistance components. (B) the sum of the branch currents. (C) the same in all parts of the circuit. (D) greater in the low resistance components.

4. In a parallel circuit, the current
(A) is greatest in the highest resistance branch. (B) in each branch is added together to determine the total current. (C) is the same in all parts of the circuit. (D) is inversely proportional to the source voltage.

5. In a SERIES circuit, the source VOLTAGE
(A) is ALWAYS divided equally among all components. (B) is applied DIRECTLY across each component. (C) forces a DIFFERENT amount of current through each component. (D) is equal to the sum of the voltages across the components.

6. In a PARALLEL circuit, the source VOLTAGE
(A) is equal to the SUM of the voltages across the components. (B) always forces the SAME amount of current through each branch. (C) is inversely proportional to the resistance of each branch. (D) appears across each branch.

7. In a series circuit, the total resistance
(A) is less than the resistance of any individual resistor. (B) is inversely proportional to the amount of source voltage. (C) is equal to the sum of the individual resistances. (D) increases when the circuit current increases.

8. In a parallel circuit, the total resistance
(A) is less than the resistance of any branch. (B) is equal to the sum of the branch resistances. (C) is greater than the resistance of any branch resistor. (D) increases when the circuit current increases.

9. In Figure 12, if the source voltage is increased from 30 volts to 60 volts,
(A) the total resistance reduces to one third its original value. (B) the voltages across R_1 and R_2 double. (C) the current through R_1 doubles and the current through R_2 is cut in half. (D) there is no change in the circuit current.

10. In Figure 19A, if R_3 is INCREASED from 40 ohms to 120 ohms,
(A) the voltage across R_3 decreases. (B) the current through R_2 decreases. (C) the current through R_3 remains constant. (D) the current through R_3 and the total current decrease.
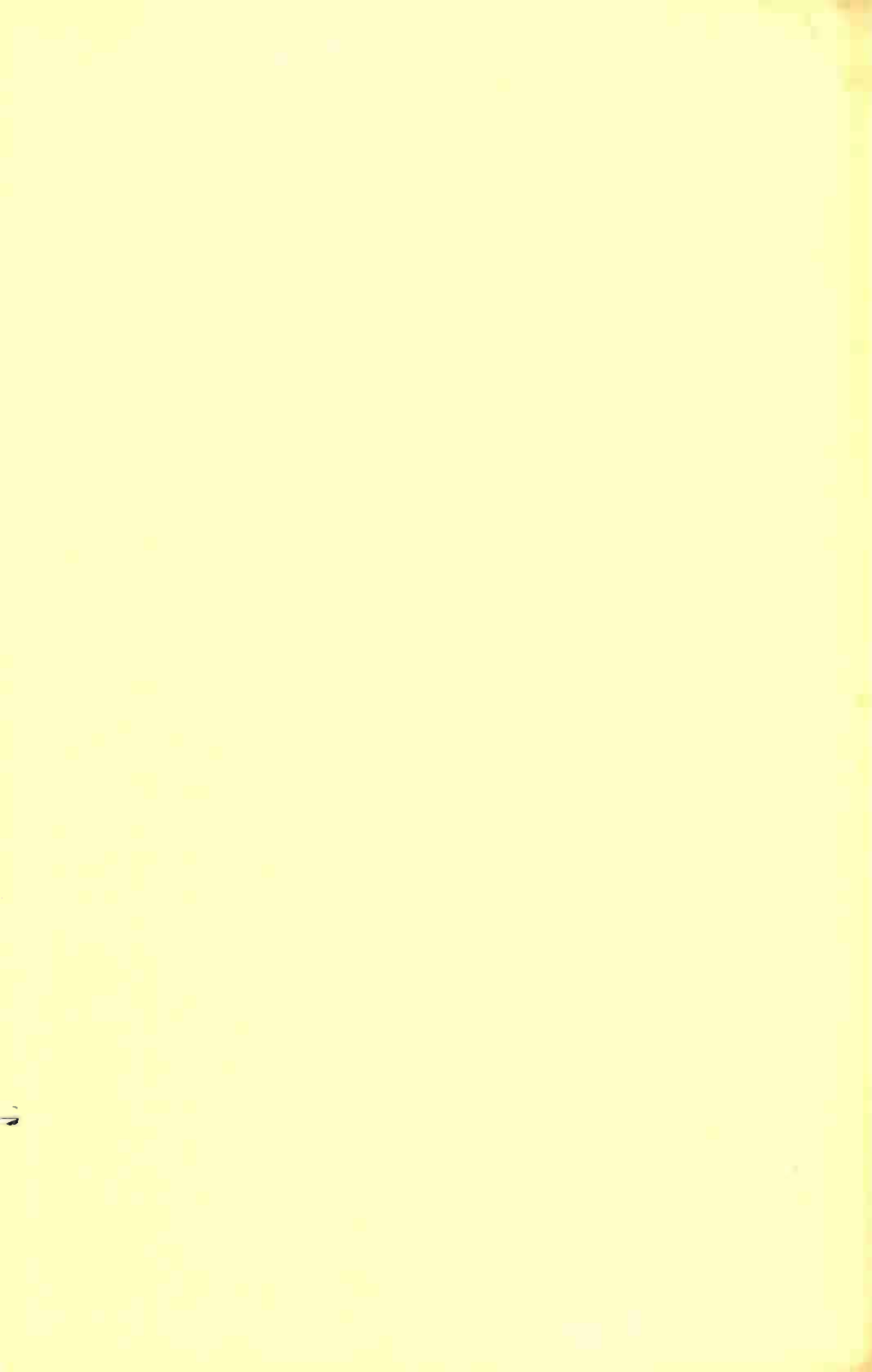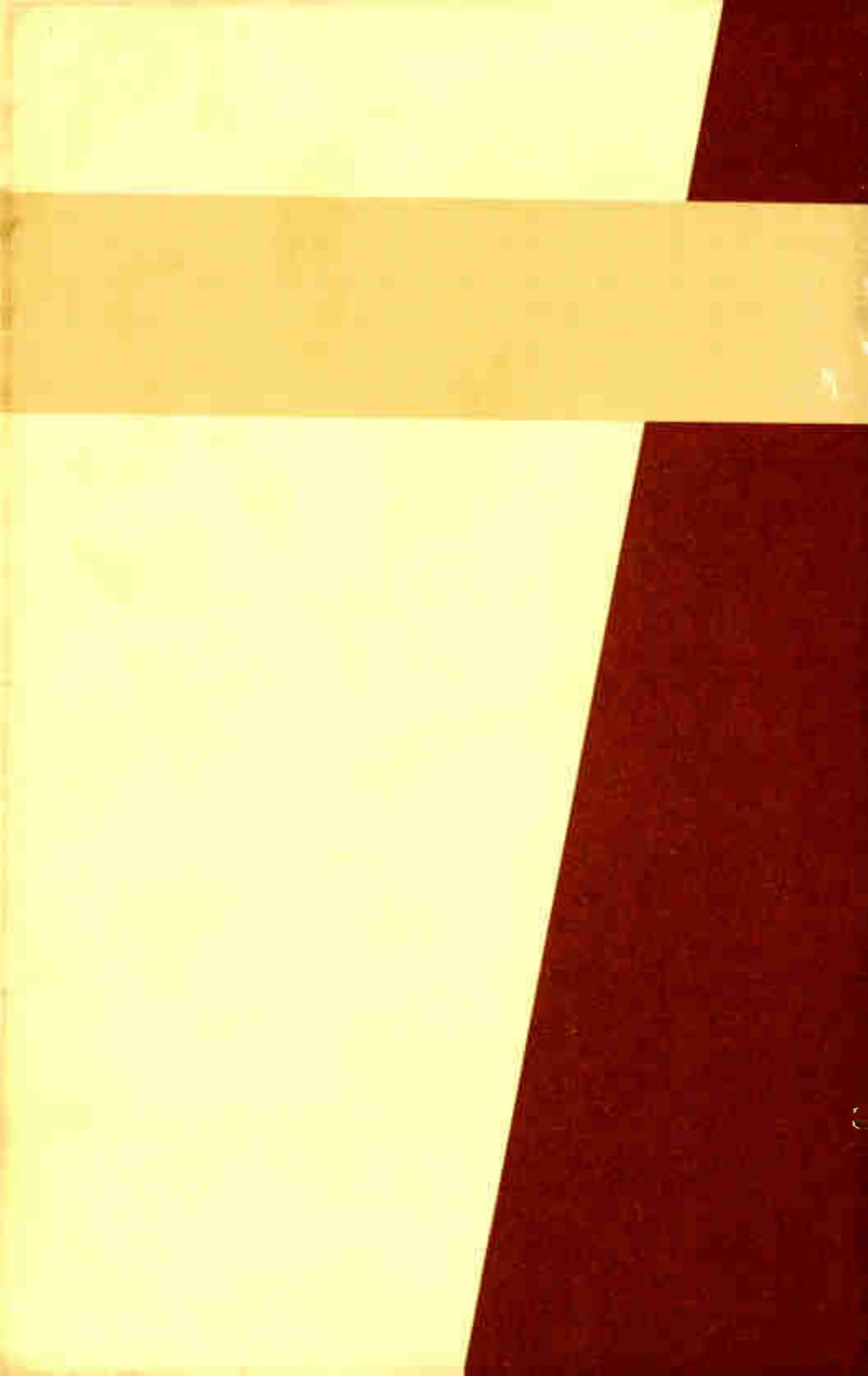
DEDICATED TO PROGRESS THROUGH EDUCATION

ELECTRIC POWER

Lesson 1018C

DeVRY Technical Institute

CHICAGO   TORONTO

YOU CAN'T STAND STILL

Men can be divided into two classes—those who move forward, and those who are going backward—no one can stand still.

Success is the reward of intelligent and persistent effort—setting your sights on a goal, and then doing everything in your power to reach it. Success does not just happen, it must be sought and worked for.

When you finish a job, don't lose time in going on to the next one. It's the daily progress that counts—the constant pull on the oars that carries you forward.

ELECTRIC POWER

Revised 1966

OPPORTUNITY
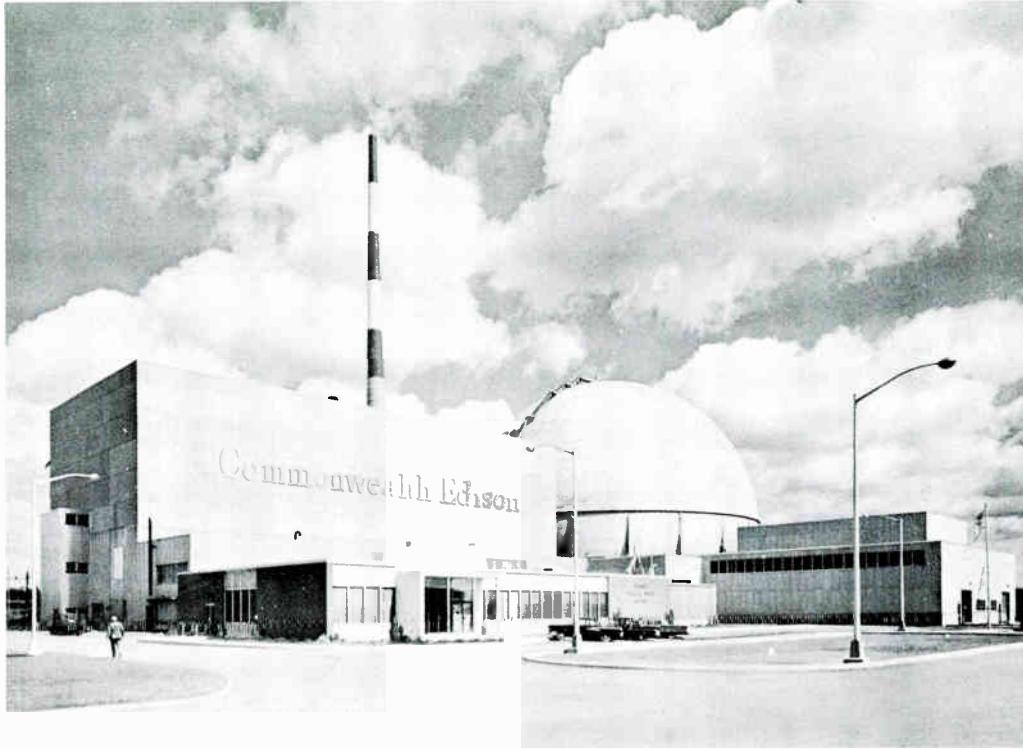
The Dresden Nuclear Power Station near Joliet, III. is capoble of providing 180,000 kilowatts of electric power. A 190 foot diameter steel sphere houses the nucleor reactor and steam generators.
Courtesy Commonwealth Edison Company

ELECTRIC POWER

CONTENTS

***

Learning is wealth to the poor,
an honor to the rich, an aid to
the young, and a support and
comfort to the aged.

Lavater

ELECTRIC POWER

Electric power is one of the most important quantities that we deal with in the study of electricity and electronics. In this lesson we will illustrate several practical ways of determining power. You will find many uses for the simple methods shown.

POWER MEASUREMENT AND POWER DISSIPATION

ELECTRIC POWER is the amount of electric energy produced or used in a given length of time. This period of time is usually one second. Therefore, ELECTRIC POWER IS THE RATE OF USING OR PRODUCING ELECTRIC ENERGY.

Electric power is a relationship between current and voltage. Be careful that you do not make the common mistake of thinking that power just means voltage. Voltage by itself is not power. Electric power is the product of BOTH current and voltage. To find the power used in a part or in a complete circuit we simply multiply the current through that part or through the circuit by the voltage across it.

Putting the method of determining power into a word formula we have:

ELECTRIC POWER = VOLTS × AMPERES

The symbol for electric power is P, that for voltage is E and the symbol for current is I. Using letter-symbol shorthand we can rewrite the power formula as:

$$P = E \times I \qquad (1)$$

*   *   *

1. The electric power of a source is determined strictly by the voltage of the source. True or False?

2.   Where electric power is concerned, both time and electric
     energy must be considered.   True or False?

3.   The ampere, the unit of current measurement, includes time
     in its definition.   True or False?

                    *   *   *

The ampere is the unit of measure of electric current, and
the volt is the unit of measure of electric pressure.   A unit
of measure is also needed for electric power.   In honor of
James Watt, a Scottish inventor, the unit of measure of
electric power is called the WATT.   By definition, a watt is
the basic unit of measure of electric power in a circuit and
is equal to one ampere of current at a pressure of one volt.

                    *   *   *

4.   What is the unit of measure of electric power? *The Watt*

                    *   *   *

Now let's see just how easy it is to find the power being used
in the simple circuit of Figure 1A.   In this circuit we have
battery E_S forcing current through load resistor R_1.   Since
power is found by multiplying the current and the voltage,
we must determine the circuit current before we can find
the power.

From the schematic of Figure 1A we see that the battery
supplies a voltage of 100 volts.   Current through resistor R_1
is found by dividing the voltage across load R_1 by its re-
sistance.   This is a form of Ohm's Law.   Therefore the
current is found by dividing the voltage (100 volts) by the
load resistance (50 ohms).   The answer is 2 amperes.

Once we have the current and the voltage we can easily find
the power.   Power is equal to voltage times current. In Fig-
ure 1A the power is equal to 2 amperes times 100 volts.   The
result of this multiplication gives us the answer 200 watts.

*   *   *

5. Knowing the voltage across a resistor and its resistance
    value, how is the current through it found? $\frac{E}{R} = ?$

6. Electric power is equal to (a) voltage times current, or EI.
    (b) current times resistance, or IR. (c) voltage divided by
    resistance, or E/R.

*   *   *

You may have wondered why some batteries can provide
heavy duty service, as in starting your car, while other
batteries with the same voltage rating are good for only light
duty service, as in operating a pocket radio. The answer
lies in the power ratings of the batteries. Let's apply what
we have learned about power so far to see why you can't use
the battery from your transistor radio to start your car.

Consider a 6 volt wet cell automobile battery with a maxi-
mum current of 500 amperes. Its power output is 6 × 500 =
3000 watts. A 6 volt dry cell battery used in a transistor
radio may have a maximum current of 20 ma. Its power
output is only 6 × .02 = .12 watt. Thus, even though the two
batteries supply the same voltage, the vast difference in cur-
rent capacity makes the automobile battery by far the more
"powerful" of the two.

Suppose you have a circuit with more than one device that
uses power. You use the same method to find the power
dissipated by these devices as you do when there is only one
device. Just multiply the voltage by the current. Finding
the power in a series or parallel circuit gives you a good
chance to apply some of the things you have already learned
about electric circuits.

For example, in Figure 1B there are two 25 ohm resistors
connected in series rather than the one 50 ohm resistor of
Figure 1A. To find the power dissipated in Figure 1B you
must find the total resistance before you can find the circuit
current.

You find the total circuit resistance in Figure 1B by adding resistances R_1 and R_2: 25 ohms + 25 ohms = 50 ohms. Cir-

The tape recorder is a very popular electric load. The amount of power required for proper operation varies from about 25 watts to about 250 watts of power, depending upon the particular recorder.
Courtesy North American Phillips Co.

cuit current is found, as before, by dividing the circuit voltage by the total circuit resistance. Thus, circuit current is 100/50 = 2 amperes. In Figure 1B the total power is equal to the circuit voltage, 100 volts, multiplied by the circuit current, 2 amperes: $100 \times 2 = 200$ watts. This amount of power is being produced by the battery and dissipated in resistors R_1 and R_2.

Notice that the battery voltage E_S is the same in both Figure 1A and Figure 1B. The circuit current is also the same in both circuits. This means the total power will be the same for both circuits. But there is one important difference between the two circuits. In Figure 1A the entire 200 watts is

being dissipated by R_1. In Figure 1B the 200 watts of power is divided between R_1 and R_2.

You can use the same general method to find the power dissipated by either resistor. Remember, POWER IS FOUND BY MULTIPLYING VOLTAGE BY CURRENT. However here you have to be a little careful. The voltage to use is the voltage across the resistor whose power you are determining. Also, the current used is the current through that particular resistor.

With these points in mind, let's find the power dissipated by each resistor in Figure 1B. We have already determined that the circuit current in Figure 1B is 2 amperes. Since this is a series circuit the same current, 2 amperes, must flow through each resistor. From this you can find the voltage across R_1. According to Ohm's Law the voltage across a resistor can be determined by multiplying the current through it by its resistance value. In this case then, the voltage across R_1 is equal to the current, 2 amperes, times its resistance, 25 ohms. The result is 50 volts.

Now that you know both the voltage across R_1 and the current through it, you can determine the power it dissipates. Simply multiply the voltage across R_1, 50 volts, by the current through it, 2 amperes: $50 \times 2 = 100$ watts.

You find the power dissipated in R_2 in the same way. Knowing the current through R_2, multiply it by the resistance value of R_2 to find the voltage across R_2. Then multiply the voltage across R_2 by the current through R_2 to find the power it dissipates. The resistance of R_2 is the same as that of R_1, and the current is the same in each. Therefore, each resistor dissipates the same amount of power, 100 watts.

The total power dissipated in a series circuit is equal to the sum of the powers dissipated in the individual components. Therefore all you have to do to find the total power dissipated in Figure 1B is to add the power of R_1 to that of R_2. Since we said that each resistor dissipates 100 watts, the

total power is 200 watts.   Using the symbol P_T to represent
the total power, P_1 to represent the power of R_1 and P_2 to
represent the power of R_2, we can write this formula using
symbols:

$$P_T = P_1 + P_2 + \ldots \text{ etc.} \qquad (2)$$

The formula above is good for any series circuit.   For in-
stance, if there were three resistors you would add together
the values of P_1, P_2 and P_3.

*   *   *

7. In Figure 1A, if you used a 200 volt battery in place of a 100
   volt battery, how much electric power would be dissipated in
   R_1?   400 watts   800 watts

*   *   *

When working with electronic components , it often happens
that the resistance of a load is hard to measure.   A vacuum
tube, for example, has a heating element whose resistance
increases considerably as its temperature increases.   Be-
cause of this, the cold resistance of the element cannot be
used to determine the current that flows in the circuit when
the tube is operating normally.

A method used to determine the power in a circuit like this
is shown in Figure 2.   In this circuit a block labeled LOAD
represents a tube heating element.   The source voltage is
12.6 volts.   Since we can't calculate the circuit current in
this circuit, we will measure it.   Ammeter A is connected
in series with the load so that the load current passes through
the meter.

Assume the ammeter indicates a current of .6 ampere.   We
now know the voltage across the load and the current through
it.   To find the power dissipated by the load we need only
multiply these values together: 12.6 volts $\times$ .6 ampere =
7.56 watts.

We can also determine the resistance of the heating element during normal operation. For this we will use a form of Ohm's Law. The resistance of the heating element is equal
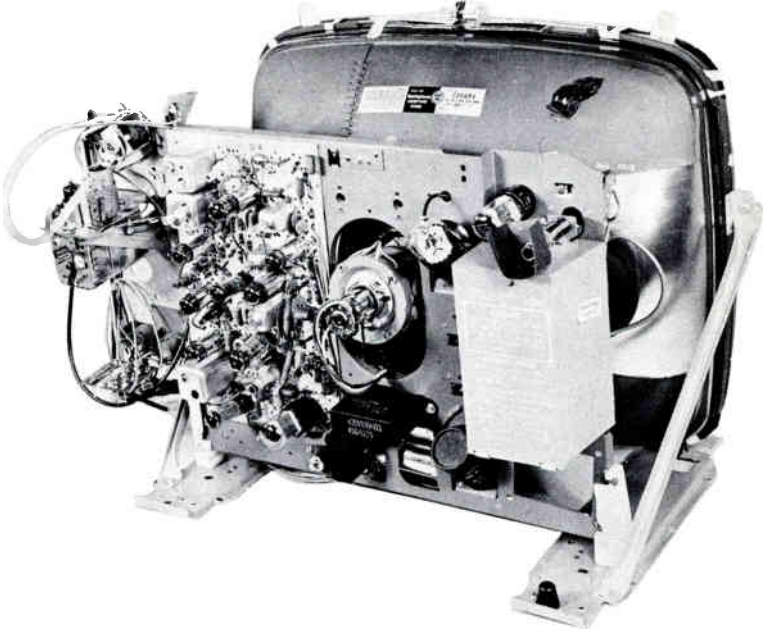
This is the rear view of a 23 inch television receiver. While it may look complicated, the receiver is actually made up of many simple series and parallel circuits.

Courtesy Westinghouse Electric Corp.

to the voltage across it divided by the current through it. The load resistance is equal to 12.6 volts divided by .6 amperes, which is 21 ohms.

You may wonder why such odd values were chosen to represent the electric quantities in this example. These are the actual heating element ratings for a type 12DQ6 vacuum tube which is used in some television receivers.

*   *   *

8. In Figure 2, assume the load is a transistorized high fidelity amplifier and the ammeter reads 3 amperes. How much power is being used by the load?

$$12.6$$
$$\underline{\times \ 3}$$
$$37.8 \ watts$$

9. If the load of Figure 2 is the transmitter in a spacecraft, and the ammeter still reads 3 amperes, how much power is being used by the transmitter? $37.3 watts$

       *   *   *

As we have already explained, the watt is the basic unit of measurement of electric power. It often happens that the power dissipated in a load is less than 1 watt. There are two smaller units of power which can be used in these cases. One is the MILLIWATT (mw). It is one-thousandth of a watt. The other unit, the MICROWATT (μw), is one-millionth of a watt. The following list is a handy comparison of these units.

> 1 watt = 1000 milliwatts
> 1 watt = 1,000,000 microwatts
> 1 milliwatt = .001 watt
> 1 microwatt = .000001 watt

To get some practice using these units we will consider the circuit of Figure 3A. The first step toward finding the total power is to find the total resistance. The total resistance is equal to the sum of the series resistors R_1 and R_2. Therefore, the total resistance equals 1K ohms + 2K ohms, or 3K ohms. This can also be written as 3000 ohms.

The total current I_T is found by dividing the source voltage E_S by the total resistance R_T. In our example the total current is equal to 30/3000, which is .01 ampere or 10 milli-amperes.

Knowing the circuit current we can easily determine the voltages across R_1 and R_2. Simply multiply the circuit current by the resistance values. E_1, the voltage across R_1, is equal to .01 $\times$ 1000 = 10 volts. E_2, the voltage across R_2, is equal to .01 $\times$ 2000 = 20 volts. This points out the fact that with equal currents through several resistors, the resistor with the greatest resistance value will have the greatest voltage across it.

The next step is to find the power dissipated in each resistor of Figure 3A.   The power used by R_1 is equal to the voltage across it, E_1, multiplied by the circuit current, I_T.   As E_1 = 10 volts and I_T = .01 ampere, the power used by R_1 equals 10 × .01 equals .1 watt.   For convenience you might want to write this as 100 milliwatts instead of .1 watt.

Power dissipated in R_2 is found the same way. It is equal to $E_2 \times I_T$.   Since E_2 equals 20 volts and I_T equals .01 amp, the power dissipated equals 20 × .01, or .2 watt.   If you prefer, you can write this as 200 milliwatts.

Total power P_T of Figure 3A is equal to the sum of the individual powers P_1 and P_2: P_T = 100 milliwatts + 200 milliwatts = 300 milliwatts or .3 watt.

Notice that to change from watts to milliwatts, you move the decimal point three places to the right.   This is the same as multiplying by 1000.   To change from milliwatts to watts, move the decimal point three places to the left.   This is the same as dividing by 1000.   It is a good idea to get used to this conversion method, because you will find both units used in technical literature and in the specifications marked on actual equipment.

Another method of determining the total power of Figure 3A is to multiply the total voltage, E_S, by the total current, I_T, as shown earlier: $P_T = E_S \times I_T$.   Therefore, total power equals 30 × .01 = .3 watt.   Both methods give the same answer.

*   *   *

10. One milliwatt is (a) one-millionth of a watt.   (b) one million watts.   (c) one-thousandth of a watt.   (d) one thousand watts.

*   *   *

Let's see what happens to the circuit power if the values of R_1 and R_2 are increased.   Figure 3B is an example.   The total resistance again is the sum of the individual resistances,

R_1 and R_2. Since R_1 = 1 megohm and R_2 = 2 megohms, R_T = 3 megohms or 3,000,000 ohms.

Total current I_T is equal to the source voltages E_S divided by the total resistance R_T. Total current equals 30/3,000,000 = .00001 ampere or 10 microamperes. The voltage across R_1 is equal to the current through it times its resistance. Therefore E_1 = .00001 × 1,000,000 = 10 volts. The voltage across R_2 is found in the same way: E_2 = .00001 × 2,000,000 = 20 volts.

We now have the information we need to determine the power in Figure 3B. The power in R_1 is equal to the voltage across it times the current through it: P_1 = 10 × .00001 = .0001 watt or 100 microwatts. The power in R_2 is equal to the voltage across it times the current through it: P_2 = 20 × .00001 = .0002 watt or 200 microwatts.

Using the above information, there are two ways of finding the total power in Figure 3B. One way is to add the individual power values. 100 microwatts plus 200 microwatts equals 300 microwatts. The other way is to multiply the source voltage E_S by the total current I_T: 30 × .00001 = .0003 watt or 300 microwatts.

To change watts to microwatts, move the decimal point six places to the right. This is the same as multiplying by 1,000,000. To change microwatts to watts, move the decimal point six places to the left, which is the same as dividing by 1,000,000.

*   *   *

11. In Figure 3A, change the source voltage from 30 volts to 60 volts. Calculate the power dissipated in each resistor and the total power.

*   *   *

In series circuits, such as shown in Figures 1B, 3A and 3B,

the total circuit power is equal to the sum of the powers dis-
sipated in all of the individual components. To see how the
total power is determined in a
parallel circuit, let's examine
Figure 4.

The current through each re-
sistor can be found by dividing
the source voltage by the re-
sistance value of the resistor.
The current through R_1 is equal
to the source voltage, 60 volts,
divided by the resistance of R_1,
30,000 ohms. I_1 = 60/30,000 =
.002 ampere. The current
through R_2 is 60/30,000 = .002
ampere. The current through
R_3 is 60/10,000 = .006 ampere.
To find the total circuit current,
just add up the individual branch
currents. Total current, I_T, is
equal to .002 + .002 + .006 =
.01 ampere.

This hand mixer is an electric load which uses
less than 100 watts of power during normal
operation.

Courtesy Sunbeam Corp.

The power in each branch can
be found by multiplying the source voltage by the current
through the branch. Again we are using Equation 1 which
states that P = EI. In the branch containing R_1, the power is
60 × .002 = .12 watt or 120 milliwatts. The power in the
branch containing R_2 also is 60 × .002 = .12 watt or 120 mil-
liwatts. The power in the R_3 branch is 60 × .006 = .36 watt
or 360 milliwatts.

We can find the total power dissipated in Figure 4 by either
of the two methods we used before. To refresh your memory
we will use them both again. One method is to multiply the
source voltage by the total circuit current. In Figure 4 the
source voltage is 60 volts and we determined the total cur-
rent to be .01 ampere. Therefore the total power is 60 × .01
= .6 watt or 600 milliwatts.

The other method is simply to add the powers in the individual branches. Total power is then .12 watt + .12 watt + .36 watt = .6 watt or 600 milliwatts. Either method should give you the same answer.   This means that you can use one method to check the answer you obtained using the other method.

Looking back at what we have learned so far, we can make the following general rule: THE TOTAL POWER IN BOTH SERIES AND PARALLEL ELECTRIC CIRCUITS IS EQUAL TO THE SUM OF THE POWER DISSIPATED IN ALL COMPONENTS.

Although the basic equation for determining power is $P = EI$, there are also other equations which may be used to save time and work. The second and third are developed from the basic equation. One equation which can be used is written as follows:

$$P = I^2R \tag{3}$$

This equation may be used when current and resistance are known but voltage would have to be calculated. The I^2 in this equation means that the current, I, must be multiplied by itself (squared).   To show this condition, the number 2 is placed at the upper right of the letter I. Thus the equation is read as: "Power equals Current squared times Resistance" or "P equals I squared R."

This power equation is very useful because it states the relationship between power, current and resistance. In the circuit of Figure 5A the only known quantities are the total current and the resistance of R_2. Without knowing anything else, we can determine the power dissipated in R_2.   According to Equation 3, to find the power dissipated in R_2, all we do is square the current value and multiply this result by the resistance value of R_2: $2^2 \times 25 = 4 \times 25 = 100$ watts.

*   *   *

12. How many watts are dissipated in a 15 ohm resistor which has 3 amps of current flowing through it?

* $\frac{15}{9}$ $\overline{135\ watts}$ *   *

A third equation may also be used for determining the power in a circuit or component. It includes the voltage across the component or source and the resistance of the compo- nent or circuit. This equation is:

$$P = \frac{E^2}{R} \qquad (4)$$

To find power using this equa- tion, the voltage is first mul- tiplied by itself (squared). The result is then divided by the resistance. This equation is read as "P equals E squared over R" and is useful because it shows the relationship be- tween power, voltage and re- sistance. You can use it to simplify problems where volt- age and resistance are known but current would have to be calculated.

Equation 4 simplifies finding the power of R_1 in Figure 5B. Here we know only the resist- ance of R_1 and the voltage across it. The power dissi- pated across the resistor is $20 \times 20/10 = 400/10 = 40$ watts.
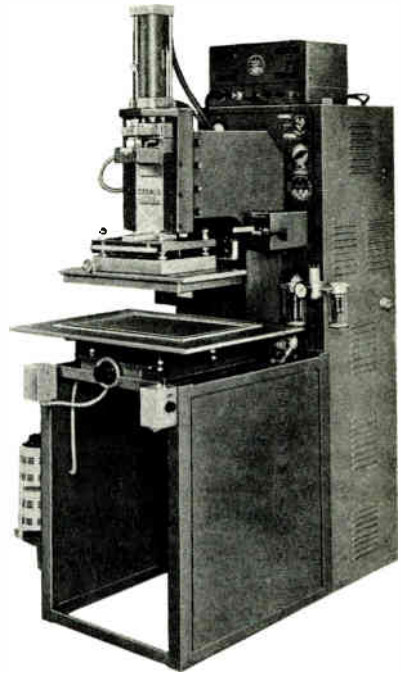
Dielectric heating units are used in many processes requiring heat, such as sealing plas- tic containers. The heater is a load which must be provided with several thousand watts of power from the source of electric energy. Courtesy Cosmos Electronic Machine Corp.

*   *   *

13. How many watts are dissipated in an 18 ohm resistor which is connected across a 6 volt source? $18 \cdot \frac{2}{36}$ watts

*   *   *

Any of the power equations may be rearranged by following

the rules of mathematics. The rearranged form of an equation may make it easier to solve a problem. For example, Equation 1, $P = EI$, can be rearranged to solve for either voltage or current. The rearranged forms of Equation 1 are

$$E = \frac{P}{I}$$

$$I = \frac{P}{E}$$

The second of these equations, $I = P/E$, is particularly useful. Many electric devices are designed to operate with a certain source voltage and to use a certain amount of power. Light bulbs, for example, usually have the voltage and wattage ratings printed on them. When used, these bulbs are connected across the ac line as indicated in Figure 6A. The contacts of switches SW_1 and SW_2 must be able to carry the current through them without becoming burned and without arcing.

The contacts of these switches are rated as to the current they can carry and the voltage they can interrupt. In this circuit the source voltage is 120 volts. Bulb R_1 is rated at 120 watts and bulb R_2 is rated at 240 watts.

Using the equation $I = P/E$ we can determine the current each switch must carry. The current through SW_1 is the wattage of R_1 divided by the source voltage: $I_1 = 120/120 = 1$ ampere. The current through SW_2 is $240/120 = 2$ amperes. Thus, switch SW_1 must be able to carry 1 ampere and switch SW_2 must be able to carry 2 amperes.

The currents in the circuit of Figure 6A can be measured by the arrangement of Figure 6B. Here the bulbs are indicated by resistors R_1 and R_2. The switches are eliminated and ammeters are connected to measure the total current; the current through R_1 and the current through R_2.

*   *   *

14. In the parallel circuit of Figure 6B, what is the relationship
     between I_T, I_1 and I_2? $I_T = I_1 + I_2$

*   *   *

In many circuits, fuses are employed as safety devices.
Basically, a fuse is a low resistance element that is de-
signed to carry a certain amount of current. If that amount
of current is exceeded, the element burns out and opens the
circuit. In this way, the fuse protects the wiring and the
source of voltage from being overloaded. As a rule, a

This dc power supply converts the ac line voltage (117 volts ac) to a dc voltage which can be ad-
justed from 0 to 32 volts. It is capable of supplying 15 amps of current for a total power capability
of about 480 watts.

Courtesy Electro Products Laboratories, Inc.

fuse is chosen so the normal load current through it is
slightly less than the current rating of the fuse.

*   *   *

15. In the circuit of Figure 7, which of the following fuses should you use? (a) 10 amp fuse   (b) 15 amp fuse   (c) 20 amp fuse   (d) 25 amp fuse

*   *   *

POWER RATINGS OF ELECTRIC LOADS

All electric loads are rated as to the amount of power they normally use or dissipate. This rating is not always specified simply in terms of wattage. Ratings may give voltage, or voltage and current, or voltage and wattage.

The power rating of a device such as a home room air conditioner, for example, is usually specified in terms of voltage and current and the unit must be operated under the proper conditions. Let's assume that an air conditioner has a motor which is designed to draw 3 amps of current when connected across 120 volts and operating normally. The power used by this motor is then 360 watts (120 volts × 3 amps).

If the only available voltage source is 240 volts, you cannot connect this motor directly across it. The current would increase and the amount of power used by the motor would be much more than normal. As a result, the motor would burn out in a very short time.

Consider this same motor, if it were connected across a source voltage much lower than 120 volts. It might not be able to develop enough turning force to move its mechanical load. If a motor does not rotate it can draw excessive current and exceed its power rating. Thus, we see that it can be important to operate an electric motor at its rated voltage if we expect it to deliver the mechanical power intended without damage to the motor.

*   *   *

16. A particular electric motor is rated at 120 volts and 5 amps.
     Why is it not rated at simply 600 watts? *Because at 270 V.*
     it would draw less current, and not develop its turning force.
     It would burn in a short time.

*   *   *

Other electric loads, such as light bulbs, have both a volt-
age and wattage rating.   Light bulbs for home use are all
rated at 120 volts but they may have wattage ratings of 60
watts, 100 watts, 150 watts, etc.   These ratings mean that
the bulb will dissipate its rated wattage when connected to a
source of 120 volts.   If the voltage source is less than 120
volts, the bulb dissipates less than its rated wattage and
gives off less light.   If the voltage source is more than 120
volts, the bulb dissipates more than its rated wattage and
will probably burn out.
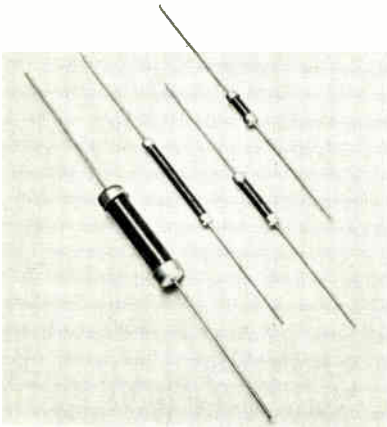
The largest of these ceramic resistors is capa-
ble of dissipating 25 watts of electric power,
while the smallest resistor is limited to about
1 watt.

Courtesy Carborundum Co.

Other common electric loads
are the vacuum tubes that are
used in radios, TV sets, and
other types of electronic equip-
ment.   Inside a vacuum tube
there is a special heating ele-
ment which heats the tube to
its proper operating tempera-
ture.   Each tube requires a
specific amount of voltage and
current, which may be differ-
ent from tube to tube. In Fig-
ure 8, the heating elements of
three tubes (designated R_1, R_2
and R_3) are connected in series
with resistor R_X.   Elements
R_1 and R_2 both require 35 volts
and .15 amp, while element
R_3 requires 12 volts and .15

amp. By connecting the three elements as a series circuit,
the total voltage required is the sum of the individual volt-
ages, or 82 volts.

If you connected the series arrangement of these three elements (without R_X) directly across the 120 volt source in your home, the power rating of each element would be exceeded and the elements would probably burn out.   To prevent this undesirable condition, resistor R_X is connected in series with the heating elements as shown in Figure 8. Since the voltage required for the three heating elements is 82 volts, the voltage across R_X must be 120 – 82, or 38 volts.

The current through R_X is the same as through the other components (.15 amp).   The required resistance of R_X is found by Ohm's Law as follows:

$$R_X = \frac{E_{R_X}}{I} = \frac{38}{.15} = 253 \text{ ohms}$$

In practice, you would connect a 250 ohm resistor for R_X so the tube heating elements would dissipate the proper amount of power.

Resistor R_X cannot be just any 250 ohm resistor.   Since it has 38 volts across it and .15 amp through it, the power dissipated by R_X is

$$P = EI = 38 \times .15 = 5.7 \text{ watts.}$$

Therefore, R_X must be capable of dissipating at least 5.7 watts without overheating. In most cases, it is a good policy to use a resistor which has a slightly higher wattage rating than the amount of wattage the resistor is actually dissipating. In this case, a 7 watt resistor will provide a margin of safety.

Keep in mind that any wattage rating greater than 5.7 watts is satisfactory for R_X in this case. However, the greater the wattage rating of a resistor, the larger and more expensive it becomes. Thus, you would probably choose a resistor which provides a small margin of safety.

*   *   *

17. In the circuit of Figure 8, if E_S were 100 volts instead of 120 volts, what value of resistance would you use for R_X? How much power would you expect R_X to dissipate? *2.7 watts*

18. Referring to Exercise 17, if the available resistors have wattage ratings of 1 w, 2 w, 5 w and 10 w, which wattage rating would you use? *5 watts*

*   *   *

As pointed out, the power ratings of electric loads are very important. Where devices such as lamps, toasters, TV sets, and radios are concerned, the power used or dissipated by each unit should be very close to the wattage rating of the unit. Otherwise, the unit will not operate properly and in some cases may be damaged. Where resistors are concerned, the wattage rating specifies the maximum amount of power that may be safely dissipated by the resistors. A 10 watt resistor should not be used in a circuit where the resistor will have to dissipate 11 watts of power. However, a 10 watt resistor may be used in a circuit where the resistor dissipates any amount of power less than 10 watts.

POWER RATINGS OF ELECTRIC SOURCES

Many people have had the unpleasant experience of trying to start a car, only to find that the starter will not turn the engine over fast enough to start it. In most cases, there is nothing wrong with the engine or the starter -- replacing or recharging the car battery clears up the trouble.

Depending on various factors (engine size, temperature, etc.), the starter in a car requires from 750 to 3000 watts of electric energy to operate properly. This energy must be supplied by the battery. The battery in your car is designed to provide the necessary electric energy to operate the starter in your car when the battery is in good condition. If the battery is defective, it is no longer capable of supply-

ing enough electric energy and your car won't start.

Each of these nickel-cadmium cells is a source of electric power which produces 1.25 volts under no-load conditions. The power capabilities of the cells, however, range from about 1 watt to about 1000 watts.

Courtesy Sonotone Corporation

Also, the battery must be sufficiently charged before it can supply power. The car generator charges the battery at a much lower rate than the rate of discharge during starting. The generator may, for example, provide 150 watts of power to charge the battery. However, the charging continues for a long period of time compared to the few seconds during starting when the battery supplies a great amount of power. Thus, a battery of this type USES a small amount of power for a long time but may DELIVER a very large amount of power for a shorter interval.

Earlier in this text, a comparison was made between a rechargeable 6 volt wet cell battery for an auto and a 6 volt dry

cell battery for a transistor radio. Many transistor radios require only .05 amp of current from a 6 volt battery for a total power consumption of .3 watt ($P = 6 \times .05$). Thus, a constant, low-level power source is needed. Some small, 6 volt batteries are capable of supplying .1 amp of current, or .6 watt of power. Such a battery could provide the power needed by the radio and still have a reserve. Usually a battery can provide a small amount of power for a longer period of time than when a large amount is provided. The small dry cell used for radios, however, could never supply enough power to start an auto, even for an extremely short time.

*   *   *

19. All 12 volt batteries are capable of supplying the same amount of electric power. True or False?

*   *   *

There are many sources of electric power other than batteries. The most common of these sources, which supply electric power to homes, factories, and businesses, are the electric power generating stations. Let's consider a generating station capable of producing 180,000 kilowatts. (The prefix "kilo" means 1000, so 180,000 kilowatts is the same as 180,000,000 watts.) The voltage produced by this particular power station is 14,400 volts, and the station is capable of supplying 12,500 amperes. Multiplying the voltage by the current gives the power capability of 180,000 kilowatts.

Keep in mind that all sources of electric power are limited as to the amount of electric power they can produce. Even the 180,000 kilowatt power station has a limit which must not be exceeded. Figure 9 is a simplified schematic diagram where E_S represents the power station and resistor R_X represents the load. In this case, the load might be all of the homes and industries in a small town, and this load might change considerably. With SW_1 closed, and assuming R_X

is 10 ohms, the current through R_X is

$$I = \frac{E_S}{R_X} = \frac{14,400}{10} = 1440 \text{ amps.}$$

Since the power station is capable of supplying 12,500 amperes, it can supply 1440 amperes very easily. The total power supplied is

$$P = EI = 14,400 \times 1440 = 20,736,000 = 20,736 \text{ kilowatts}$$

which is considerably less than the 180,000 kilowatts the station is capable of supplying.

On the other hand, if the homes and industries suddenly started using more electricity, this would effectively reduce the resistance of R_X. Let's assume that R_X reduces to 1 ohm. Now the current is

$$I = \frac{E_S}{R_X} = \frac{14,400}{1} = 14,400 \text{ amps}$$

and the power is

$$P = EI = 14,400 \times 14,400 = 207,360 \text{ kilowatts.}$$

In this case, the total current and total power demanded by the load are greater than the station is capable of supplying. As a result, the equipment in the power station is overworked and will probably be damaged if precautions are not taken. To prevent damage to the equipment, power stations have special switching arrangements which automatically remove excessive loads.

The power rating of any source, then, tells you the MAXIMUM amount of power the source can supply to a load. For example, a source that is rated at 1000 watts should not be used to supply more than 1000 watts of power or it may be damaged.

Internal Resistance of the Source

There are several reasons why a source of electric energy
is limited as to its power capabilities. One of these reasons
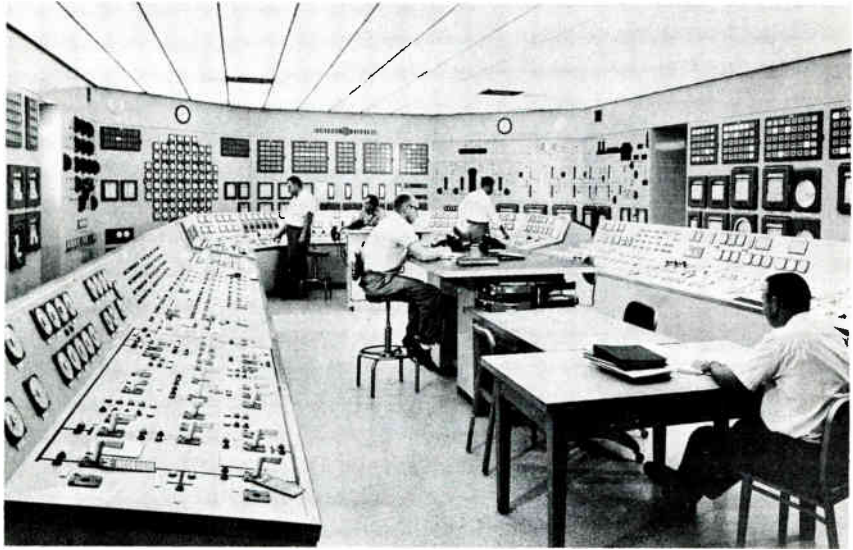
The control room of the Dresden Nuclear Power Station. A vast amount of electric equipment is
necessary to help supervise the production of 14,400 volts with a current capability of 12,500 am-
peres. The power is eventually distributed at a voltage of 138,000 volts.

Courtesy Commonwealth Edison Company

is that all sources of electric power have internal resistance.
This is indicated in Figure 10A by dividing the battery into
two parts and inserting the internal resistance, R_I, between
the two parts. Resistance R_I is not a resistor which is con-
nected into the circuit, it is a part of the battery.

Often, the internal resistance of a source is not shown on
a schematic diagram. When it is shown, however, it is
usually drawn in series with the source as in Figure 10B.
As all current delivered by the source flows through this
resistance, Figure 10B is basically the same as Figure 10A.
It is easier to draw and use, however.

*   *   *

20. In Figures 10A and 10B, what does R_I represent? ~~The~~
           The   internal   Resistance   of   the   Source .
                    *   *   *

Referring to Figure 10B, let's assign some values to the var-
ious components. Assume E_S is 100 volts, R_L is 99 ohms,
and R_I is 1 ohm. The total resistance in the circuit is the
sum of R_L and R_I, or 100 ohms. The total current, I_T, is

$$I_T = \frac{E_S}{R_T} = \frac{100}{100} = 1 \text{ amp.}$$

The voltage across R_L is

$$E_{R_L} = I_T R_L = 1 \times 99 = 99 \text{ volts.}$$

The voltage across R_I is

$$E_{R_I} = I_T R_I = 1 \times 1 = 1 \text{ volt.}$$

The 1 volt across R_I cannot be measured with a voltmeter
since it occurs inside the battery. The net effect is that
the voltage actually available at the battery terminals is 99
volts instead of 100 volts. It is this reduced E_S that appears
across load resistance R_L.

A loss of 1 volt out of 100 volts is not too serious and can be
tolerated. Suppose, however, that R_L is changed from 99
ohms to 9 ohms. The total resistance is now 10 ohms and
the total current becomes 10 amps. With 10 amps of cur-
rent in the circuit, the voltage across the internal resist-
ance R_I is 10 volts, which leaves only 90 volts at the battery
terminals. Under these conditions, the power used by the
load resistance R_L is 900 watts (90 volts $\times$ 10 amps) while
the power dissipated by the internal resistance R_I is 100
watts (10 volts $\times$ 10 amps).

Since the power dissipated by the internal resistance of the
source is wasted, it is desirable that the internal resistance
be as small as possible. The ideal situation would be an
internal resistance of zero. Unfortunately, this is not pos-
sible, and all power sources have some internal resistance.

*   *   *

21. In the circuit of Figure 10B, minimum loss is obtained when
     (a) R_L is as small as possible. (b) R_I is equal to R_L. (c) R_I
     is as small as possible. -

*   *   *

Resistance of Connecting Wires

Another cause of power losses is the resistance of the wires
that connect the source to the load. This resistance is dis-
tributed evenly along the entire length of the wires as sug-
gested by the schematic diagram of Figure 11A. Here the
circuit current flows through the distributed resistance, R_D,
as well as through the load resistance, R_L. The voltage
across the distributed resistance is wasted, since this volt-
age does not appear across the load resistance.

*   *   *

22. In the circuit of Figure 11A, the resistors labeled R_D (a) are
     voltage dropping resistors to prevent overloading R_L.
     (b) represent the resistance of the wires that connect the
     source to the load. (c) are unimportant and have no effect
     on any circuits.

*   *   *

Rather than show the distributed resistance as many resis-
tors on a schematic diagram, it is common practice to show
the entire resistance of the connecting wires as one resis-
tor. Thus, in Figure 11B the single resistor R_D represents
the resistance of the wires that connect the source to the
load.

The effects of distributed resistance are best illustrated by
examples. In your home, an electric toaster may require
1800 watts of electricity at 120 volts for proper operation.
We can determine the current drawn by the toaster as follows:

$$I = \frac{P}{E} = \frac{1800}{120} = 15 \text{ amps}$$

Using Ohm's Law and solving for the resistance of the toaster:

$$R = \frac{E}{I} = \frac{120}{15} = 8 \text{ ohms}$$

Now we have all of the necessary information about the toaster. It operates on 120 volts, has 8 ohms of resistance, draws 15 amperes of current, and dissipates 1800 watts of power. We still need information concerning the line cord used to connect the toaster to the source of electricity. Let's assume the line cord is 8 feet long and is made with No. 18 stranded wire. The resistance of No. 18 wire is about .006 ohm per foot. Since an 8 foot line cord has 16 feet of wire, the total resistance of the line

Resembling a motor, this device is an electric generator capable of producing 115 volts dc at approximately 4.4 amps. Thus, the power capability is about 500 watts.
Courtesy General Electric Co.

cord is about .1 ohm. With 15 amps of current through the line cord, the voltage lost is

$$E = IR = 15 \times .1 = 1.5 \text{ volts.}$$

The power dissipated in the line cord is

$$P = EI = 1.5 \times 15 = 22.5 \text{ watts.}$$

In this case, the 22.5 watts of power dissipated in the line is wasted as it does nothing except heat the line cord. Although 22.5 watts of power distributed over an 8 foot line cord is undesirable, no real damage would occur and the toaster would operate normally.

Suppose, however, that most of the strands in the cord have

become broken through use and the resistance of the cord increases to 1 ohm. The circuit would now be as shown in Figure 12A. The total resistance is

$$R_T = R_D + R_L = 1 + 8 = 9 \text{ ohms.}$$

The circuit current now becomes

$$I = \frac{E}{R} = \frac{120}{9} = 13.3 \text{ amps.}$$

The voltages across R_D and R_L are as follows:

$$E_{R_D} = IR_D = 13.3 \times 1 = 13.3 \text{ volts}$$

$$E_{R_L} = IR_L = 13.3 \times 8 = 106 \text{ volts}$$

The power dissipated by R_D is

$$P_{R_D} = E_{R_D}I = 13.3 \times 13.3 = 177 \text{ watts (approx.).}$$

The power dissipated by R_L is

$$P_{R_L} = E_{R_L}I = 106 \times 13.3 = 1410 \text{ watts (approx.).}$$

The power used in the toaster is now only 1410 watts instead of the normal 1800 watts, so the toaster may not function properly. In addition, the power wasted in the line cord resistance is 177 watts, which is far greater than the average line cord can withstand, so the cord may burn up.

*   *   *

23. In Figure 12B, how much power is used in R_L?   How much power is lost in R_D?   *512 watts , 128 watts*

*   *   *

We can see that it is very important that the resistance of connecting wires between the source and the load, and the

internal resistance of the source, be kept as low as possible. Both of these resistances limit the amount of power that can be supplied by a source or used by a load.

SUMMARY

The power rating of a source of electric energy — battery, power station, etc. — tells you the maximum amount of power the source can supply. The power rating of a resistor tells the maximum amount of power the resistor can safely dissipate. The power rating of some loads tells you that the load should dissipate a specific amount of power. If the load dissipates more power, it will probably be damaged. If it dissipates less power, it will not function properly.

The total power being used in any electric circuit may be determined in various ways. The source voltage can be multiplied by the total current ($P = EI$); the square of the source voltage can be divided by the circuit resistance ($P = E^2/R$); the circuit current can be squared and multiplied by the circuit resistance ($P = I^2R$); or the power dissipated by each component may be calculated and added together to obtain the total power dissipated ($P_T = P_1 + P_2 + P_3 \ldots$ etc.)

IMPORTANT DEFINITIONS

ELECTRIC POWER - The rate of producing or using elec-
   tric energy.

INTERNAL RESISTANCE - The resistance that is part of an
   electric device because of its physical construction.

KILOWATT (kw) - [KIL uh waht] - One thousand watts.

MICROWATT (μw)- [MIGH kroh waht] - One-millionth of a
   watt.

MILLIWATT (mw) - [MIL i waht] - One-thousandth of a watt.

WATT (w) - [waht] - The unit of measure of electric power.
   One watt is equal to one ampere of current at a pres-
   sure of one volt.

ESSENTIAL SYMBOLS AND EQUATIONS

E - voltage   (volts)

I - current   (amperes)

P - power   (watts)

R - resistance   (ohms)

$$P = EI \tag{1}$$

$$P_T = P_1 + P_2 + \ldots \text{ etc.} \tag{2}$$

$$P = I^2 R \tag{3}$$

$$P = \frac{E^2}{R} \tag{4}$$

STUDENT NOTES

PRACTICE EXERCISE SOLUTIONS

1. False -- The power of a source is related to BOTH its voltage and current.

2. True -- By definition, electric power is the rate of using or producing electric energy.

3. True -- An ampere is defined as one coulomb of charge passing a given point in one second.

4. the watt

5. The current is found by dividing the voltage across the resistor by its resistance value. This is a form of Ohm's Law and can be written: $I = E/R$.

6. (a) voltage times current, or EI.

7. 800 watts -- With E_S equal to 200 volts, the current is 200 ÷ 50 or 4 amps. The power is 200 × 4, or 800 watts.

8. 37.8 watts -- $P = EI = 12.6 \times 3 = 37.8$ watts.

9. 37.8 watts -- It doesn't matter what kind of a load is using the power.

10. (c) one-thousandth of a watt.

11. Power of R_1 = .4 watt, power of R_2 = .8 watt, total power = 1.2 watts. -- The problem is solved as follows:
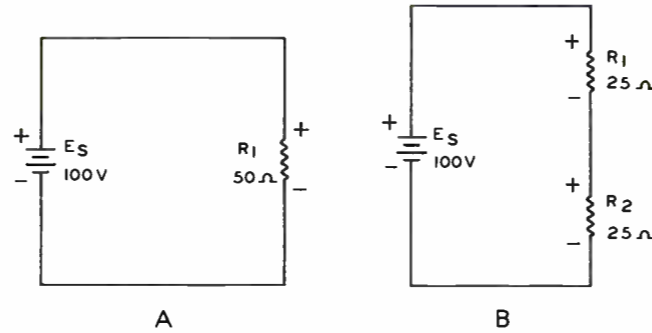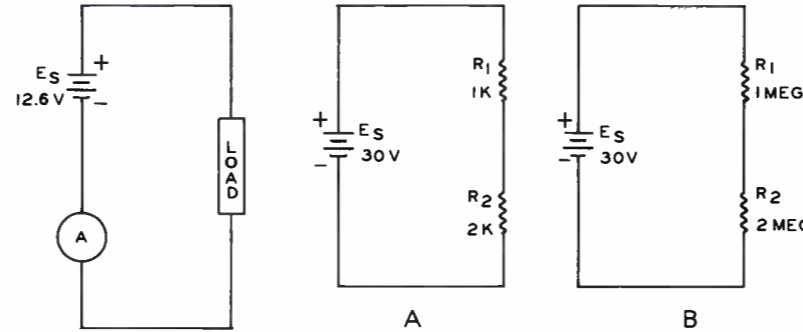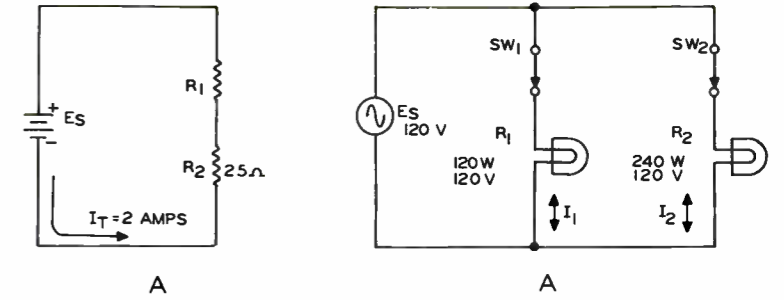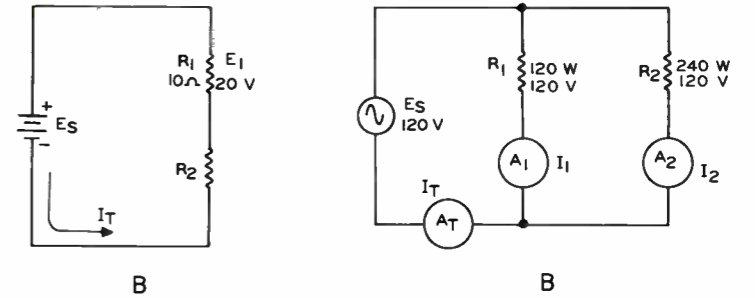
Total resistance	=	1000 + 2000 = 3000 ohms
Total current	=	60/3000 = .02 ampere
Voltage across R_1	=	.02 × 1000 = 20 volts
Voltage across R_2	=	.02 × 2000 = 40 volts
Power of R_1 = 20 × .02	=	.4 watt
Power of R_2 = 40 × .02	=	.8 watt
Total power = 60 × .02	=	1.2 watts
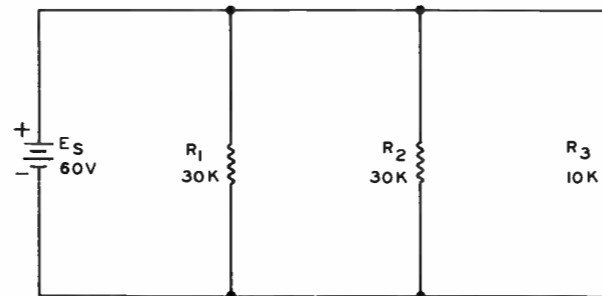
FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

FIGURE 5

FIGURE 6

FIGURE 7

FIGURE 8

FIGURE 9

A

B

FIGURE 10

A

B
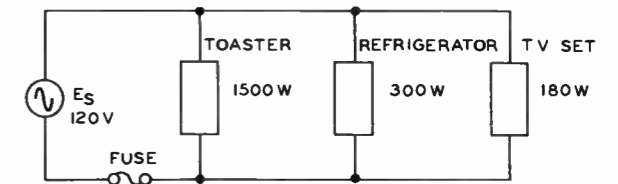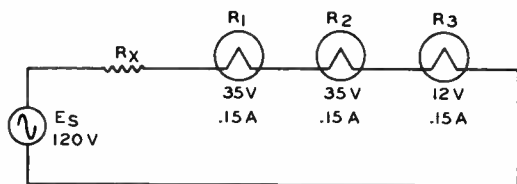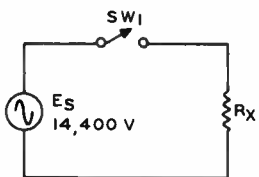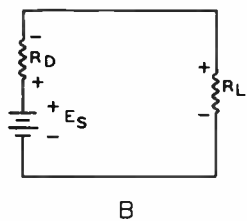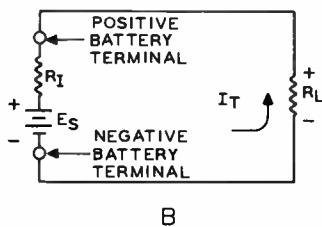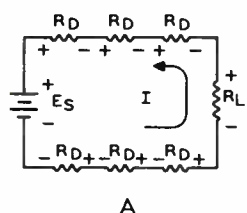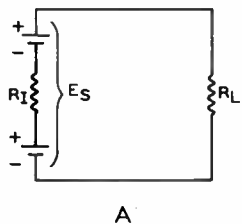
FIGURE 11

PRACTICE EXERCISE SOLUTIONS (Continued)

12. 135 watts -- $P = I^2R = 3^2 \times 15 = 9 \times 15 = 135$ watts

13. 2 watts -- $P = \dfrac{E^2}{R} = \dfrac{6^2}{18} = \dfrac{36}{18} = 2$ watts

14. $I_T = I_1 + I_2$ -- In a parallel circuit, the total current is equal to the sum of the branch currents.

15. (c) 20 amp fuse -- When the wattage and voltage are known, current is determined by $I = P/E$. Thus, the toaster current is 12.5 amps, the refrigerator current is 2.5 amps, the TV set current is 1.5 amps, and the total current is the sum of these currents, which is 16.5 amps. Since the fuse must carry the total current, the 20 amp fuse is the smallest of the choices which is rated at more than 16.5 amperes.

16. Because operation at the proper voltage is important. In addition, motors are not usually compared according to wattage used, but more often by the mechanical horsepower they can produce.

17. 120 ohms, 2.7 watts -- The voltage across R_X would be 100 - 82, or 18 volts. The resistance of R_X would have to be

$$R_X = \frac{E_{R_X}}{I_T} = \frac{18}{.15} = 120 \text{ ohms}$$

The power dissipated by R_X would be

$$P_{R_X} = E_{R_X}I_T = 18 \times .15 = 2.7 \text{ watts}$$

18. 5 w -- The resistor must have a wattage rating equal to, or greater than the amount of power it dissipates. The 10 watt resistor could be used as well as the 5 watt resistor. However, a 5 watt resistor provides a sufficient safety factor for most applications, and at a lower cost.

19. False -- The voltage produced by a battery does not alone determine its power capabilities. The power it can supply is determined by both its voltage and its current capabilities.

20. The internal resistance of the source.

PRACTICE EXERCISE SOLUTIONS (Continued)

21. (c) R_I is as small as possible.

22. (b) represent the resistance of the wires that connect the source to the load.

23. P_{R_L} = 512 watts, P_{R_D} = 128 watts -- The problem is solved as follows:

$$R_T = R_D + R_L = 8 + 32 = 40 \text{ ohms}$$

$$I_T = \frac{E_S}{R_T} = \frac{160}{40} = 4 \text{ amps}$$

$$E_{R_D} = I_T R_D = 4 \times 8 = 32 \text{ volts}$$

$$E_{R_L} = I_T R_L = 4 \times 32 = 128 \text{ volts}$$

$$P_{R_D} = E_{R_D} I_T = 32 \times 4 = 128 \text{ watts}$$

$$P_{R_L} = E_{R_L} I_T = 128 \times 4 = 512 \text{ watts}$$
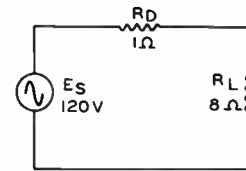
A
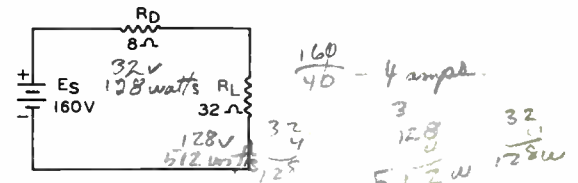
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FIGURE 12
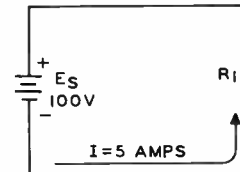
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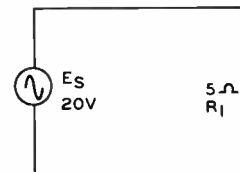
B

FIGURE 13

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question, as illustrated in the example below.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

LESSON CODE

1018C

Example: A famous river in Africa is the
(A) Mississippi. (B) Ganges. (C) Nile. (D) Rhine.

1. In an electric circuit where the source voltage is 200 volts and the total circuit current is 2 amperes, how much power is being used?
(A) 400 watts, (B) 100 watts, (C) 600 watts, (D) 202 watts.

2. Of the following sources, which can provide the most power?
(A) a 60 volt source capable of supplying 10 amperes, (B) a 12 volt source capable of supplying 10 amperes, (C) a 100 volt source capable of supplying 10 amperes, (D) a 30 volt source capable of supplying 10 amperes.

3. The unit of measure of electric power is the
(A) watt. (B) ampere. (C) volt. (D) ohm.

4. When a resistor has a 10 watt rating, this means it
(A) always dissipates exactly 10 watts of power. (B) always provides 10 watts of power. (C) can safely dissipate 10 watts, or less, of power. (D) should be used in a circuit where it will dissipate more than 10 watts of power.

5. An energy source with a 10 watt power rating can safely be used to supply
(A) a 100 watt load. (B) a 1000 watt load. (C) a 5 watt load. (D) a 20 watt load.

6. In the circuit of Figure 13A, the power dissipated in R_1 is
(A) 20 watts. (B) 500 watts. (C) 25 watts. (D) 100 watts.

7. In the circuit of Figure 13B, the power dissipated in R_1 is
(A) 100 watts. (B) 4 watts. (C) 5 watts. (D) 80 watts.

8. In any circuit consisting of three resistors, the total power being dissipated is
(A) less than the power being dissipated by any one resistor. (B) determined by multiplying the source voltage by the current through one of the resistors. (C) divided equally among the resistors. (D) equal to the sum of the powers dissipated in all three resistors.

9. Electric power is the
(A) rate of using or producing electric energy. (B) total number of electrons forced through a circuit. (C) number of electrons passing a given point in one second. (D) same as electric pressure.

10. How much current is drawn by a computer which dissipates 4800 watts of power when the source voltage is 120 volts?
(A) 20 amps, (B) 200 amps, (C) 400 amps, (D) 40 amps.

PROBLEMS IN ELECTRICITY

Lesson 1021A

DeVRY Technical Institute

CHICAGO   TORONTO

OPPORTUNITY

They do me wrong who say I come no more
When once I knock and fail to find you in;
For every day I stand outside your door,
And bid you wake, and rise to fight and win.

Wail not for precious chances passed away,
Weep not for golden ages on the wane;
Each night I burn the records of the day;
At sunrise every soul is born again.

PROBLEMS IN ELECTRICITY

Revised 1966

OPPORTUNITY
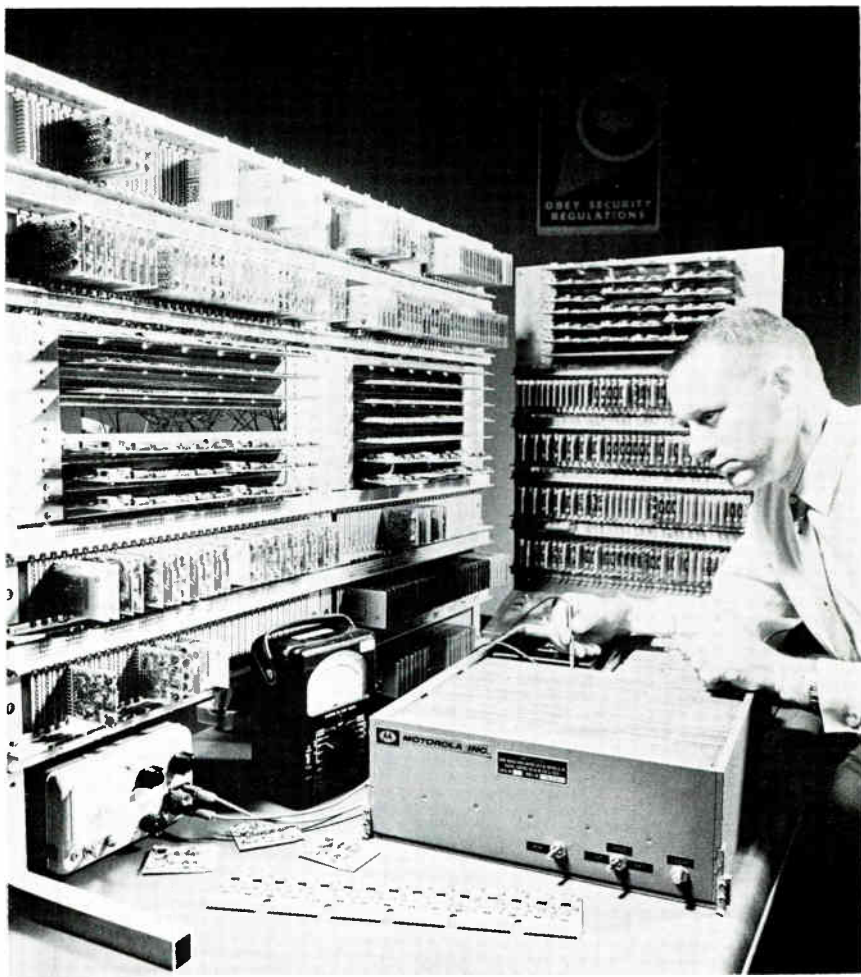
A technician often calls on his problem solving knowledge when servicing and testing electronic equipment.

Courtesy Motorola, Inc.
Military Electronics Div.

PROBLEMS IN ELECTRICITY

CONTENTS

******

Thank God every morning when you get up that
you have something to do that day which must
be done, whether you like it or not. Being re-
quired to work, and forced to do your best,
will breed in you temperance and self-control,
diligence and strength of will, cheerfulness
and content, and a hundred virtues which the
idle never know.

                         - Charles Kingsley

PROBLEMS IN ELECTRICITY

Some people are frightened by problems and numbers. In most cases they have never learned the basic methods and short cuts which make problem solving easy. Your technical knowledge really becomes practical when you can approach a problem with confidence in your ability to solve it.

The "know how" of solving problems comes from understanding the simple methods of problem solving and from PRACTICE in using these methods. The more problems you solve, the easier the next one will be. In a short time you will gain the know how it takes to quickly attack and solve problems. This knowledge is a powerful tool that aids understanding and relates theory to practice.

SCIENTIFIC NOTATION

Engineers and scientists must solve many problems when designing equipment or when performing basic research on some new concept. Many of the short cuts they use in solving these problems are very simple and can be applied to basic electric and electronic problems. One of the simplest and most useful short cuts is SCIENTIFIC NOTATION. Scientific notation is a streamlined method of writing numbers with many zeros, or numbers with many decimal places.

To illustrate what we mean by scientific notation, consider a simple problem involving Ohm's Law. Suppose you are servicing a circuit that contains a 1000 ohm resistor which carries a current of 2 amperes. To find the voltage across this resistor you would use one form of Ohm's Law, $E = IR$. This formula states that voltage equals current times resistance. Using this formula, you find the voltage across the resistor as shown below:

$$E = IR = 2 \text{ amperes} \times 1000 \text{ ohms}$$
$$= 2000 \text{ volts}$$

In scientific notation, the answer to the above problem, 2000, can be written as 200×10^1. The 1 placed above and to the right of the 10 is called the **EXPONENT**. The exponent indicates how many places the decimal point is moved. (When a decimal point is not shown it is assumed to be at the right of the rightmost digit.) In going from 2000 to 200×10^1 move the decimal point one place to the left as shown below. You can disregard the zero to the right of the decimal point.

$$2000 = 200.\underset{\smile}{0}. \times 10^1 = 200 \times 10^1$$

The number 2000 can also be written as 20×10^2. In this case the decimal point is moved two places to the left and thus the exponent of 10 is 2.

$$2000 = 20.\underset{\smile}{00}. \times 10^2 = 20 \times 10^2$$

Following the same procedure, the number 2000 can be written as 2×10^3. In this case the decimal point is moved three places to the left.

$$2000 = 2.\underset{\smile}{000}. \times 10^3 = 2 \times 10^3$$

The number 2000 can therefore be expressed as 200×10^1, 20×10^2, or 2×10^3. If you use the last notation there are no zeros to keep track of. This is the big advantage of scientific notation. Scientific notation is also referred to as "powers of ten".

The method of converting a number into scientific notation can be summarized by stating: **WHEN YOU MOVE THE DECIMAL POINT TO THE LEFT YOU INCREASE THE EXPONENT OF 10.**

$$*\qquad\qquad*\qquad\qquad*$$

The following resistors are located in a digital computer you are servicing. Convert their values into scientific notation.

1. 5000 ohms 5×10^3
2. 10,000 ohms 1×10^4
3. 500,000 ohms 5×10^5

*   *   *

Now let's start out with a number expressed in scientific notation and convert it into a regular number. To do this move the decimal point to the right. The exponent of 10 must be decreased by 1 for each place the decimal point is moved.

To illustrate this procedure convert 2×10^3 into a regular number. If you move the decimal point one place to the
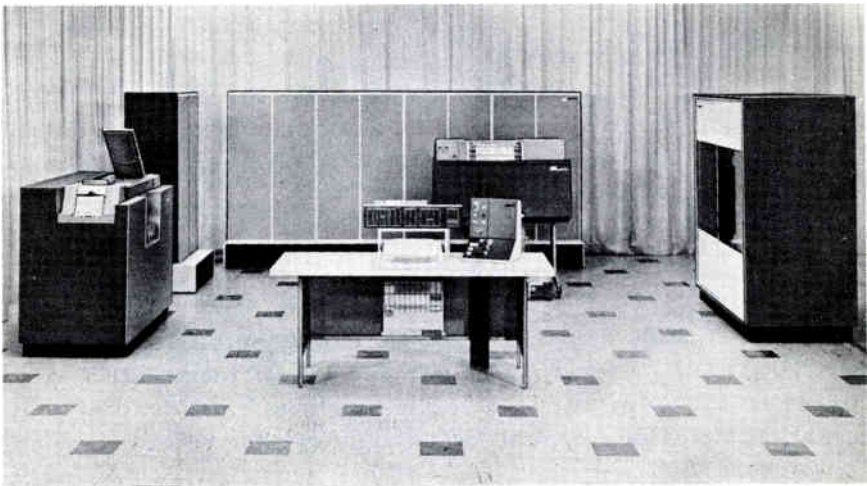
Many business and scientific problems are solved with the aid of digital computers like the one shown above.

Courtesy International Business Machine Corporation

right, you must decrease the exponent by 1. Add a zero as shown below:

$$2 \times 10^3 = 2\underset{\smile}{.0.} \times 10^2 = 20 \times 10^2$$

Following the same procedure, move the decimal point

another place to the right, reduce the exponent by 1, and add another zero:

$$20 \times 10^2 = 20 \underset{\smile}{.0.} \times 10^1 = 200 \times 10^1$$

To complete the conversion, move the decimal point one more place to the right. When the 10 has an exponent of zero you can disregard it. Thus, the number is now in conventional form:

$$200 \times 10^1 = 200 \underset{\smile}{.0.} \times 10^0 = 2000$$

*   *   *

The following quantities are answers for three electronic problems. Convert them into conventional numbers.

4. 4×10^4 ohms $40,000 \ \Omega$
5. 3×10^2 volts $300 \ V$
6. 9×10^1 amperes $90 \ a.$

*   *   *

Suppose you move the decimal point in the number 2000×10^0 another place to the right. To do this you must decrease the exponent by 1. Since the original exponent is zero, indicate that it has been decreased by 1 by writing an exponent of -1 as shown below:

$$2000 \times 10^0 = 2000 \underset{\smile}{.0.} \times 10^{-1} = 20,000 \times 10^{-1}$$

If you move the decimal point another place to the right, you must again decrease the exponent by 1. Thus, the exponent changes from -1 to -2:

$$20,000 \times 10^{-1} = 20000 \underset{\smile}{.0.} \times 10^{-2} = 200,000 \times 10^{-2}$$

Therefore, when the decimal point is moved to the right past the point where the exponent of 10 becomes zero, the exponent becomes negative.

As far as the number 2000 is concerned, moving the decimal point to the right adds more zeros and makes it harder to handle. However, this procedure can be used to simplify numbers with many decimal places.

For example, suppose the value of current in a problem is .0005 amperes. To simplify this number write .0005 as .0005 $\times 10^0$. Since 10^0 equals 1, you can multiply any number by 10^0 without changing the value of the number. Now move the decimal point one place to the right and decrease the exponent by 1. Since the original exponent is zero, decreasing it by 1 makes the exponent -1 as shown below:

$$.0005 \times 10^0 = .0.005 \times 10^{-1} = .005 \times 10^{-1}$$

Move the decimal point another place to the right. To do this, decrease the exponent by 1, making it -2:

$$.005 \times 10^{-1} = .0.05 \times 10^{-2} = .05 \times 10^{-2}$$

Now if you move the decimal point two more places to the right the number is completely simplified:

$$.05 \times 10^{-2} = .05. \times 10^{-4} = 5 \times 10^{-4}$$

In summary, WHEN YOU MOVE THE DECIMAL POINT TO THE RIGHT YOU DECREASE THE EXPONENT OF 10.

*   *   *

Convert the following values of current into scientific notation.

7.   .0003 ampere 3×10^{-4} a
8.   .02 ampere
9.   .009 ampere 2×10^{-2} a
                          9×10^{-3} a

*   *   *

To convert a number expressed in scientific notation into a conventional number, just reduce the exponent of 10 to zero.

Let's convert 5×10^{-4} into a conventional number. Since the exponent of 10 is negative, move the decimal point to the left to make the exponent 10^0. To change 10^{-4} to 10^0, you must move the decimal point four places to the left:

$$5 \times 10^{-4} = .5 \times 10^{-3} = .0.5 \times 10^{-2} = .0.05 \times 10^{-1}$$

$$= .0.005 \times 10^0 = .0005$$

*   *   *

Convert the following quantities into conventional numbers.

10. 7×10^{-1} volts   _07v_   . 7v.
11. 3×10^{-3} amperes .003a.
12. 6×10^{-5} watts   .00006 w.

*   *   *

CONVERTING TYPICAL NUMBERS

The numbers that appear in electrical and electronic problems are not always simple numbers such as 2000. Quite often you will run into numbers such as 2500, 37,500, .0025, .000193, and the like. However, you can streamline these numbers by converting them into scientific notation. Use the same simple methods you used earlier.

For example, convert 2500 into scientific notation. To do this move the decimal point two places to the left to get rid of the zeros:

$$2500 = 25.00. \times 10^2 = 25 \times 10^2$$

You can leave the number as 25×10^2 or you can move the decimal point one more place to the left:

$$25 \times 10^2 = 2.5. \times 10^3 = 2.5 \times 10^3$$

Now you have converted the number 2500 to 2.5×10^3. This

makes it easy to work with and will enable you to solve prob-
lems quickly. This is the basic form of scientific notation.
It would be just as correct, however, to leave the number
as 25×10^2 or even as 250×10^1. If you express the number
as 25×10^2 you do not have to worry about a decimal point.

Converting numbers such as .0055 is just as easy. To convert
this number into scientific notation move the decimal point
three places to the right:

$$.0055 = .005.5 \times 10^{-3} = 5.5 \times 10^{-3}$$

The number .0055 has thus been simplified to 5.5×10^{-3}.
To completely eliminate the decimal point, move it another
place to the right. Now .0055 equals 55×10^{-4} and you have
no decimal point to worry about.

*   *   *

Convert the following quantities into scientific notation.

13. 250 volts $2.5 \times 10^2 \, v.$
14. 470,000 ohms $4.7 \times 10^5 \, \Omega$
15. .0033 ampere $3.3 \times 10^{-3} \, a.$
16. .00079 ampere $7.9 \times 10^{-4} \, a.$

*   *   *

USING SCIENTIFIC NOTATION

Various arithmetic operations can be performed with num-
bers expressed in scientific notation. The use of scientific
notation greatly simplifies multiplication, division, etc.
since you do not have to keep track of zeros or a number of
decimal places. Thus, electrical and electronic problems
solving is greatly simplified.

Problems Involving Multiplication

Many problems require that quantities be multiplied. For

example, when you use the formula $E = IR$ you multiply the
current by the resistance. Suppose a certain circuit in a
transmitter you are servicing has a resistance of 300 ohms
and carries a current of 20 amperes. To determine the
circuit voltage you multiply the resistance by the current
as shown below:

$$E = 20 \text{ amperes} \times 300 \text{ ohms} = 6000 \text{ volts}$$

To solve this problem using regular numbers you must keep

This counter-timer is actually an electronic adder.
Courtesy Computer Measurements Co.

track of a number of zeros. You avoid this by using scientific
notation. To work this problem using scientific notation,
first convert the values of current and resistance into scien-
tific notation:

$$20 \text{ amperes} = 2 \times 10^1 \text{ amperes}$$

$$300 \text{ ohms} = 3 \times 10^2 \text{ ohms}$$

Now you have two numbers less than 10 to multiply together
(2 and 3). After you multiply the two numbers together, just

add the exponents of 10 in both numbers to obtain the exponent of 10 for the answer:

$$E = 2 \times 10^1 \text{ amperes} \times 3 \times 10^2 \text{ ohms} = 6 \times 10^3 \text{ volts}$$

To check the answer, convert it back to a regular number by moving the decimal point to the right:

$$6 \times 10^3 \text{ volts} = 6.000. \times 10^0 = 6000 \text{ volts}$$

As another example, suppose a 10,000 ohm resistor in a transistor computer circuit carries a current of .005 ampere. Ohm's Law, $E = IR$, can be used to determine the voltage developed across this resistor.

If you multiply the values of current and resistance as they are given, you have to keep track of a number of zeros and decimal places. To simplify the problem, first convert the values of current and resistance into scientific notation:

$$10,000 \text{ ohms} = 1 \times 10^4 \text{ ohms}$$

$$.005 \text{ ampere} = 5 \times 10^{-3} \text{ amperes}$$

To solve the problem you first multiply 1 by 5. Then to obtain the exponent of 10 for your answer, add the exponents of 10 in each number. Since both exponents do not have the same sign, you add them by subtracting the smaller from the larger. The sign of the result is the sign of the larger. In this case you subtract 3 from 4 to obtain 1 as the exponent of 10 in the answer:

$$E = IR = 5 \times 10^{-3} \text{ amperes} \times 1 \times 10^4 \text{ ohms} = 5 \times 10^1 \text{ volts}$$

<div align="center">or 50 volts</div>

In summary, to multiply numbers expressed in scientific notation, MULTIPLY THE NUMBERS TOGETHER AND ADD THE EXPONENTS. (If the exponents do not have the same sign, subtract the smaller from the larger and use the sign of the larger.)

*
2.5×10^1 a.
2×10^3 ~
5.0×10^4 v

*
5.0×10^4 v or 50,000 v.

17. One of the transmitting tubes in a radar system carries a cur-
rent of 25 amperes. If this tube has a resistance of 2000 ohms,
how much voltage is developed across the tube? (Use scien-
tific notation and Ohm's Law, E = IR, to solve this problem.)

18. A circuit in a satellite has a resistance of 22,000 ohms. If
this circuit carries a current of .004 ampere, what is the
circuit voltage? (Use scientific notation and Ohm's Law,
E = IR, to solve this problem.)

2.2×10^4 ~
4×10^{-3} a   *
8.8×10^1 v or   88 v.
$8.8 \ 10^1$ v.

Problems Involving Division

Scientific notation can also be used in problems where num-
bers must be divided. Typical problems are those when
current (I = E/R) and resistance (R = E/I) must be deter-
mined.

To illustrate the process of dividing numbers expressed in
scientific notation, let's find the current through a 5000
ohm resistor which has 30 volts across it. To solve this
problem, use the form of Ohm's Law I = E/R. Using con-
ventional numbers you can solve the problem as shown
below:

$$I = E \div R = 30 \text{ volts} \div 5000 \text{ ohms} = .006 \text{ ampere}$$

This problem requires that you keep track of zeros and
decimal places. To simplify the problem, convert the value
of resistance into scientific notation:

$$5000 \text{ ohms} = 5 \times 10^3 \text{ ohms}$$

To divide the numbers, first write them as a fraction with
the number you are dividing (dividend) on the top and the
number you are dividing by (divisor) on the bottom:

$$I = \frac{E}{R} = \frac{30 \text{ volts}}{5 \times 10^3 \text{ ohms}}$$

Divide the top number by the bottom number as you normally would. In this case divide 30 by 5 to obtain 6. Next, move the 10 and its exponent from the bottom number up to the top and change its sign. (If it is positive make it negative, and vice versa.) In this example the exponent is positive (10^3), so you make it negative when you move it up on top (10^{-3}):

$$I = \frac{30 \times 10^{-3}}{5 \; \times 10^3}$$

$$I = 6 \times 10^{-3} \text{ amperes}$$

To check this answer with the one previously obtained (.006), convert 6×10^{-3} to a conventional number. (Move the decimal point three places to the left since the exponent is -3.):

6×10^{-3} amperes = $.006. \times 10^0$ ampere = .006 ampere

Note that this answer compares to the one previously obtained and yet you did not have to keep track of zeros or decimal places.

You could have converted 30 into 3×10^1 in working this problem. However, if you did you would have to divide 3 by 5. This would produce a decimal answer. The problem becomes much simpler if you arrange the numbers so you are dividing a larger number by a smaller number.

As another example, suppose a circuit is connected to a 400 volt supply. If the circuit draws a current of .008 ampere, what is its resistance? To solve this problem the simple way, we use scientific notation and the equation $R = E/I$. The first step is to get rid of the decimal places and zeros. In converting the numbers to scientific form, keep in mind that you will be dividing the 400 by the .008, and that the

calculation will be simpler if you divide a larger number by a smaller number. Therefore, instead of converting 400 to 4×10^2, as you might ordinarily do, convert it to 40×10^1:

$$400 \text{ volts} = 40 \times 10^1 \text{ volts}$$

$$.008 \text{ ampere} = 8 \times 10^{-3} \text{ amperes}$$

Then write the numbers as a fraction as in $R = E/I$ and divide. Remember, bring the bottom 10 and its exponent up above the line and change the sign of the exponent. Then add the exponents:

$$R = E/I = \frac{40 \times 10^1 \text{ volts}}{8 \times 10^{-3} \text{ amperes}}$$

$$R = \frac{40 \times 10^1 \times 10^3}{8 \; \overset{}{\times 10^{-3}}}$$

In this case the exponent of the bottom number is negative so you change it to positive when you move it above the line. Then, add the two exponents and convert the answer to a regular number by moving the decimal point four places to the right:

$$R = 5 \times 10^4 \text{ ohms or } 50,000 \text{ ohms}$$

In summary, to divide numbers expressed in scientific notation **WRITE THE NUMBERS AS A FRACTION AND DIVIDE THEM AS YOU NORMALLY WOULD. THEN CHANGE THE SIGN OF THE EXPONENT ON THE BOTTOM AND ADD IT TO THE EXPONENT ON THE TOP.**

After you change the sign of the exponent below the line and move it above the line, you may find that the new sign of this exponent is opposite that of the exponent you want to add it to. In this case you just subtract the smaller from the larger and use the sign of the larger. For example suppose you have a 10^2 above the line and a 10^3 below the line. When

you move the 10^3 above the line you change it to a 10^{-3}, so you must now add 10^2 to 10^{-3}. The result is 10^{-1}.

$$\frac{20 \times 10^1}{5 \times 10^3 \, \Omega} \quad * \quad = \quad 4 \times 10^{-2} \, a \quad * \quad \text{or} \quad .04 \, a \qquad *$$

19. What is the current through a 5000 ohm resistor that has 200 volts developed across it? (Use scientific notation and Ohm's Law, $I = E/R$, to solve this problem.)

20. If an electric heating unit draws .1 ampere from a 75 volt battery, what is its resistance? (Use scientific notation and Ohm's Law, $R = E/I$.)

$$\frac{7.5 \times 10^1}{1 \times 10^{-1}} \quad * \quad = 7.5 \times 10^2 \quad * \quad \text{or} \quad 750 \, \Omega \qquad *$$

Addition and Subtraction

Numbers expressed in scientific notation can also be added and subtracted. However, the numbers you add or subtract

must all have the same exponent of 10. If they do not, change the numbers so they do. Then add or subtract as you normally would.
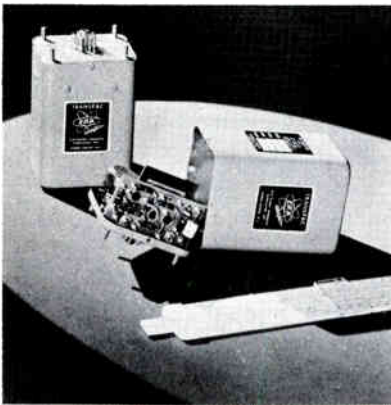
To illustrate the process of addition, suppose the solving of an electrical problem requires the addition of 500, 18,000 and 2500. First convert each number to scientific notation:

$$500 = 5 \times 10^2$$
$$18,000 = 1.8 \times 10^4$$
$$2500 = 2.5 \times 10^3$$

Since all three numbers do not have the same exponent, two of them must be changed. It does not make any difference which ones you change. Let's change 5×10^2 and 1.8×10^4

each to a number times 10^3. In the case of 5×10^2 the exponent must be increased and thus the decimal point must be moved to the left:

$$5 \times 10^2 = .5. \times 10^3 = .5 \times 10^3$$

In the case of 1.8×10^4 the exponent must be decreased and thus the decimal point must be moved to the right:

$$1.8 \times 10^4 = 1.8. \times 10^3 = 18 \times 10^3$$

Now that the numbers all have the same exponent you can add them. Just line up the decimal points and add. The exponent of 10 in the answer is the same as it is in the numbers that are added:

$$
\begin{array}{r}
.5 \times 10^3 \\
18. \ \times 10^3 \\
+ \ 2.5 \times 10^3 \\
\hline
21.0 \times 10^3 \ \text{or} \ 21,000
\end{array}
$$

As another example, add 1.5×10^{-1}, 3.3×10^1, and 9.1×10^2. Here again the exponents of each number must be made the same. Let's change 1.5×10^{-1} and 9.1×10^2 each to a number times 10^1. In the case of 1.5×10^{-1} the exponent must be made positive and thus the decimal point is moved to the left. For 9.1×10^2 the exponent must be decreased and thus the decimal point is moved to the right:

$$1.5 \times 10^{-1} = .01.5 \times 10^1 = .015 \times 10^1$$

$$9.1 \times 10^2 = 9.1. \times 10^1 = 91 \times 10^1$$

Now you can add the numbers as follows.

$$
\begin{array}{r}
.015 \times 10^1 \\
3.3 \ \ \times 10^1 \\
+ \ 91. \ \ \ \times 10^1 \\
\hline
94.315 \times 10^1 \ \text{or} \ 943.15
\end{array}
$$

*   *   *

21. Is it necessary that all of the exponents of 10 be the same when numbers expressed in scientific notation are added?
yes

22. Using scientific notation, add the following numbers: 4500, 50,000 and 900. 4.5×10^3

4.5×10^3
5×10^4 50.0×10^3
* 9×10^2 * $.9 \times 10^3$ *
                              ——————————
                              55.4×10^3

The process for subtraction is just as simple as the one for addition. If necessary, change one of the numbers so they both have the same exponent. Then subtract as you normally would. The exponent in the answer is the same as for the quantities being subtracted. As an example, subtract 1500 from 30,000. First change both numbers into scientific notation:

$$1500 = 1.5 \times 10^3$$

$$30,000 = 3 \times 10^4$$

Since both numbers do not have the same exponent, one of them must be changed. Either one can be changed. Let's change 3×10^4 to some number times 10^3. To do this the exponent of 10 must be decreased and thus the decimal point must be moved to the right:

$$3 \times 10^4 = 3.0 \times 10^3 = 30 \times 10^3$$

Now you can subtract the numbers:

$$\begin{array}{r} 30 \times 10^3 \\ - 1.5 \times 10^3 \\ \hline 28.5 \times 10^3 \end{array}$$

As another example, subtract 5×10^{-1} from 2.1×10^1. Here again the exponent of one of the numbers must be changed. Let's change 5×10^{-1} to some number times 10^1. To do this the decimal point must be moved to the left and

the exponent made positive:

$$5 \times 10^{-1} = .05. \times 10^1 = .05 \times 10^1$$

Now you can subtract the numbers:

$$
\begin{array}{r}
2.1 \times 10^1 \\
- .05 \times 10^1 \\
\hline
2.05 \times 10^1
\end{array}
$$

*   *   *

23. Can 3×10^1 be directly subtracted from 9×10^2 without making any changes in the exponents of 10? *NO*

24. Subtract 9×10^2 from 1.8×10^3.

$$
\begin{array}{r}
18 \times 10^2 \\
9 \times 10^2 \\
\hline
9 \times 10^2
\end{array}
$$

*   *   *

In summary, THE EXPONENTS OF 10 MUST BE THE SAME WHEN NUMBERS EXPRESSED IN SCIENTIFIC NOTATION ARE ADDED OR SUBTRACTED.   The numbers are then added or subtracted in a normal fashion.

REARRANGING OHM'S LAW

There are three forms of Ohm's Law:

$$E = IR \qquad\qquad I = E/R \qquad\qquad R = E/I$$

Actually, these three forms are all ways of stating the same law.   The two forms $I = E/R$ and $R = E/I$ are obtained from $E = IR$ by rearranging this formula.

The Ohm's Law formula $E = IR$ is an equation. As the name implies, an equation is an expression of equality.   That is, in the equation $E = IR$, the voltage E is equal to the product of current I and resistance R.   You can perform any arithmetic operation on an equation as long as you do the SAME thing to both sides.   For example, consider the equation

shown below:

$$4 = 4$$

This equation states that 4 equals 4. Let's multiply both sides of the equation by 2:

$$2 \times 4 = 4 \times 2$$

$$8 = 8$$

Although this changes the values of both sides of the equa-
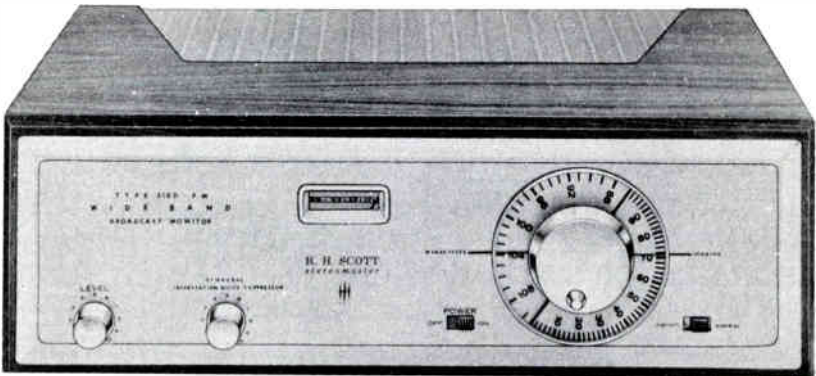
Many simple calculations go into the design of an FM tuner such as the one shown above.
Courtesy H.H. Scott, Inc.

tion, note that the left side still equals the right side. Take the original equation and divide both sides by 2:

$$4/2 = 4/2$$

$$2 = 2$$

Here again the values of both sides have been changed, but the left side still equals the right side.

Now let's take the Ohm's Law expression $E = IR$ and divide both sides of the equation by R:

$$E = IR$$

$$\frac{E}{R} = \frac{I\cancel{R}}{\cancel{R}}$$

$$\frac{E}{R} = I$$

On the right side of the equation, R divided by R equals 1, so the R's can be dropped. As a result we obtain the form of Ohm's Law $I = E/R$.

By dividing both sides of the Ohm's Law equation $E = IR$ by I we can obtain another form of Ohm's Law:

$$E = IR$$

$$\frac{E}{I} = \frac{\cancel{I}R}{\cancel{I}}$$

$$\frac{E}{I} = R$$

On the right side of the equation I divided by I equals 1 and thus the I's can be dropped. Thus, another form of Ohm's Law, $R = E/I$, can be obtained.

The three forms of Ohm's Law are thus $E = IR$, $I = E/R$ and $R = E/I$. To find voltage when you know the current and resistance, you use $E = IR$. If you know the voltage and resistance, and you want to find the current, you use $I = E/R$. You use the form $R = E/I$ if you know the voltage and current, and want to find the resistance.

*   *   *

25. What are the three forms of Ohm's Law?

$E = IR$, $R \frac{E}{I}$, $I = \frac{E}{R}$

26. How are the other two forms of Ohm's Law obtained from
    $E = IR$? $\frac{E}{R} = \frac{IR}{R}$ $\frac{1}{R} \cdot I$ $\frac{E}{I} = \frac{IR}{I}$ - $\frac{E}{I} = R$
                   *   *   *

COMBINING OHM'S LAW AND THE POWER FORMULA

The electric power formula $P = EI$ enables you to find power
when voltage and current are known. This formula can be
combined with Ohm's Law to enable you to determine power
when current and resistance or voltage and resistance are
known.

One form of Ohm's Law states that $E = IR$. Since $E = IR$
we can substitute IR for E in the electric power formula as
shown below:

$$P = EI$$

$$P = (IR) I$$

I multiplied by itself, $I \times I$, equals I^2. Therefore, the power
formula becomes:

$$P = I^2R$$

You use this form of the power formula to find the electric
power when you know the current and resistance.

Another form of Ohm's Law states that $I = E/R$. Therefore,
we can substitute E/R for I in the power formula as shown
below:

$$P = EI$$

$$P = E(E/R)$$

E multiplied by itself, $E \times E$, equals E^2. Therefore, the
power formula becomes:

$$P = E^2/R$$

In summary, the three forms of the electric power formula
are $P = EI$, $P = I^2R$ and $P = E^2/R$. When voltage and cur-
rent are known you can use the form $P = EI$. To find power
when current and resistance are known you use the form
$P = I^2R$. The form $P = E^2/R$ is used when voltage and re-
sistance are known.

*   *   *

27. What are the three forms of the electric power formula?
    $P = IR$ $P = \frac{E}{R}$ $P = EI$
28. If current and resistance are given, what formula would you
    use to determine power?
    $P = I^2R$

*   *   *

SOLVING PROBLEMS

Electric and electronic problem solving becomes very simple
once you know the basic methods of problem solving. Prob-
lem solving consists of a few simple steps. The first step
is to determine the quantity that must be found (the "un-
known"). Next you should determine what quantities are
known. Once you have determined the unknown and known
quantities you must find an expression that relates the known
and unknown quantities. For example, suppose you know
the voltage and current and must find the resistance. You
would use the formula $R = E/I$ since it relates the unknown
quantity R to the known quantities E and I.

The next step is to replace the symbols for the known quan-
tities with their number values. Finally you solve the
formula for the unknown quantity. Once the problem is
solved, check the results. Make sure they seem reason-
able. If the problem involves some circuit or experiment,
check the results against circuit operation or against the
results of the experiment. We all make errors and a few
moments spent checking the results will often show up any
errors.

Basic Units

The values you use in a formula must be in the BASIC UNITS
of the formula. For example, in the Ohm's Law formula
the basic units are volts for E, amperes for I and ohms for
R. Likewise, in the power formula the basic unit for power
is the watt. Therefore, you cannot use K ohms, megohms,
μa, ma, etc. directly in a formula. They must be converted
into basic units.

Scientific notation can be used to simplify the conversion
into basic units. Since 1 milliampere (1 ma) is equal to
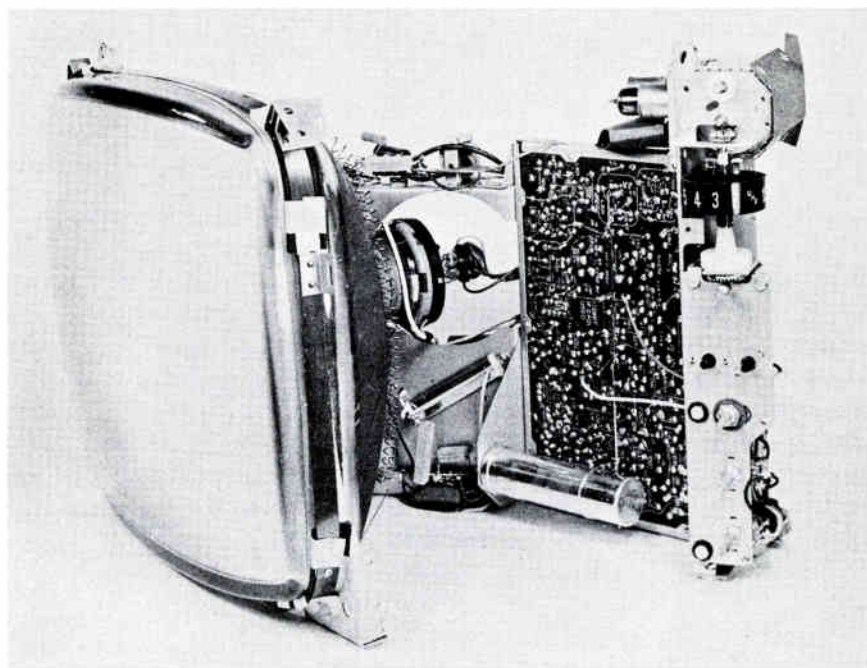
If you know the electric power consumed by a TV receiver, and the line voltage, you can find the
current drawn by the set by using the power formula $I = P/E$.

Courtesy Westinghouse Electric Corp.

.001 ampere, 1 ma can be written as 1×10^{-3} ampere.
Thus, when a value of current appears in ma, just multiply
this value by 10^{-3} to convert it to amperes. For example,

suppose the value of current is given as 35 ma. To convert it to amperes, just drop the ma and multiply 35 by 10^{-3} to obtain 35×10^{-3} amperes. If you prefer, this can also be written as 3.5×10^{-2} amperes.

Values of current expressed as microamperes can be converted into amperes in a similar manner. Since 1 microampere (1 μa) is equal to .000001 ampere, 1 μa can be written as 1×10^{-6} ampere. Thus, when a value of current appears in μa, just multiply this value by 10^{-6} to convert it to amperes. As an example, suppose the value of current in a problem is 15 μa. To convert this value into amperes, multiply it by 10^{-6} to obtain 15×10^{-6} or 1.5×10^{-5} amperes.

Like current, resistance is not always given in basic units. The letter K, which represents 1000, is often used. Since 1K ohms equals 1000 ohms, 1K ohms can be written as 1×10^{3} ohms. Thus, when a value of resistance is given in K ohms, multiply it by 10^{3} before you use it in a formula that calls for resistance in ohms. For example, suppose the value of resistance in a circuit is 5K ohms. To convert this value, multiply by 10^{3} to obtain 5×10^{3} ohms.

Resistance values are also given in megohms. Since 1 megohm equals 1,000,000 ohms, 1 megohm can be written as 1×10^{6} ohms. Therefore, when a value of resistance is given in megohms, multiply this value by 10^{6} to convert this value into ohms. To illustrate this process, suppose the value of resistance is 4.7 megohms. To convert this value into ohms, multiply by 10^{6} to obtain 4.7×10^{6} ohms.

*   *   *

Convert the following values into basic units using scientific notation.

29. 35 ma 35×10^{-3} or $3.5 \cdot 10^{-2} a$.
30. 1.9 μa $1.9 \times 10^{-6} a$.
31. 68K ohms $6.8 \times 10^{4} \Omega$
32. 2.2 megohms $2.2 \times 10^{6} \Omega$

*   *   *

Ohm's Law Problems

Many electric and electronic problems involve the use of one of the forms of Ohm's Law. To illustrate the method of using Ohm's Law, let's solve a typical problem. Suppose a certain circuit in a satellite transmitter offers a resistance of 4K ohms to the supply battery. If this transmitter operates from a 28 volt battery, how much current does it draw?

The unknown quantity in this problem is current, and the known quantities are voltage and resistance. To solve this problem you would use the Ohm's Law formula $I = E/R$. Before using the values in the formula, determine if they are in their basic units. Since resistance is given in K ohms, it must be converted to ohms by multiplying by 10^3. That is, 4K ohms equals 4×10^3 ohms.

The problem can now be solved by replacing the letter symbols in the formula with the values of voltage and resistance:

$$I = \frac{E}{R} = \frac{28 \text{ volts}}{4 \times 10^3 \text{ ohms}}$$

$$= \frac{28 \times 10^{-3}}{4 \; (\times 10^3)}$$

$$= 7 \times 10^{-3} \text{ or } .007 \text{ ampere}$$

Note that the 28 was not converted into scientific notation. It is much easier to divide 28 by 4 than 2.8×10^1 by 4.

As another example, suppose you wish to determine the voltage developed across a 22K ohm resistor that is carrying a current of 5 ma. Since resistance and current are known and voltage is unknown, the Ohm's Law formula $E = IR$ is used. Before using the values of resistance and current in the formula, they must be converted to basic

units as shown below:

$$22K \text{ ohms} = 22 \times 10^3 \text{ ohms} \text{ or } 2.2 \times 10^4 \text{ ohms}$$

$$5 \text{ ma} = 5 \times 10^{-3} \text{ amperes}$$

These values of resistance and current can now be used in the formula:

$$E = IR = 5 \times 10^{-3} \text{ amperes} \times 2.2 \times 10^4 \text{ ohms}$$

$$= 11.0 \times 10^1 \text{ or } 110 \text{ volts}$$

*   *   *

33. To find current when you know voltage and resistance, what Ohm's Law formula would you use? $I = \frac{E}{R}$

34. What is the effective resistance of the circuits in a portable transistor radio if they draw 2.5 ma from a 9 volt battery?

35. If a 470K ohm resistor in a TV receiver carries a current of 50 μa, how much voltage appears across the resistor?

*   *   *

Electric Power Problems

In problems involving electric power, one of the forms of the power formula is often used; $P = EI$, $P = I^2R$ and $P = E^2/R$. To show how the power formula is used, let's solve an example problem. Suppose you wish to find the power developed by a tube in a radar transmitter if it draws 2.5 amperes from a 5000 volt supply. Since voltage and current are known, you use the formula $P = EI$ to solve this problem. Although the current and voltage are in basic units, the voltage can be simplified by using scientific notation:

$$5000 \text{ volts} = 5 \times 10^3 \text{ volts}$$

The problem is solved by inserting the values in place of the letter symbols, just as in using Ohm's Law:

$$P = EI$$

$$= 5 \times 10^3 \text{ volts} \times 2.5 \text{ amperes}$$

$$= 12.5 \times 10^3 \text{ or } 12,500 \text{ watts}$$

As another example, suppose you wish to find the power dissipated by a 5K ohm resistor which is carrying a current of 10 ma. Since resistance and current are known, you use the formula $P = I^2R$ to solve this problem. The values of current and resistance must be converted into basic units:

$$10 \text{ ma} = 10 \times 10^{-3} \text{ or } 1 \times 10^{-2} \text{ ampere}$$

$$5K \text{ ohms} = 5 \times 10^3 \text{ ohms}$$

The problem is now solved by inserting the values as shown below:

The solutions of many Ohm's Law problems go into the design and testing of an analog computer like the one shown above.
Courtesy Electronic Associates, Inc.

$$P = I^2R = (1 \times 10^{-2} \text{ ampere})^2$$

$$\times 5 \times 10^3 \text{ ohms}$$

Note that the current must be squared. To square a number in scientific notation, just square the number and double the exponent of 10:

$$P = 1 \times 10^{-4} \times 5 \times 10^3$$

$$= 5 \times 10^{-1} \text{ or } .5 \text{ watt}$$

*   *   *

36. To find power when you know the voltage and resistance, what
     electric power formula is used? $P = \frac{E^2}{R}$

37. A 10K ohm resistor in a circuit carries 5 ma. If this resistor
     has a 10 watt rating, is it dissipating more or less power than
     its rated wattage?
     $P = (5 \times 10^{-3})^2 \times 1 \times 10^4 \, \Omega$. $\sqrt{\cdots} \times 1 \times 10^4 = 25 \times 10^{-2} \, \text{or} \, .25 \, w$

*   *   *

In some electric power problems you may know the power
and resistance, and you may want to calculate the current.
For example, suppose the power dissipated by a 2000 ohm
resistor is 5 watts. To find the current through the resistor
you rearrange the formula $P = I^2R$ to the form:

$$I^2 = \frac{P}{R}$$

$$I = \sqrt{\frac{P}{R}}$$

Inserting the power and resistance values, you get:

$$I = \sqrt{\frac{5}{2000}} = \sqrt{.0025}$$

$$= \sqrt{25 \times 10^{-4}}$$

To find the square root of a number expressed in scientific
notation, you simply take the square root of the number and
divide the exponent of 10 by 2.   The square root of 25 is 5,
and -4 divided by 2 is -2.   Thus, the current through the
resistor in this example is 5×10^{-2} ampere or .05 ampere
(50 ma).

The exponent of 10 should be an even number.   A number
such as 2.5×10^{-3} can be put into this form by moving the

decimal point one place to the right. $(2.5 \times 10^{-3} = 25 \times 10^{-4})$

*   *   *

38.   What is the square root of 16×10^6? 4×10^3

*   *   *

SUMMARY

Scientific notation can be used to simplify numbers with many zeros or decimal places. Like anything new, this method of handling numbers requires practice. Once you learn to use it, however, you can easily handle very large or very small numbers. It is truly a short cut worth mastering.

Arithmetic operations can be performed with numbers expressed in scientific notation. When adding or subtracting, make sure the exponents of the numbers are the same, and then add or subtract the numbers. To multiply numbers, multiply as you normally would, and then add the exponents. For division, divide as you normally would, and then change the sign of the exponent in the divisor and add the exponents.

Ohm's Law and the electric power formulas are often used to solve electric and electronic problems. Depending on which quantities are known and unknown, one of the three forms of Ohm's Law can be used: $E = IR$, $I = E/R$ or $R = E/I$. Likewise, depending on the known and unknown quantities, one of the three power formulas can be used: $P = EI$, $P = I^2R$ or $P = E^2/R$.

The quantities substituted into the Ohm's Law or electric power formulas must be in basic units: volts for E, amperes for I, ohms for R, and watts for P.

PRACTICE EXERCISE SOLUTIONS

1. 5000 ohms = 5×10^3 ohms

2. 10,000 ohms = 1×10^4 ohms -- As 1 times any quantity is the quantity itself, 1×10^4 could also be written as simply 10^4.

3. 500,000 ohms = 5×10^5 ohms

4. 4×10^4 ohms = 40,000 ohms

5. 3×10^2 volts = 300 volts

6. 9×10^1 amperes = 90 amperes

7. .0003 ampere = 3×10^{-4} amperes

8. .02 ampere = 2×10^{-2} amperes

9. .009 ampere = 9×10^{-3} amperes

10. 7×10^{-1} volts = .7 volt

11. 3×10^{-3} amperes = .003 ampere

12. 6×10^{-5} watts = .00006 watt

13. 250 volts = 2.5×10^2 volts

14. 470,000 ohms = 4.7×10^5 ohms

15. .0033 ampere = 3.3×10^{-3} amperes

16. .00079 ampere = 7.9×10^{-4} amperes

17. 5×10^4 or 50,000 volts -- Converting current and resistance into scientific notation yields: 25 amperes = 2.5×10^1 amperes, and 2000 ohms = 2×10^3 ohms. The voltage across the tube is then equal to:

$$E = IR = 2.5 \times 10^1 \text{ amperes} \times 2 \times 10^3 \text{ ohms} = 5 \times 10^4$$

$$\text{or } 50,000 \text{ volts}$$

18. 8.8×10^1 or 88 volts -- Converting current and resistance into

PRACTICE EXERCISE SOLUTIONS (Continued)

scientific notation yields: .004 ampere = 4×10^{-3} amperes, and 22,000 ohms = 2.2×10^4 ohms. The circuit voltage is then equal to:

$$E = IR = 4 \times 10^{-3} \text{ amperes} \times 2.2 \times 10^4 \text{ ohms}$$

$$= 8.8 \times 10^1 \text{ or } 88 \text{ volts}$$

19. 4×10^{-2} or .04 ampere -- Converting voltage and resistance into scientific notation yields: 200 volts = 20×10^1 volts and 5000 ohms = 5×10^3 ohms. The current is then equal to:

$$I = \frac{E}{R} = \frac{20 \times 10^1}{5 \times 10^3} = \frac{20 \times 10^1 \times 10^{-3}}{5 \quad (\times 10^3)}$$

$$= 4 \times 10^{-2} \text{ or } .04 \text{ ampere}$$

20. 7.5×10^2 or 750 ohms -- Converting voltage and current into scientific notation yields: 75 volts = 7.5×10^1 volts and .1 ampere = 1×10^{-1} ampere. The resistance is then:

$$R = \frac{E}{I} = \frac{7.5 \times 10^1}{1 \times 10^{-1}} = \frac{7.5 \times 10^1 \times 10^1}{1 \; (\times 10^{-1})}$$

$$= 7.5 \times 10^2 \text{ or } 750 \text{ ohms}$$

21. Yes

22. 55.4×10^3 or 55,400 -- Changing each number into scientific notation with the same exponent of 10 yields: 4500 = 4.5×10^3, 50,000 = 50×10^3, and 900 = $.9 \times 10^3$. The numbers are then added:

$$4.5 \times 10^3$$

$$50 \quad \times 10^3$$

$$\underline{.9 \times 10^3}$$

$$55.4 \times 10^3 \text{ or } 55,400$$

PRACTICE EXERCISE SOLUTIONS (Continued)

23. No -- Both numbers must have the same exponent of 10 before they can be subtracted.

24. $.9 \times 10^3$ or 900 -- Changing 9×10^2 to some number times 10^3 yields: $9 \times 10^2 = .9 \times 10^3$. The numbers can then be subtracted:

$$1.8 \times 10^3$$

$$- .9 \times 10^3$$

$$.9 \times 10^3 \text{ or } 900$$

25. $E = IR$, $I = E/R$, and $R = E/I$

26. The other forms are obtained by rearranging $E = IR$. The form $I = E/R$ is obtained by dividing both sides of $E = IR$ by R, and $R = E/I$ is obtained by dividing both sides of $E = IR$ by I:

$$E = IR$$

$$\frac{E}{R} = \frac{I\cancel{R}}{\cancel{R}} \qquad\qquad \frac{E}{I} = \frac{\cancel{I}R}{\cancel{I}}$$

$$I = \frac{E}{R} \qquad\qquad R = \frac{E}{I}$$

27. $P = EI$, $P = I^2R$, and $P = E^2/R$

28. $P = I^2R$

29. 35×10^{-3} or 3.5×10^{-2} amperes

30. 1.9×10^{-6} amperes

31. 68×10^3 or 6.8×10^4 ohms

32. 2.2×10^6 ohms

33. $I = E/R$

34. 3600 or 3.6K ohms -- To solve the problem, you would use the Ohm's Law formula. Since current is given in ma it must first be converted to amperes: $2.5 \, ma = 2.5 \times 10^{-3}$ amperes. The problem is then solved as shown below:

$$R = \frac{E}{I} = \frac{9 \text{ volts}}{2.5 \times 10^{-3} \text{ amperes}}$$

$$= \frac{9 \times 10^3}{2.5 \times 10^{-3}} = 3.6 \times 10^3 \text{ or } 3600 \text{ ohms}$$

35. 23.5 volts -- To solve this problem, you would use the Ohm's Law formula $E = IR$. Current and resistance must be converted to basic units; $470K \text{ ohms} = 470 \times 10^3 \text{ ohms} = 4.7 \times 10^5$ ohms, and $50 \, \mu a = 50 \times 10^{-6}$ amperes $= 5 \times 10^{-5}$ amperes. The problem is then solved as shown below:

$$E = IR = 5 \times 10^{-5} \text{ amperes} \times 4.7 \times 10^5 \text{ ohms}$$

$$= 23.5 \times 10^0 \text{ or } 23.5 \text{ volts}$$

36. $P = E^2/R$

37. less (.25 watt) -- To solve this problem you use the formula $P = I^2R$. Since the values of current and resistance are not in basic units, they must be converted: $5 \, ma = 5 \times 10^{-3}$ amperes, and $10K \text{ ohms} = 10 \times 10^3$ or 1×10^4 ohms. The power dissipated is then found as shown below:

$$P = I^2R = (5 \times 10^{-3} \text{ amperes})^2 \times 1 \times 10^4 \text{ ohms}$$

$$= 25 \times 10^{-6} \times 1 \times 10^4$$

$$= 25 \times 10^{-2} \text{ or } .25 \text{ watt}$$

Since the resistor is a 10 watt resistor, it is dissipating less than its rated power.

38. 4×10^3 -- The square root of 16 is 4, and the square root of 10^6 is 10^3.

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question, as illustrated in the example below.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

LESSON CODE

1021A

Example: An apple is a
(A) meat, (B) vegetable, (C) fruit, (D) soup.

1. In the number 5.5×10^2, the 2 above and to the right of the 10 is called the
(A) sum. (B) divisor. (C) difference. (D) exponent.

2. 47,000 ohms expressed in scientific notation is
(A) 4.7×10^{-4} ohms. (B) 4.7×10^4 ohms. (C) 470×10^3 ohms. (D) 470×10^{-3} ohms.

3. In scientific notation .0022 ampere equals
(A) 2.2×10^{-3} amperes. (B) 2.2×10^3 amperes. (C) 22×10^{-3} amperes. (D) $.22 \times 10^{-1}$ ampere.

4. The number 3.7×10^4 equals
(A) 370. (B) 370,000. (C) 37. (D) 37,000.

5. What voltage is developed across a 5×10^3 ohm resistor that is carrying 4×10^{-2} amperes?
(A) 20,000,000 volts, (B) 4×10^{-1} volts, (C) 2×10^2 volts, (D) 8×10^{-2} volts.

6. If a circuit has a resistance of 5000 ohms and is connected to a 75 volt battery, how much current flows?
(A) 15×10^1 amperes, (B) 9×10^{-3} amperes, (C) 1.5×10^{-2} amperes, (D) 25×10^{-1} amperes.

7. If voltage and current are known and resistance must be found, the formula to use is
(A) R = E/I. (B) I = $\sqrt{P/R}$. (C) P = I^2R. (D) E = P/I.

8. If current and resistance are known and power must be found, the formula to use is
(A) E = P/I. (B) R = E/I. (C) P = I^2R. (D) E = IR.

9. Converting 9.7 ma into basic units with scientific notation produces
(A) 9.7×10^6 amperes. (B) 9.3×10^{-2} amperes. (C) 9.7×10^{-3} amperes. (D) 7.9×10^{-6} amperes.

10. How much power does a 5K ohm resistor dissipate if it carries 9 ma?
(A) .405 watt, (B) .593 watt, (C) 593 watts, (D) 4,050 watts.
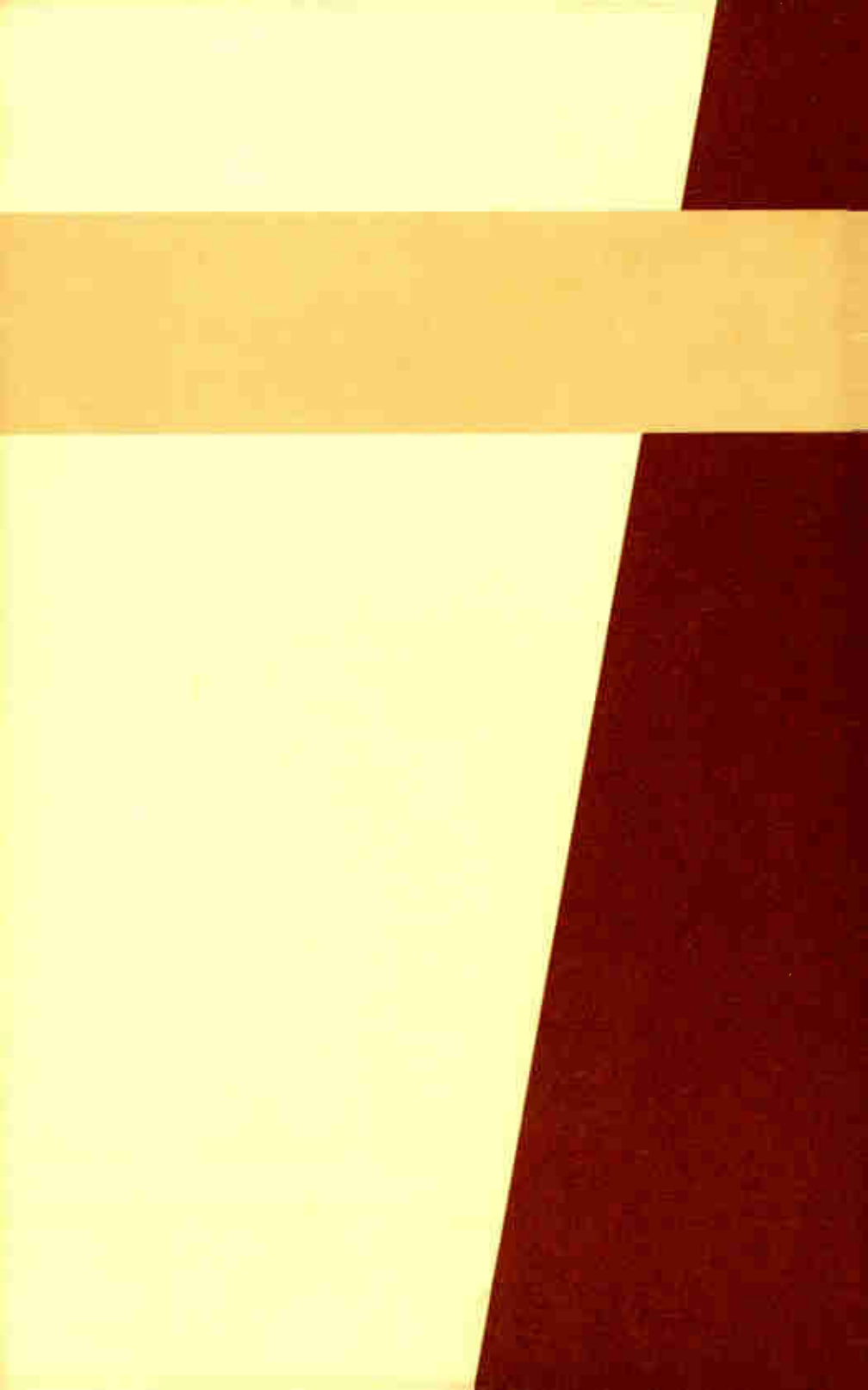
DEDICATED TO PROGRESS THROUGH EDUCATION

SYNC CIRCUITS AND
D-C RESTORERS

Lesson T2C-10

DeVRY INSTITUTE of TECHNOLOGY

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SYNC CIRCUITS AND DC RESTORERS

Revised 1968

OPPORTUNITY

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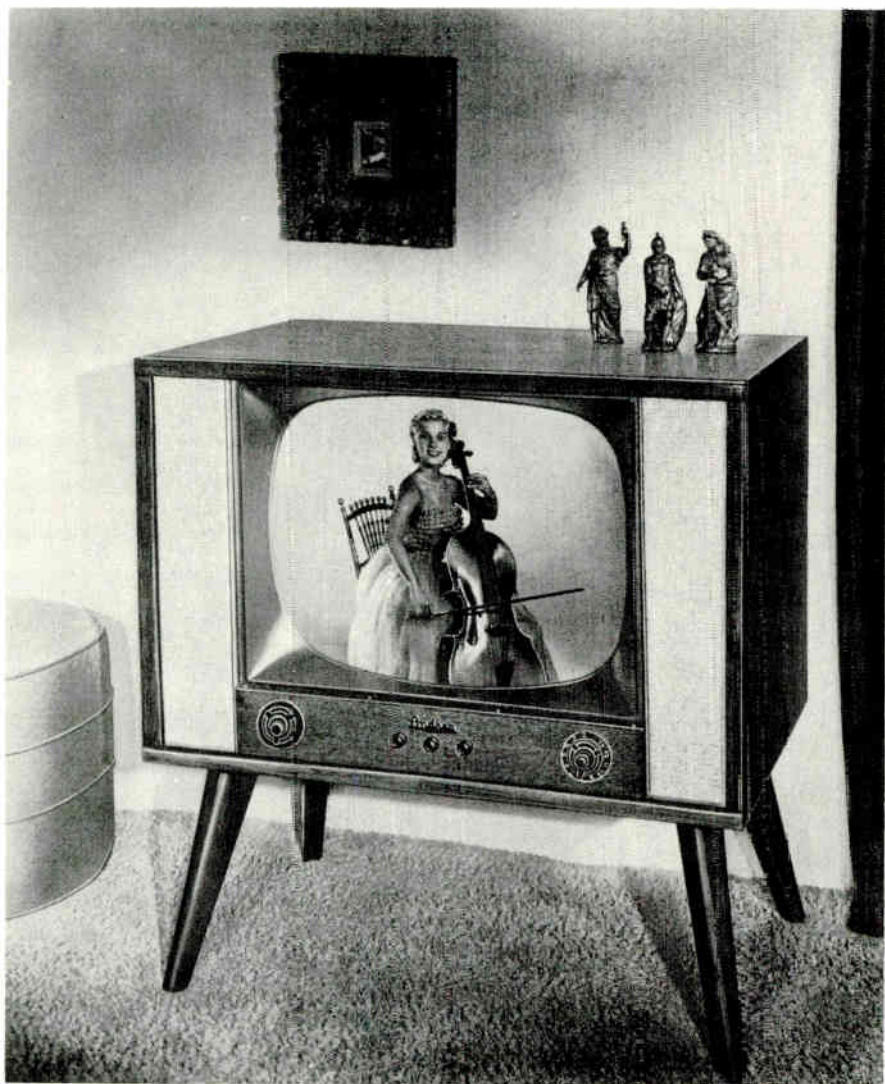
Simplicity is the keynote in the cabinet design of this console television receiver.
Courtesy Andrea Radio Corp.

SYNC CIRCUITS AND DC RESTORERS

Contents

Lots of folks have a good aim in life . . . but most
of them don't know when to pull the trigger.

—Gilerafter

SYNC CIRCUITS AND DC RESTORERS

To efficiently troubleshoot the many different models of television receivers, you must know the requirements of the various sections of the television receiver. An understanding of the operation of basic electronic circuits is also very important. With this combined knowledge, you can employ systematic troubleshooting techniques to determine whether or not a given section performs all of the functions assigned to it.

You have already studied the functions of the group of circuits known as the sync section. Also explained were the filter circuits and vacuum tube and transistor circuits which combine to produce synchronization at the television receiver. The basic circuits are combined in a number of ways by the various manufacturers to accomplish the desired results. Thus, in analyzing a circuit arrangement which you have not encountered previously, you apply your knowledge of circuit theory to determine which functions are performed by each stage or group of components in the section.

In this lesson you study a number of sync circuit combinations used in commercial television receivers. The knowledge gained in the study of these circuits will enable you to analyze the sync sec-

tions in other makes and models of television receivers.

The sync circuits separate the sync signals from the remainder of the video wave. Also, they amplify and invert the sync pulses when required, and filter the composite sync signal so that only pulses of the proper frequency are applied to each deflection circuit. The sync circuits also include some means of preventing noise energy from passing through the sync section to cause a loss of sync in the horizontal or vertical deflection oscillators.

Operating as limiters, both the sync separator and the sync amplifier remove some noise energy by clipping off portions of the signal applied to their input. Besides this, resistor and capacitor networks are used to block noise in some circuits, while others employ one or more electron tube or transistor stages which function as noise limiters. In fact, most sync circuit designs are very much alike except for the methods used to eliminate noise pulses.

COMPLETE SYNC CIRCUITS

Figure 1 shows a sync section typical of those in many receivers. In this circuit, V_1 is the video amplifier stage, V_2 is a grid leak sync separator, and V_3 is a sync

phase inverter. The plate circuit of V_1 contains peaking coils L_1 and L_2 and load resistor R_1. Capacitor C_1 couples the video amplifier output to the cathode of the picture tube. From the junction between L_2 and R_1, the negative picture phase video signal is coupled through C_2 and parallel components C_3 and R_3 to the grid of sync separator tube V_2. The plate of this triode is operated at a low dc potential and the cathode is grounded. The peaks of the positive going sync pulses of the input signal produce grid current which charges C_2 and C_3 to the polarities indicated.

Between sync pulses, C_2 discharges slightly through R_2 to produce a grid leak bias voltage, E_{R_2}. This voltage is in series with the voltage E_{C_3} between the grid and cathode of V_2. These two voltages are series aiding, and thus bias the tube negative beyond cutoff so that plate current is produced only by the positive sync pulses. These sync pulses cause pulses of plate current which produce the negative voltage pulses indicated at the plate of V_2.

In this receiver, positive sync pulses are required to properly control the deflection oscillators. Therefore, the V_3 stage is employed to invert the phase of the pulses as shown. In addition, the V_3 stage also amplifies the sync pulses.

The V_3 sync phase inverter stage is operated with grid leak bias and a low plate potential. Thus, it also serves as a second sync clipper. From the junction between R_7 and R_8, the positive sync pulses are applied to the differentiating circuit C_5R_{11} and the two section integrating circuit R_9C_6 and $R_{10}C_7$. The outputs of the differentiating and integrating networks are applied to the appropriate deflection circuits.
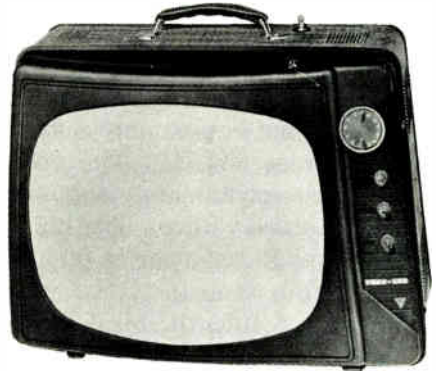
Modern circuitry and construction practices permit the design of small, lightweight television receivers with excellent electrical characteristics.
Courtesy Trav-Ler Radio Corporation

Together with C_2 and R_2, resistor R_3 and capacitor C_3 form what is known as a dual time constant network in the grid circuit of the sync separator. The purpose of this arrangement is to prevent large amplitude noise pulses or "spikes" from changing the bias on the separator. Increased bias for even the short period of a noise pulse can cause

a partial or total loss of vertical synchronism.

Like the sync pulses, the noise spikes have positive polarity in the video amplifier output, but may have even greater amplitude. When such a noise spike or pulse occurs, it produces a large grid current in V_2 which charges both C_2 and C_3 as shown.

However, capacitor C_3 has a value of only 220 $\mu\mu f$ compared with the .01 μf of C_2. Because the capacitance of C_3 is so much less than that of C_2, the charging current quickly increases E_{C_3} to a high value but causes only a very slight increase of E_{C_2}. The voltage E_{C_3} is approximately equal to the noise pulse voltage. The noise voltage and E_{C_3} are series opposing, and thus tend to cancel each other. As a result, the bias (E_{R_2}) is determined only by the charge on C_2, which has not changed appreciably. After the noise pulse is ended, capacitor C_3 discharges through R_3.

It was mentioned that the sync phase inverter V_3 operates with grid leak bias. Grid leak bias exists even though the output of V_2 consists of negative going sync pulses. In the V_2 plate circuit, R_4 and R_5 form a voltage divider between B+ (125 v) and ground. The junction of these resistors supplies $+100$ volts to the plate of V_2. Thus, during the intervals

between pulses, the ungrounded end of R_5 is 100 volts positive. When sync pulses swing the V_2 plate in the negative direction, coupling capacitor C_4 discharges slightly through R_6 to provide negative pulses at the grid of V_3. The resulting reductions of V_3 plate current produce the positive plate voltage pulses as indicated.

In the plate circuit of the sync separator V_2, as each negative sync pulse is completed, the plate voltage returns to its operating value of $+100$ volts. However, as the waveform drawn at this point in the figure shows, a slight oscillation occurs during the first part of which the plate voltage rises to slightly over 100 volts. This overshoot, as it is called, applies a momentary positive voltage to the grid of V_3, producing cathode to grid electron flow which charges C_4 to a little over 101 volts, and with the polarity indicated. During the remainder of the cycle, the series opposing voltages, E_{C_4} and E_{R_5}, apply a net bias of $100-101$, or -1 volt to the grid of V_3.

Figure 2 shows another common sync circuit. In this circuit, V_2 is the grid leak sync separator and triode V_3 serves as the sync clipper and sync phase inverter. From the junction between L_2 and R_2 in the video amplifier plate circuit, the negative picture phase video signal is coupled through R_1, C_2, and the parallel

circuit R_3 and C_3 to the grid of the sync separator. Resistor R_1 serves as an isolating resistor to prevent the input capacitance of the sync separator tube from shunting the plate circuit of the video amplifier.

Together with coupling capacitor C_2 and grid resistor R_4, the parallel circuit R_3C_3 forms a dual time constant network to prevent changes in grid bias due to noise pulses. Grid current charges C_2, and electrons leak off C_2 through R_3 and R_4. The resulting voltage across R_4 biases the tube beyond cutoff so that only sync pulses cause conduction. R_3 has a resistance which permits C_3 to discharge relatively quickly after being charged by a noise pulse.

In the circuit of Figure 2, the video signal input to the grid of V_2 may vary between 25 and 135 volts peak to peak, but the sync separator limits the output pulses to 25 volts peak to peak. Thus, the sync pulses in the output have amplitude as great as that of the entire input video signal when the input is only 25 volts p-p. However, since the plate current is varied from cutoff to saturation, even with this low input level, an increase of input signal amplitude cannot increase the output level. That is, the amplification obtained decreases as the input signal increases, to provide the constant output amplitude indicated.

As shown in the figure, the plate of V_2 is direct-coupled to the grid of the sync clipper V_3. Both the V_2 plate and V_3 grid operate at 21 volts positive with respect to ground. The voltage across cathode resistor R_{10} places the V_3 cathode at $+21.5$ volts with respect to ground. Therefore, the sync clipper tube operates with its grid at 0.5 volt negative with respect to its cathode, and with its plate 145 volts positive with respect to ground. The 25 volt p-p amplitude of the input pulses is sufficient to drive V_3 into cutoff during the negative peaks. This clips the peaks to provide output pulses with more constant flat tops.

From the plate of V_3, 70 volt p-p positive pulses are applied to the three-section integrating circuit, R_6C_4, R_7C_5, R_8C_6, the output of which is coupled to the vertical deflection circuit. This receiver employs a horizontal frequency control circuit which requires both positive and negative sync pulses. To provide these outputs, the sync clipper is operated as a phase splitter. Thus, resistor R_{10} is the cathode circuit section of the plate load, while R_9 and R_{11} form a voltage divider in the plate circuit section. Positive sync pulses, 25 volts p-p, are coupled through C_7 to the horizontal frequency control circuit, while the V_3 cathode supplies 25 volt p-p

negative pulses to this circuit through capacitor C_8.

Figure 3 shows the circuit of a television sync section which incorporates a pentagrid sync separator. V_1 is the video amplifier, V_2 the pentagrid sync separator, and V_3 the sync phase inverter. A positive video signal from the L_3R_5 junction is applied to the third grid of V_2 through the dual time constant network consisting of C_6R_7 and C_7R_6. A negative video signal obtained from the L_2C_3 junction (point X) is applied through C_5 to the first grid of V_2. Figure 3 includes the video circuits in order to show the method of obtaining these out-of-phase video signals. The signal obtained from the V_1 plate circuit is clipped by the limiting action of the V_2 third grid to produce a sync signal output free of picture and blanking information. The signal obtained from the D_1 video detector is used to cut off V_2 when a noise pulse which exceeds the amplitude of the sync pulses is present.

In the detector circuit, the semiconductor diode D_1 is connected so that the i-f voltage alternations which make the upper end of the T_1 secondary negative produce diode current. On these alternations, electrons flow from the upper end of T_1 through D_1, L_1, L_2 and R_1 to ground, and back to the lower end of T_1. As a result, the ungrounded end of load resistor R_1 is made negative. Thus, at point X, the video signal has positive picture phase (negative going sync pulses). This signal is coupled through C_3 to the control grid of video amplifier V_1 and also through C_5 to grid 1 of sync separator V_2.

Inverted by the video amplifier, the video signal has negative picture phase (positive going sync pulses) at the plate of V_1 and at point Y. From the junction between L_3 and R_5 (point Y), the positive sync pulse video signal is applied through C_6 and the parallel combination C_7 and R_6 to grid 3 of the sync separator tube. This grid and the cathode act as a diode which rectifies the applied signal, charging C_6 to the polarity indicated. Between pulses this charge partially leaks off through R_6 and R_7 to the cathode, producing a voltage across R_7 which biases the grid negative. This bias cuts off the tube, but because the charge is allowed to partially leak off, the next sync pulse can overcome the bias and cause the tube to conduct.

The pulses of plate current cause the V_2 plate voltage to fall, thus producing negative sync pulses, stripped free of blanking and picture information, at point Z. Applied to the grid of the phase splitter tube V_3, these negative pulses are reproduced as positive going pulses at the V_3 plate, and negative going pulses

at the cathode. From these points, they are applied through integrating and differentiating circuits to the respective deflection circuits as indicated.

A small positive voltage is applied to the first grid of V_2, causing this grid to lose complete control of plate current. This voltage is obtained from the voltage divider circuit consisting of R_8, R_{18}, and R_{19}. Normally, the video signal applied from point X is too small to drive the V_2 first grid negative with respect to the cathode. But when the signal contains a noise pulse which exceeds the amplitude of the sync pulses, this noise pulse drives the grid negative to cut off the tube. With the tube thus cut off, neither noise nor sync pulses appear in its output for the duration of the noise pulse. During the period in which V_2 is cut off, the deflection oscillators are held in sync by their own stability.

The positive voltage required on the first grid of V_2 depends upon the amplitude of the received signal. When the signal is strong, the grid must be operated sufficiently positive so that the negative going sync pulse cannot drive the tube into cutoff. If the sync pulse tips cut off the tube, the amplitude of the pulses produced in the output is reduced to cause partial loss of synchronism. However, the more positive the grid is operated, the less control

it has, with the result that the noise cancelling action occurs only for relatively large amplitude noise pulses. Cancelling action on low as well as high amplitude noise pulses can be obtained when the received signal is weaker by operating the grid less positive, thus giving it more control.
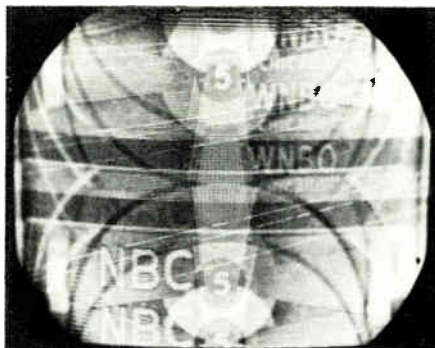
Vertical rolling of the image is caused when noise pulses trigger the vertical deflection oscillator. This loss of synchronism may be due also to a sync circuit defect which prevents proper application of the sync signal to the vertical oscillator.

The sync circuit of Figure 3 provides a means of selecting different positive voltages for the first grid of V_2. When potentiometer R_{18} is set in the position of maximum resistance, the minimum amount of positive voltage is applied to grid 1 of V_2. In this position, weak noise pulses can cut off V_2. In strong signal areas, potentiometer R_{18} is set in the position of minimum resistance. Thus, the maximum amount of positive voltage is applied to grid

1 of V_2 and relatively large amplitude noise pulses are required to cut off V_2. Resistor R_{19} is used to limit the maximum amount of positive voltage that can be applied to grid 1 of V_2.

Because of their good switching characteristics, transistors make excellent sync separators. Figure 4 shows the circuit of a transistor sync section. A video signal with negative sync pulses is obtained from the R_1R_2 junction in the V_1 collector circuit. This signal is coupled through the dual time constant network consisting of C_1R_4 and R_3C_2 to the base of the V_2 sync separator stage. No fixed base bias is used on the V_2 stage. Thus, with no input signal, the sync separator transistor is cut off because of the lack of forward bias on the base-emitter junction.

When a negative sync pulse arrives, the transistor is driven to saturation and current flows from the base to the emitter, charging C_1 as shown. The charging time constant of C_1 is fairly short because of the low input resistance of V_2 when saturated. Therefore, C_1 charges completely during the time the horizontal sync pulse is present. The magnitude of the voltage across C_1 depends upon the amount of base current and the duration of the sync pulse.

At the end of the sync pulse, the transistor is cut off as the

signal level rises from the sync tips to the blanking level, and then to the video level. The blanking and video information are always more positive than the cutoff voltage of the transistor.

While the transistor is cut off, it presents a high resistance between its base and emitter. Therefore, C_1 discharges through the parallel combination of C_3 and R_4. As C_1 discharges, the base voltage becomes less negative. When the next sync pulse arrives, the voltage across C_3 has decreased to the point where the transistor is easily driven into saturation by the negative sync pulse. By the proper choice of C_3 and R_4, it is possible to automatically control the base bias voltage over a wide range of input signals and still permit sync pulses to drive the transistor into saturation.

If the input signal suddenly decreases, the V_2 bias still varies around the voltage established across capacitor C_3. If the level has changed so much that the next sync pulse does not drive the transistor into saturation, less current flows into C_3 during the charging cycle. Therefore, capacitor C_3 charges to a smaller positive value, and the base voltage is closer to zero when the next sync pulse arrives. Thus, in the event the input signal drastically reduces in amplitude, only a very few horizontal sync pulses are

lost before the circuit regains its control action.

This action is very similar to that of a grid leak vacuum tube sync separator stage. In both instances, the bias will vary and produce a constant amplitude output signal with a wide range of input signals.

The circuit of Figure 4 provides excellent protection with very strong signals. The strong signals will drive the V_2 stage well into saturation and result in more base current. The increased base current increases the positive voltage across C_3 and thus, reduces the gain of the V_2 stage.

The sync pulse output of the V_2 stage is applied through coupling capacitor C_4 to the base of the V_3 sync phase inverter. Resistors R_6 and R_7 form the V_3 base bias voltage divider circuit. The negative sync pulse signal developed across the V_3 collector load resistor, R_9, is applied through an integrating network to the vertical deflection circuits. The positive sync pulse signal developed across the R_8 emitter load resistor is applied through the C_5R_{10} differentiating network to the horizontal deflection circuits.

If positive going sync pulses were required to control the vertical deflection circuit, the vertical integrating network would be connected to the V_3 emitter circuit. Also, if negative sync pulses were required to control the horizontal deflection circuit, the horizontal differentiating circuit would be connected to the V_3 collector circuit.

Figure 5 shows the circuit of a transistor noise switch which is used to reduce the effects of noise pulses in transistor television receivers. A positive video signal with negative sync pulses is obtained from the R_5R_6 junction in the video amplifier collector circuit. This signal is applied, through a dual time constant network, to the base of the V_2 sync separator stage. When the V_3 noise switch is conducting, there is only a small dc potential between the V_3 collector and emitter. Thus, the V_2 emitter is effectively at ground potential. Transistor V_3 is biased so that it is normally in conduction. The V_2 stage is biased so that it is normally cutoff and functions in the same manner as the sync separator stage of Figure 4. The negative sync pulses cause V_2 conduction and the sync pulse output appears across collector load resistor R_9. The sync pulse output is applied through differentiating and integrating networks to the respective deflection circuits.

Another video signal is applied to the anode of diode D_2. This signal is obtained from the out-

put of the D_1 video detector circuit and is 180° out of phase with the signal applied to the base of the sync separator. The cathode of D_2 is biased so that it is normally more positive than the anode. The D_2 anode and cathode bias voltages are obtained from the two voltage divider circuits consisting of $R_{14}R_{15}$ and $R_{16}R_{17}$.
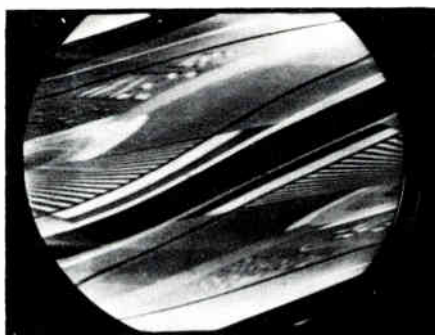
A sync circuit defect which causes loss or partial loss of the sync pulses needed by the horizontal control circuit results in loss of horizontal synchronism with this effect on the image.

When a noise pulse occurs which has a higher potential than the D_2 cathode bias, D_2 conducts and the noise pulse is applied to the base of V_3 through C_{13}. Thus, the positive noise pulse opposes the V_3 base bias and causes V_3 to go into cutoff. When V_3 is in cutoff the V_2 emitter circuit is open since V_2 and V_3 are effectively connected in series. Thus, no sync pulses are obtained from the V_2 output. During the period in which a noise pulse occurs, the receiver is held in sync by the stability of its deflection oscillators.

The sync circuits described in this lesson are common to those found in actual television receivers. There are many variations of these sync circuits, but a good understanding of basic sync circuit operation will enable you to analyze and service any sync circuit you may encounter.

DC RESTORATION

On the receiver screen, the brightness of the scanning line pattern, or raster, is determined by the bias on the picture tube control grid. The more negative the grid with respect to the cathode, the fewer the electrons which reach the screen, and the lower the brightness level. If the grid bias is decreased, more electrons reach the screen and a higher level of brightness is obtained. Called a brightness or brilliance control, a potentiometer is included in the picture tube cathode or control grid circuit. This control provides a means of adjusting the grid bias, and thus determines the operating point of the tube. The video signal voltage is applied to the grid circuit and causes the instantaneous grid voltage to vary about the operating point.

Although these signal variations produce picture elements

which are respectively darker and brighter than the average level of screen brightness, they do not give any information regarding the average brightness of the scene scanned at the studio. Therefore, when this potentiometer is the only brightness control in the receiver, the viewer can adjust it for some desired level of average brightness, but he does not know whether a generally dark or bright scene is being viewed by the television camera. To overcome this disadvantage, many receivers incorporate an automatic brightness control.

To provide a basis for the proper adjustment of the brightness controls of the receivers tuned to any particular station, the transmitted signal contains a brightness reference level. This reference could be the zero signal level which produces maximum white on the screen, or a level corresponding to some definite shade of gray, between maximum white and black.

Since the various degrees of screen brilliance vary with different picture tubes and receiver circuits, the only practical reference is the signal level which causes zero brightness or a "black" screen. Known as the black level, this is the reference used in present television systems.

NATURE OF A
TELEVISION SIGNAL

For any particular picture tube, the cutoff grid voltage is always the same. Therefore, the grid bias must be controlled in such a way that the blanking pulses are able to reduce the scanning spot intensity to zero, regardless of the average brightness of the picture being received.

To provide this condition, the blanking pulses have greater amplitude than the black level, and the viewer may use them as a reference. To cause the picture details to have their correct brightness levels with respect to black, it is simply necessary that the blanking pulses reduce the screen brightness to zero.

As explained, the black level is transmitted at a fixed signal amplitude, while the modulation corresponding to the details of the scene causes the signal level to vary from instant to instant in accordance with the relative intensities of the picture elements scanned by the camera. For proper reproduction of a television scene, not only the picture details, but also the background must have the proper brightness with respect to black. The background brightness level may be thought of as zero axis with the instantaneous intensities of the picture details varying above and below.

This zero axis, or background brightness level, may remain constant for a comparatively long period of time, or it may change slowly, or more rapidly. However, even the relatively rapid changes are quite slow compared to the video frequencies corresponding to the details of the scene. Whether constant or changing, the background brightness seldom decreases to zero or black level.

The background brightness of the picture tube screen is determined by the bias applied between its grid and cathode.
Courtesy Radio Corporation of America

Hence, there is a dc difference of potential between the zero axis and the black level of the picture signal. If the background of the reproduced image is to have the proper level with respect to black, the transmitted signal must retain this dc component. Furthermore, the receiver should operate in such a way that the dc component controls the grid bias of the picture tube. For this reason, many television receivers contain an automatic brightness control circuit which, together with the brightness control potentiometer, determines the actual negative bias on the picture tube grid. The automatic brightness control (abc) circuit must be responsive to changes in the dc component so that any variations of background illumination are reproduced.

DC Insertion
at the Transmitter

In the process of forming the complete video signal at the transmitter, the picture signal ac axis may be adjusted to its proper value with respect to the blanking level by the addition of a direct voltage. The magnitude of this dc voltage is determined by the average brightness of the scene. This direct voltage usually is inserted in the grid circuit of one of the tubes in the transmitter mixing circuit. Its amplitude is adjusted by an engineer seated in the control booth where he can observe the scene being televised.

For example, when a generally dark scene is being scanned in the studio, a low direct voltage is

inserted so that the signal ac axis is not far below the level of the blanking pulses, as indicated by E_{dc} in Figure 6E. When a bright scene is being scanned, a higher direct voltage is inserted and the ac axis falls well below the blanking level, as indicated by E_{dc} in Figure 6F.

Modulated by the video signals of Figures 6E and 6F, the television r-f carrier can be represented by the curves of Figures 6A and 6B, respectively. Regardless of the nature of the transmitted scene, the carrier increases to 75% of its peak amplitude for the blanking pulses and to 100% for the sync pulses. However, the average amplitude, above or below the zero axis, is greater in the case of the dark picture of Figure 6E than it is for the bright scene of Figure 6F.

In the mixer stage of the receiver, modulated carriers like those of Figures 6A and 6B are heterodyned with the output of a local oscillator and the modulation is transferred to a lower or intermediate frequency. The modulated i-f is increased in magnitude as it passes through the i-f amplifier. Except for its lower frequency and greater amplitude, the output of the i-f amplifier is a replica of the incoming signal with an envelope like those of Figures 6A or 6B.

With the signal of Figure 6A applied, the video detector diode has an output as shown in Figure 6C. With an input signal like Figure 6B, the detector output is like Figure 6D. However, in practice, the detector load resistor is shunted by the capacitances of the detector diode and circuit which filters the intermediate frequency. Thus, the actual usable output has a form which more closely resembles those shown in Figures 6E and 6F. Hence, the detector demodulates the i-f carrier, and its output waveform is a replica of the original video signals produced at the transmitter.

The video amplifier increases the magnitude of the detector output voltage without causing any change of frequencies. Therefore, the curves of Figures 6E and 6F can represent the video signal voltage impressed across the control grid circuit of the picture tube.

Figure 7A shows a resistance-capacitance coupling circuit. Here e_{v-f} represents the video frequency signal obtained from the video amplifier stage, and e_g is the portion of e_{v-f} which appears across crt grid resistor R_1. C_1 is the coupling capacitor between the video amplifier and the grid of the picture tube. The cathode of the crt connects to the slider on potentiometer R_2, which is part of a voltage divider between the

positive connection of the plate or collector voltage supply and ground.

The grid bias is controlled by the position of the sliding contact of R_2, and the portion in series with the cathode is by-passed by capacitor C_2. By regulating the bias supply voltage E_{cc}, potentiometer R_2 serves as the manually operated brilliance or brightness control.

COMMON SYNC CIRCUIT TUBES

SEPARATOR OR CLIPPER	AMPLIFIER AND/OR PHASE INVERTER
6AL5	½ 6AN8
½ 6AN8	½ 6AU8
½ 6AU8	½ 6AW8
½ 6AW8	½ 6BU8
6BE6	½ 6CG7
6BY6	½ 6CN7
½ 6CG7	½ 6SN7
½ 6CN7	½ 6U8
½ 6CG7	½ 12AU7
½ 6SN7	
½ 6U8	
½ 12AU7	

In television, the polarity of the signal voltage is important because the blanking pulses must drive the picture tube grid negative to produce a "black" screen. These pulses are indicated as positive in the curves of Figures

6E and 6F. With this polarity, they can be applied to the cathode of the picture tube, or they can be inverted and impressed on the grid with negative polarity as indicated in the curves of Figure 7B.

In the normal action of an amplifier stage, the input grid voltage is 180° out of phase with the output plate voltage. Therefore, with a detector output as shown in Figure 6, an odd number of video amplifier stages provide the inverted output voltage of Figure 7B.

With a signal voltage like that of Figure 6E inverted and applied across the e_{v-t} terminals of Figure 7A, the coupling capacitor C_1 blocks the dc component and only the variations or ac component appears across grid resistor R_1. This ac component e_g is indicated by the dark picture curve of Figure 7B, and the average level is indicated by the reference line or axis located so that the curve forms equal areas above and below it. To emphasize the action in the curves of Figure 7B, the sync and blanking pulses have been enlarged and the actual picture signals reduced.

With a signal like that of Figure 6F inverted and applied across the e_{v-t} terminals of Figure 7A, the resulting voltage e_g is indicated by the bright picture curve of Figure 7B. Although

both curves of Figure 7B are drawn on the same average level or base line, the pulses of the dark picture are less negative than those of the bright picture, while the other parts of the bright picture are more positive than those of the dark picture. Thus, the dc blocking action of the coupling capacitor has changed the fixed reference for the signal from the blanking level to the average signal level.

To illustrate the transfer of these changes of grid voltage to corresponding variations of screen brightness, the I_bE_c characteristic curve of the picture tube of Figure 7 is shown in Figure 8. The e_g voltages of Figure 7B are added to the dc bias E_{cc} and, for this explanation, assume that control R_2 has been set so that the negative blanking pulses of the bright picture drive the grid negative to cutoff.

To illustrate this action, the direct voltage applied to the grid is indicated by the broken vertical line that extends to about the middle of the I_bE_c curve in Figure 8. The ac grid voltage is shown by superimposing the e_g curves of Figure 7B on this line. Projecting these values upward to the characteristic curve, the resulting instantaneous changes of screen brightness are plotted to the right.

The brightness curves of Figure 8 indicate the reproduction of the bright picture would be satisfactory, as the image details are between gray and white while the blanking pulses drive the grid negative to cutoff and cause a black screen. However, for the dark picture, the image details are too bright and the blanking pulses are not sufficiently negative to cause a black screen. By increasing the negative bias until the dark picture pulses drive the grid to cutoff, correct reproduction could be obtained, but then the bright pictures would be too dark.

DC RESTORER CIRCUITS

To reproduce pictures with proper average brightness and blanking pulses sufficiently negative to reach the black level, it would be necessary to adjust the bias voltage in the circuit of Figure 7A for each change of scene. While this is possible, it is not practical as almost constant adjustment would be necessary. Therefore, circuits have been developed to make the required changes automatically. In effect the automatic change of bias restores the dc component of the original signal, so the circuit is known as a dc restorer. The common types of dc restorers are described in the remainder of this lesson.

Diode DC Restorer

Figure 9A shows the circuit of a diode dc restorer. For simplicity, all frequency compensating and decoupling units are omitted and only the basic coupling units between the video amplifier stage and picture tube are indicated. Diode D_1 is connected in parallel with picture tube grid resistor R_1.

blocks the dc plate or collector voltage of V_1, but as the incoming signals cause variations of plate or collector voltage, the resulting charge and discharge currents of C_1 are carried by the $R_1 D_1$ combination.

When the receiver power is turned on, the plate or collector voltage of V_1 is impressed across
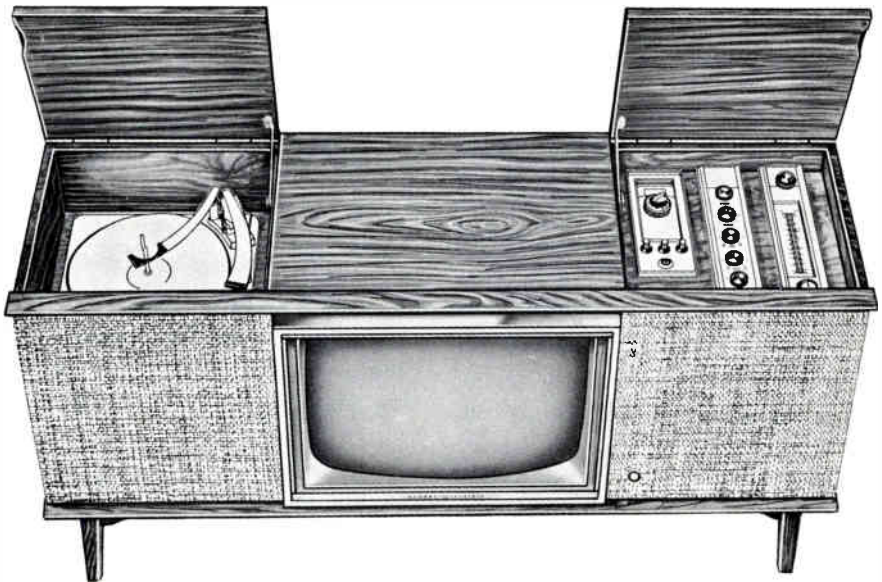
This modern console incorporates a 23″ UHF/VHF television receiver, and AM-FM tuner, and a stereophonic phonograph. For convenience, all of the controls are located at the top of the cabinet.

Courtesy General Electric Co.

The parallel combination of R_1 and D_1 is in series with coupling capacitor C_1 between the plate or collector of V_1 and ground, and also in series with the dc bias voltage E_{cc} in the V_2 grid-cathode circuit. Coupling capacitor C_1

capacitor C_1, which charges through grid resistor R_1. Electrons flow from ground through resistor R_1 to one capacitor plate, which becomes negative, thereby forcing electrons from the other plate through resistor R_L to the

positive terminal of the power supply and through the power supply to ground. This flow of electrons through R_1 causes a voltage which is positive toward the grid of V_2 as indicated.

With capacitor C_1 charged and no change of V_1 control grid or base voltage, there is no electron flow through, or voltage across, R_1. Therefore, the negative plate of C_1, the grid end of R_1, the cathode of diode D_1, and the control grid of picture tube V_2 are at ground potential. However, the cathode of tube V_2 is maintained positive with respect to ground by the voltage across the lower portion of potentiometer R_2. With the cathode as the reference point, the control grid of V_2 is negative by the amount of the E_{cc} voltage.

With signal voltages like those of Figures 6E and 6F impressed on the control grid or base of V_1 in Figure 9A, the voltage across R_L varies according to the curves of Figure 7B. These changes are impressed on coupling capacitor C_1. However, the v-f amplifier plate or collector is never negative with respect to ground. Therefore, the curves of Figure 7B represent the variations of positive voltage. By considering the horizontal line as normal or no-signal plate or collector voltage, the positive portions of the curve represent increases while the negative portions represent decreases of plate voltage.

Connected between the plate or collector of V_1 and ground, capacitor C_1 charges as the plate or collector voltage increases and discharges as the voltage decreases. During the capacitor charge, the electron flow follows the path explained previously, and the resulting voltage across R_1 has the indicated polarity. While the capacitor discharges, the electron flow is from the negative plate through R_1 to ground and through V_1 to the capacitor positive plate. During intervals of capacitor discharge, the polarity of the voltage across R_1 is reversed so that its grounded end is positive. Thus, variations in the positive voltage on the plate or collector of V_1 cause an alternating voltage across resistor R_1.

Connected with its anode to ground, diode D_1 is in parallel with resistor R_1. Therefore, any voltage across the resistor is impressed across D_1 also. While capacitor C_1 is charging, the polarity of the voltage across R_1 drives the cathode of D_1 positive with respect to the anode. Therefore, the diode is nonconductive. However, with capacitor C_1 discharging, the polarity across R_1 reverses, the cathode of D_1 is negative with respect to the anode, and the diode becomes conductive. Because of this action, C_1 charges through the comparatively high resistance of R_1 and discharges

through the low resistance of R_1 and D_1 in parallel.

C_1 and R_1 are so chosen that the RC time constant of the charging circuit is equal to the interval of about 10 horizontal lines. Therefore, for each individual line of the image, the charging current is fairly constant. Carried by resistor R_1, the charging current causes a voltage which is impressed on the grid-cathode circuit of the picture tube.

In the circuit of Figure 9A, there are two sources of voltage. First, voltage E_{cc} across the lower portion of potentiometer R_2. E_{cc} maintains the grid negative with respect to the cathode.

Second, the voltage across resistor R_1 is proportional to the charging current of capacitor C_1. This voltage has a polarity that tends to drive the V_2 grid positive with respect to the cathode. Thus, the E_{R_1} voltage opposes E_{cc}, and the net grid bias is equal to the difference.

When capacitor C_1 discharges, diode D_1 becomes conductive and the resulting low resistance of the parallel combination reduces the voltage across R_1 to a negligible value. Under these conditions E_{cc} is the only effective voltage in the grid-cathode circuit of V_2.

Potentiometer R_2 is adjusted so that, with no signal input, the picture tube grid is biased to beam cutoff, or zero screen brightness. Also, with the receiver in operating condition and with no signal input, coupling capacitor C_1 is charged to the plate or collector voltage of V_1 and there is no voltage across R_1.

To illustrate the action with signal voltages like those of Figure 7B, the plan of Figure 8 has been used for Figure 9B. Again, the signal voltages on the picture tube grid are shown at the lower left, and the bias voltage E_{cc} is adjusted to slightly beyond cutoff. As the first positive blanking pulse causes a sudden drop in the plate or collector voltage of V_1, capacitor C_1 discharges rapidly to the lower value. Diode D_1 conducts and the discharge has no appreciable effect on the grid voltage of V_2.

At the end of the blanking pulse, the plate or collector voltage of V_1 rises suddenly to its former value and capacitor C_1 starts to charge immediately. Diode D_1 is nonconductive, and the charging current is carried by resistor R_1. The resulting voltage across R_1 drives the grid of V_2 more positive or less negative. The voltage across R_1 is proportional to the difference between the average plate or collector voltage of V_1 and the lower value caused by the blanking pulse. The magnitude of this difference is

shown by the E_{R_1} arrow in the bright picture curve of Figure 9B.

Since E_{cc} is greater than E_{R_1}, the net bias is equal to $E_{cc} - E_{R_1}$. In this case it is indicated by the position of the vertical dashed line that intersects the I_b-E_c curve near its middle. Intersecting the curve at the same point, a horizontal dashed line indicates the relatively high average beam current and, therefore, high average screen brightness, due to the bright picture signal.

For a dark picture, the general action is exactly the same, but the difference between the average signal level and the negative blanking pulses is much less than for the bright picture. Therefore, the blanking pulses cause a smaller reduction of V_1 plate or collector voltage and capacitor C_1 discharges less. After the expiration of the blanking pulse the plate or collector voltage rises to its average value and the capacitor starts to charge. However, as this voltage increase is comparatively small, the charging current is correspondingly low. The resulting voltage across R_1 is indicated by the E_{R_1} arrows at the lower left of Figure 9B. Since E_{R_1} is small, the net bias, $E_{cc} - E_{R_1}$, is large so that the operating point is near the low end of the I_b-E_c curve. As a result, the average brightness of the scene is reduced to its proper value.
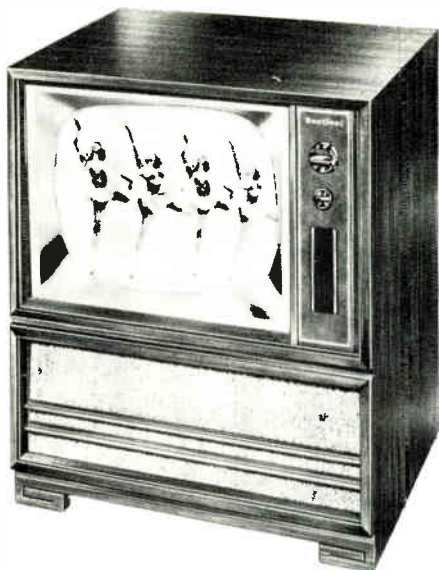
For a bright scene such as this, the picture tube grid operates only slightly negative with respect to the cathode voltage.

Courtesy Sentinel Radio Corp.

This arrangement automatically varies the picture tube screen brightness to correspond to the difference between the dark level and average level of the transmitted signal. Thus, in effect, it restores the dc component indicated as E_{dc} in Figure 6E and 6F.

In the upper right section of Figure 8, the screen brightness varies above and below the average level of the signals and the blanking pulses of the dark picture do not reach the black level. In the upper right section of Figure 9B, all blanking pulses extend to the black level, which is the reference, and the average

brightness level is at the proper distance above the reference.

To simplify the explanations of Figure 9, it was assumed that each blanking pulse caused diode D_1 to become conductive. In actual operation a state of balance is reached after which only the extremely negative sync pulses overcome the voltage across E_{R_1} and cause conduction of D_1. The diode current during these pulses is indicated by curve I_d of Figure 9B. Due to these short current pulses, the voltage across R_1 varies with scenes of different average brightness to provide the action as explained.

Grid Leak DC Restorer

A second type of dc restorer circuit, used in vacuum tube receivers, is shown in Figure 10A. The output of video amplifier V_1 is direct coupled to the grid of picture tube V_2. C_1 and R_1 provide grid leak bias for V_1 while R_L serves as the V_1 plate load resistor and as the grid resistor for V_2. Potentiometer R_2 is the manual brightness control.

Reviewing briefly, the grid leak bias is produced as a result of cathode to grid electron flow in V_1. The positive peaks of input signal e_{in} drive the amplifier grid positive with respect to the grounded cathode. Captured by the grid, electrons travel to C_1 which thus becomes charged to

the value of e_{in} and to the polarity indicated. During the interval between positive signal peaks, C_1 discharges slightly through R_1. The electrons leave the negative plate of C_1 and flow down through R_1 to ground so that the voltage E_{R_1} has the polarity indicated.

The capacitance of C_1 and the resistance of R_1 are relatively large. Therefore, C_1 does not discharge to any great extent between positive signal peaks, but is recharged fully by each peak. Because of this, the discharge current of C_1 maintains the grid bias, E_{R_1}, at a value only slightly less than the peak applied signal voltage. Thus, only the positive sync pulses are able to overcome this bias and cause cathode to grid conduction of V_1.

The bias E_{R_1} is directly proportional to the peak amplitude of the applied signal. Therefore, it is greater for a bright-picture signal having high amplitude blanking pulses than for a dark-picture signal having low amplitude blanking pulses. In other words, tube V_1 operates with a variable grid bias which is determined by the amplitude of the blanking pulses of the video signal.

The I_b-E_c characteristic of V_1 is represented by the curve of Figure 10B. The waveforms in the lower left show that a bright-picture signal develops a large bias E_{R_1}, causing the tube to op-

erate at a low point on the curve. In contrast, a dark-picture signal develops a small bias, causing the tube to operate at a high point on the curve.

In the upper right of the figure, the horizontal dashed lines represent the average plate current for the respective picture conditions. As shown, the difference in these values results in the tops of the blanking pulses being at the same level. That is, the dc component has been restored by the action of the V_1 grid leak bias circuit.

To retain the reinserted dc component, it is necessary to employ direct coupling between the output of the video amplifier and the picture tube. Therefore, no dc blocking capacitor is used between the plate of V_1 and the grid of V_2 in Figure 10A.

As explained for Figure 9, the dc component of the video signal is employed to automatically vary the bias of the picture tube so that the average brightness level of the screen corresponds to that of the transmitted scene. In the circuit of Figure 10A, the picture tube grid-cathode dc circuit includes R_L and the portion of potentiometer R_2 between $B+$ and the slider. Since it is connected through R_L to $B+$, the picture tube grid would be positive with respect to the cathode by an amount equal to E_{cc} if there were no voltage across R_L. However, V_1 plate cur-

rent develops a voltage, E_{R_L}, having the polarity indicated, so that the V_2 grid-cathode circuit contains the two series-opposing direct voltages, E_{R_L} and E_{cc}. Determined by the setting of brightness control R_2, E_{cc} has a fixed value, while the average of E_{R_L} varies directly with that of the V_1 plate current, as indicated at the extreme right of Figure 10B.

Figure 10C shows the I_b-E_c characteristic curve of the picture tube of Figure 10A. With the cathode potential as a reference, voltage E_{cc} is shown as a positive value. However, the series opposing negative voltage E_{R_L} is greater than E_{cc}, so the net grid bias E_c is negative. For a bright picture signal, the average value of E_{R_L} is low, and the difference between it and E_{cc} is small, causing the tube to operate at a relatively high point on the curve. For a dark picture signal, the greater average video amplifier plate current produces a higher voltage across R_L. The large difference between E_{R_L} and E_{cc} provides a high net negative bias E_c so tube V_2 operates nearer cutoff as indicated.

Figure 10C shows that the screen brightness level is high in the case of the bright picture signal and low when the dark picture signal is being received, while all blanking pulses reduce the brightness to the black level. These, of

course, are the desired picture tube operating conditions and correspond to those shown in Figure 9B.
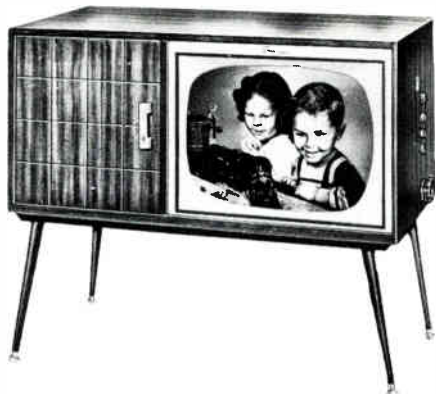
Average scenes, such as this, have backgrounds which are about midway between white and black. If the brightness and contrast controls are set for proper reception of this type of scene, generally the lack of dc reinsertion is not noticeable.

Courtesy Emerson Radio and Phonograph Corp.

In the circuit of Figure 10A, a loss of input signal will result in V_1 operating at zero bias, and thus permit a heavy plate current. A high E_{R_L} is produced to bias the V_2 grid to cutoff. In like manner, in the circuit of Figure 9A, failure of the signal results in loss of the positive direct voltage E_{R_1} allowing the negative bias to cut off the picture tube beam. Thus, both of these circuits automatically reduce the spot intensity to the black level. Therefore, the fluorescent coating of the picture tube screen is not damaged by excessive electron bombardment when,

for any reason, there is no signal input to the video amplifier.

The grid leak type dc restorer is used in the video amplifier circuit of Figure 11. Operated with its cathode at ground potential, video amplifier V_1 has its bias developed across grid resistor R_1. A dc blocking capacitor is not employed in the output coupling circuit, the V_1 plate being connected directly through coil L_1 to the grid of picture tube V_2. The cathode of V_2 obtains a positive voltage from the slider on potentiometer R_7, while the grid is connected through L_2 and R_5 to the +200 volt terminal of the power supply. Thus, the grid voltage is equal to 200 volts minus the voltage, E_{R_5}, produced by the V_1 plate current.

The slider on R_7 is set so that the V_2 cathode is more positive than the grid, thus providing the proper grid-cathode operating voltages for the picture tube. The action of this circuit is like that explained for the simplified circuit of Figure 10A. Briefly, in Figure 11, the V_1 grid leak bias is proportional to the amplitude of the blanking pulses of the applied video signal. Thus, the high amplitude pulses of a bright picture signal result in low plate current and voltage, E_{R_5}, permitting V_2 to operate with small negative bias and high average beam current, while the low amplitude

pulses of a dark-picture signal result in a high E_{R_5} so that V_2 operates with reduced average beam current.

Direct Coupling

As mentioned earlier, the dc component of the video signal is lost as the signal passes through the dc blocking capacitors of the video stages. This loss of the dc component is prevented, and the need for a dc restorer eliminated, by employing dc coupling between the video detector, video amplifier, and picture tube.

The circuit of Figure 12 shows how direct coupling is used in a vacuum tube video amplifier circuit. Detector diode D_1 is coupled directly through L_1 and L_2 to the grid of the V_1 video amplifier stage. The video amplifier plate circuit is then coupled directly to the V_2 picture tube cathode through 4.5 mc sound trap L_3. Thus, with direct coupling from the output of the detector to the grid of the picture tube, the video signal dc component is maintained at all times.

Potentiometer R_5 functions as the manual brightness control. This control is connected as a voltage divider between $B+$ and ground, and supplies the grid-cathode bias to the picture tube. C_4 is a v-f bypass capacitor and is used to place the picture tube control grid at signal ground potential.

Figure 13 shows the circuit of a direct coupled transistor video section. Detector diode D_1 is coupled directly through L_1 and L_2 to the base of the V_1 video amplifier stage. Resistors R_2 and R_3 form the V_1 base bias voltage divider circuit and R_1 is the D_1 diode load resistance. The base bias obtained at the $R_2 R_3$ junction is applied to the V_1 base through R_1. This configuration prevents the base bias voltage from biasing the detector diode which would cause clipping of the video signal. Capacitor C_4 places the lower end of the T_1 secondary at signal ground potential.

The V_1 collector circuit is direct coupled to the picture tube grid through sound trap coil L_3. Thus, direct coupling is used from the detector output to the picture tube grid and the dc component is retained. The grid-cathode bias voltage of the picture tube is determined by the setting of the R_7 brightness control. Capacitor C_5 places the picture tube cathode at signal ground potential.

SCENE VARIATIONS

As explained, if there is no dc restorer in a receiver which employs a coupling capacitor between the video amplifier and picture tube, either a bright scene is reproduced too dark, or a dark scene is reproduced too bright, depending upon the setting of the

brightness control. However, since only a few scenes are very bright or very dark, an optimum setting of the brightness control can be found such that the absence of dc restoration is scarcely noticeable for most of the scenes.

In the case of a bright scene, the overall darker image produced on the screen of a receiver without a dc restorer or direct coupling is not very noticeable, since the viewer has no way of knowing how bright the scene is at the studio. But in the case of a dark

Although the background is dark in this image, the vertical white central portion supplies energy during each scanning line to maintain the large bias needed by the picture tube grid for proper operation, even though the receiver may not contain a dc restorer.

Courtesy Bendix Radio Division of Bendix Aviation Corp.

scene, dc restoration may be required for proper reproduction.

For example, suppose brightness control R_2 in Figure 9A is set to provide operation as indicated for the bright picture signal in Figure 9B, in a receiver which does not have a dc restorer. As coupling capacitor C_1 connects through R_1 to ground, this capacitor is charged to a voltage equal to the average of the plate or collector voltage of V_1 with respect to ground. The V_1 plate or collector voltage variations cause C_1 to alternately charge and discharge through R_1, thus producing a signal voltage across this resistor which is applied to the grid of V_2. This signal voltage varies the V_2 grid positive and negative with respect to the bias E_{cc}.

Due to the bright picture signal, the average plate or collector voltage of V_1 is relatively high. Therefore, the average voltage across C_1 is high also. Suppose now, the picture signal changes to the form produced by a dark scene at the studio. For the dark picture signal, the average V_1 plate or collector potential falls to a lower positive value. To reduce to this lower average voltage, the coupling capacitor discharges, with electrons flowing from the negative plate of C_1, down through R_1 to ground, through V_1 to the opposite capacitor plate. This discharge current produces a direct

voltage component E_{R_1}, which aids the bias E_{cc}. In this case, the polarity of E_{R_1} is opposite that indicated in the figure.

With the negative voltage E_{R_1} added to E_{cc}, the total bias on V_2 is relatively high, and the picture tube grid operates near cutoff as indicated for the dark picture signal. However, as C_1 continues to discharge, its discharge current gradually decreases and the negative voltage E_{R_1} decreases. If the scene contains one or more vertical "white columns", or lines, this information is represented by large amplitude positive swings of the signal during a portion of each scanning line. These highly positive excursions of the signal recharge C_1 to some extent to replenish the energy lost due to its discharge during the dark parts of the scene. With its charge replaced by the white columns in the scene, C_1 can provide a reasonably large discharge current during the remainder of each scanning line, and thus maintain the negative voltage E_{R_1}. So long as E_{R_1} is provided in this manner, the total bias on the picture tube grid is large, and the grid operating point is near the lower end of the I_b-E_c curve, as it should be for proper reproduction of a mostly dark scene. Because of the action just described, a mostly dark scene containing white columns results in reasonably good reproduction in a receiver using capac-

itive coupling, even though a dc restorer is not employed. Due to this fact, and because the lack of dc restoration is not noticeable for most other types of scenes, many manufacturers do not include a dc restorer in their television receivers.

To continue with the above example, suppose the dark scene does not contain white columns, but instead, has only one or two relatively small white objects. That is, the white objects have short vertical dimensions so that they cover only a few scanning lines. An example is a lighted candle in a darkened room. In the reproduced image, the room should be nearly black, except for the area near the candle.

In this case, after the picture signal changes from the bright to the dark form, Figure 9B, the coupling capacitor begins to discharge as before, to produce the negative voltage E_{R_1}. At the beginning of the discharge action, the discharge current and therefore E_{R_1} are large. This value of E_{R_1} added to E_{cc} produces a high total bias to operate the picture tube near cutoff, as shown for the dark picture signal in Figure 9B. For the portions of the scene in which there are no bright objects, there are no positive swings of the signal to recharge capacitor C_1. Therefore, C_1 continues to discharge with an ever decreasing

discharge current. The negative voltage E_{R_1} decreases at a rate determined by the time constant R_1C_1.

As E_{R_1} decreases, the total negative bias on the grid of V_2 becomes less, so that the operating point gradually shifts toward positive, or to the right in Figure 9B. Finally, when C_1 has discharged to the lower average voltage of the V_1 plate or collector there is no more discharge current, and the direct voltage component E_{R_1} becomes zero. With E_{R_1} equal to zero, the only bias on the picture tube grid is E_{cc}. The dark picture signal then varies about the operating point determined by E_{cc}, as shown in Figure 9B. Thus, instead of being black, or nearly black, the "dark" portion of the reproduced scene is only dark gray, or even light gray, depending upon the setting of the brightness control.

The small white objects permit C_1 to recharge to some extent, so that proper operation is obtained during the scanning lines containing the objects, and a few lines thereafter. But, as the discharge current of C_1 dies down, the screen again becomes gray. Thus, with a dark scene, improper shading of the background is produced in the picture of a receiver which employs capacitive coupling without a dc restorer.

Usually, it is necessary to make correcting adjustments in signal level and shading at the transmitting station when the program switches from a studio scene to film pickup, or vice versa. If these adjustments aren't made at the station, the motion picture scenes may appear too dark at the receiver, or the studio scenes too bright, due to the faithful reproduction by a receiver containing a dc restorer. As a result, to provide accurate reproduction, the viewer must make compensating adjustments of contrast and brightness each time such a program switch occurs.

SUMMARY

Synchronizing pulses are transmitted along with the video information from the television transmitter. The sync section of the television receiver removes these sync pulses from the video carrier and processes them so that they can be used to control the frequencies of the horizontal and vertical sweep generators. Thus, the deflection circuits are held in step with the deflection circuits of the television camera.

A dc component is also transmitted along with the video information and the sync pulses. This dc component is used by some television receivers to automatically vary the picture tube bias so that the average bright-

ness level of the screen corresponds to that of the transmitted scene. Many receivers incorporate dc blocking capacitors between the video detector and the video amplifier stages and between the video amplifier stages and the picture tube grid-cathode circuit. Thus, the dc component is lost between stages and the average brightness level of the screen must be set manually with the brightness control by the operator.

To overcome this inconvenience, some television receivers incorporate a dc restorer or automatic brightness control. The dc restorer automatically adjusts the average brightness level of the screen so that it corresponds to the dc component transmitted along with the video information.

PRACTICE EXERCISES

In Exercises 1-5, fill in the blank spaces to complete the statements.

1. In the circuit of Figure 1, resistors R_9 and R_{10} and capacitors C_6 and C_7 form an ....

2. In the circuit of Figure 2, the V_3 stage is operated as a ....
....

3. In the circuit of Figure 3, resistors R_6 and R_7 and capacitors C_6 and C_7 form a ....

4. In the circuit of Figure 3, C_9 and R_{14} form a ....
....

5. In the circuit of Figure 5, V_3 is cut off only when a ....
.... occurs.

Enter the word TRUE or the word FALSE in the space preceding each of the following statements.

6. .... Receivers which incorporate dc coupling in all stages between the video detector and picture tube do not require a dc restorer for accurate reproduction of the transmitted scene.

7. .... A dc restorer is an absolute necessity in a television receiver.

8. .... A sync separator is an absolute necessity in a television receiver.

9. .... Both positive and negative going output signals can be obtained from a sync phase inverter.

10. .... For proper picture tube operation, a positive video signal must be applied to the picture tube control grid.

IMPORTANT DEFINITIONS

AUTOMATIC BRIGHTNESS CONTROL— (abc) —Circuits in a television receiver which cause the average brightness level of the television screen to be proportional to the dc component of the transmitted television signal.

DC COMPONENT—In television, the video signal level which corresponds to the background brightness of the televised scene.

DC RESTORER—In a television receiver, a circuit which provides automatic regulation of the crt bias in such a way that the dc component of the video signal is reinserted.

SYNC AMPLIFIER—An amplifier stage which is used to increase the amplitude of the sync pulses.

SYNC PHASE INVERTER—A vacuum tube or transistor circuit which produces one normal and one inverted replica of the input waveform in its output.

SYNC SEPARATOR—A vacuum tube or transistor stage which removes the sync pulses from the composite video signal.

TRANSISTOR NOISE SWITCH—A sync separator circuit which incorporates two transistors and is used to minimize the effects of noise pulses.

STUDENT NOTES

STUDENT NOTES

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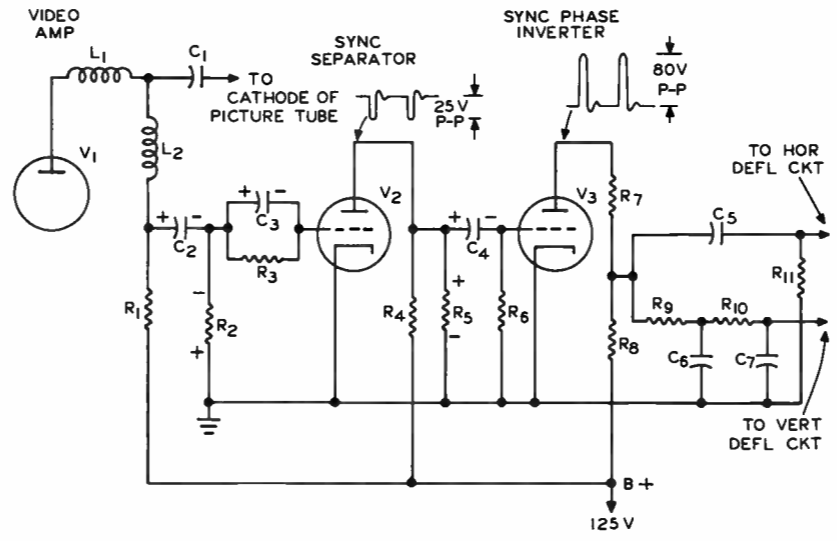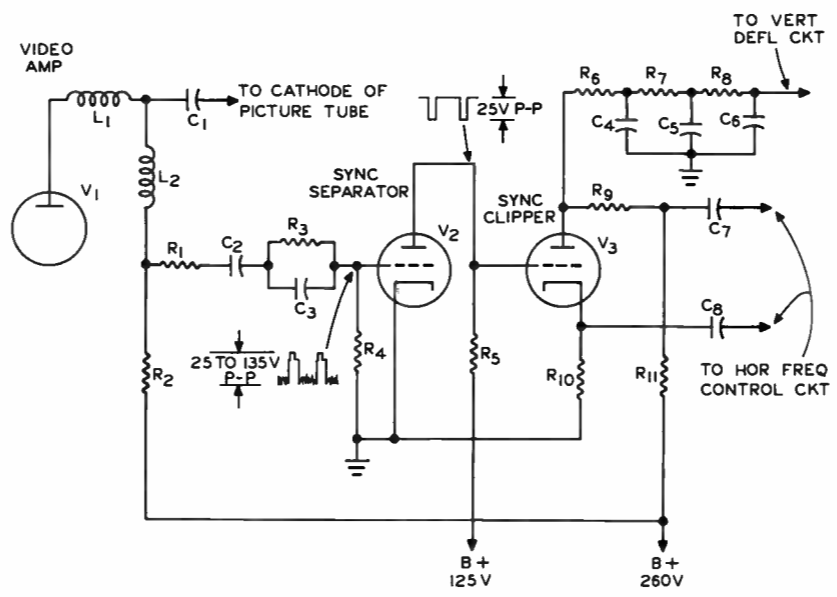
FIGURE 1

FIGURE 2

T2C-10
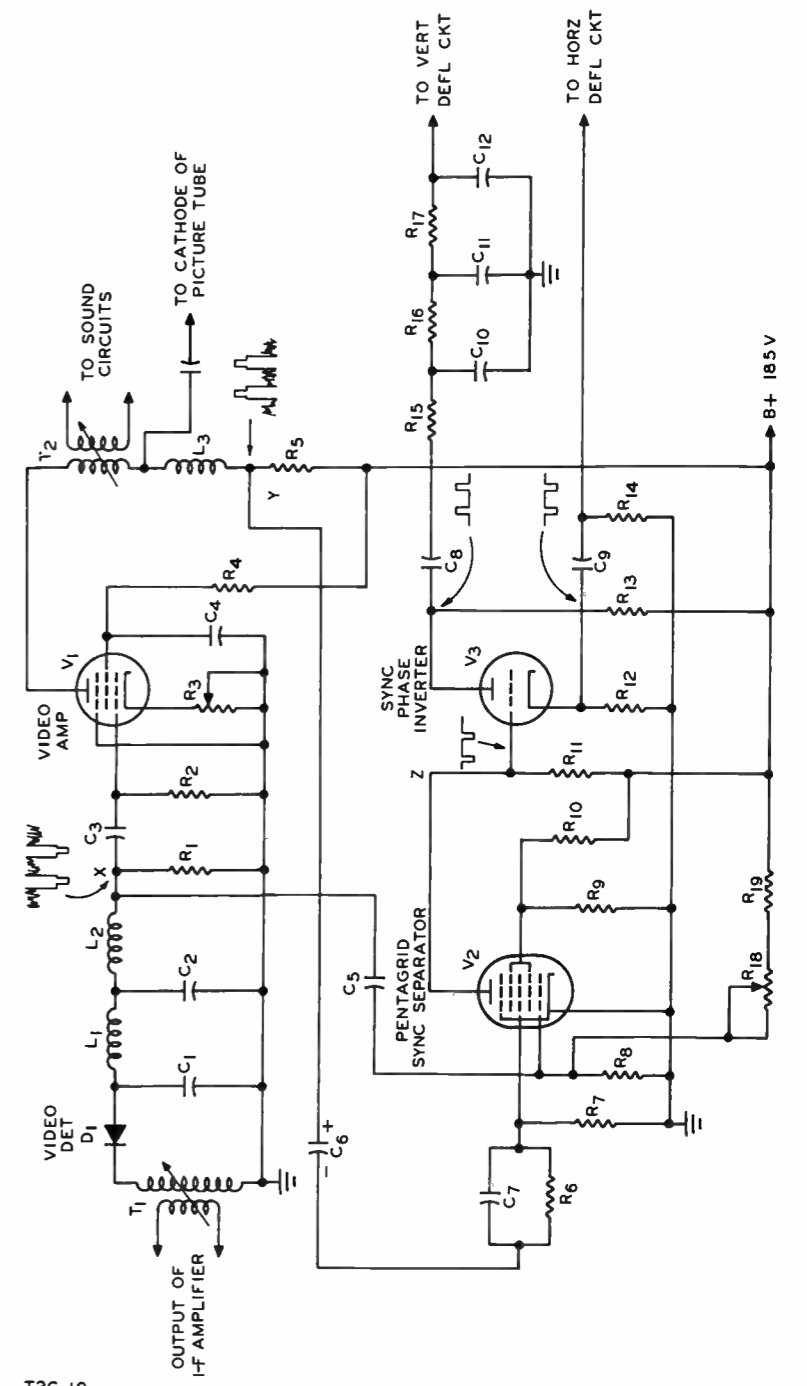
FIGURE 3

T2C-10
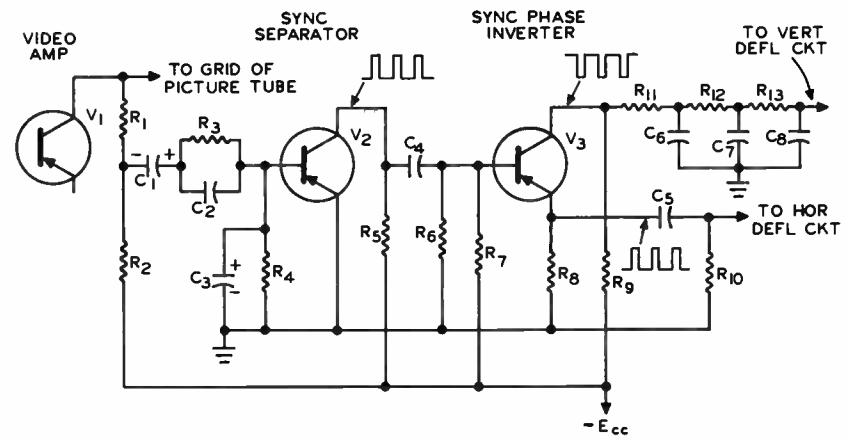
FIGURE 4
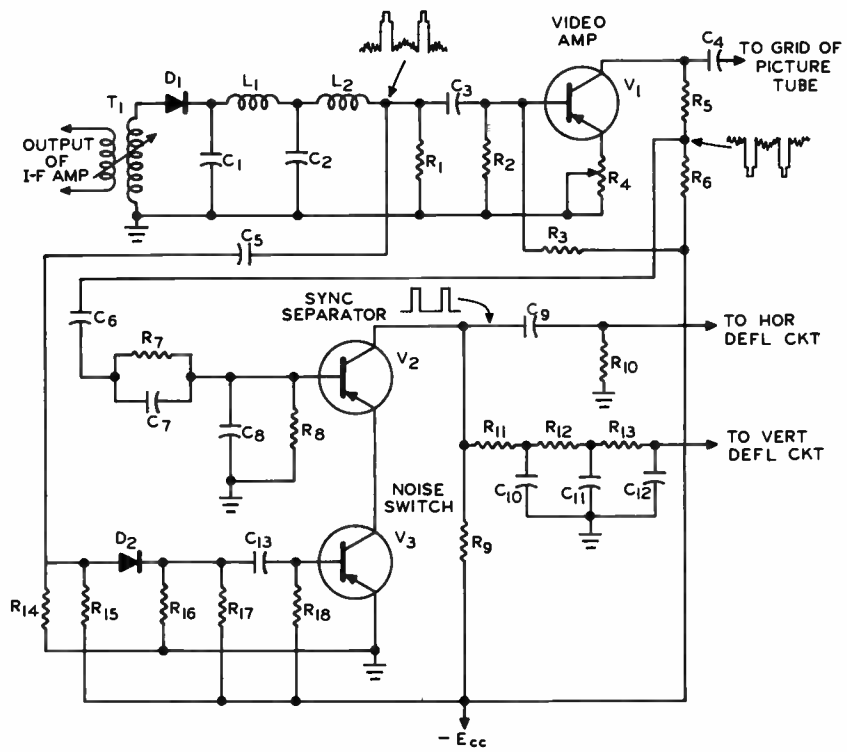
FIGURE 5
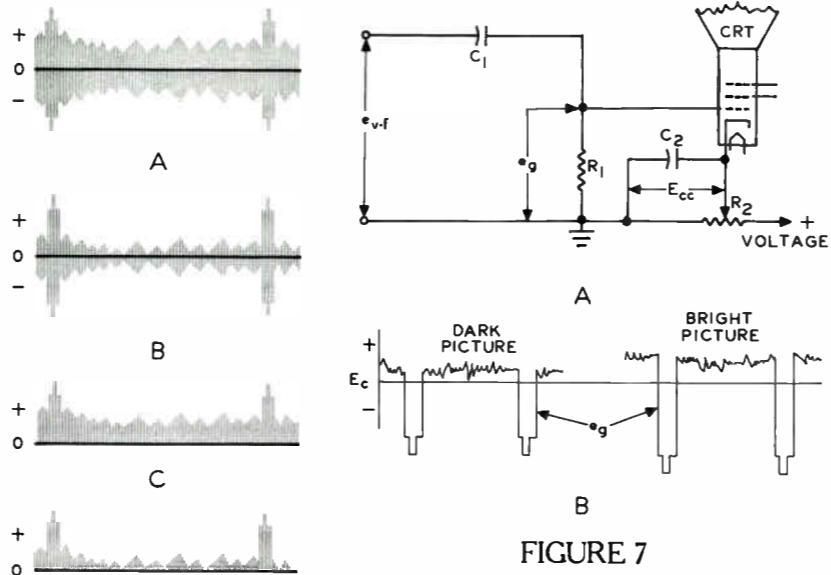
T2C-10

A

B

C

D

E

F

FIGURE 6

A

B

FIGURE 7

FIGURE 8

A

B

FIGURE 9

A

B

C

FIGURE 10

FIGURE 11

FIGURE 12

T2C-10
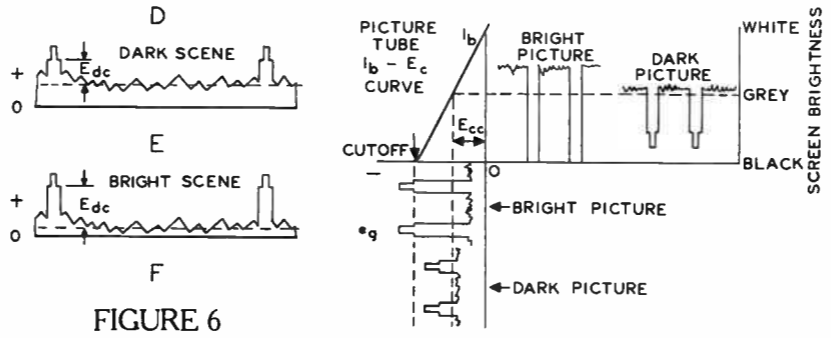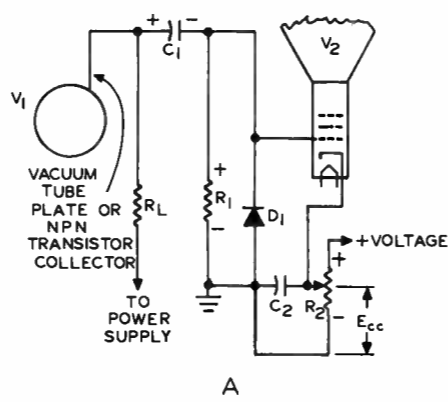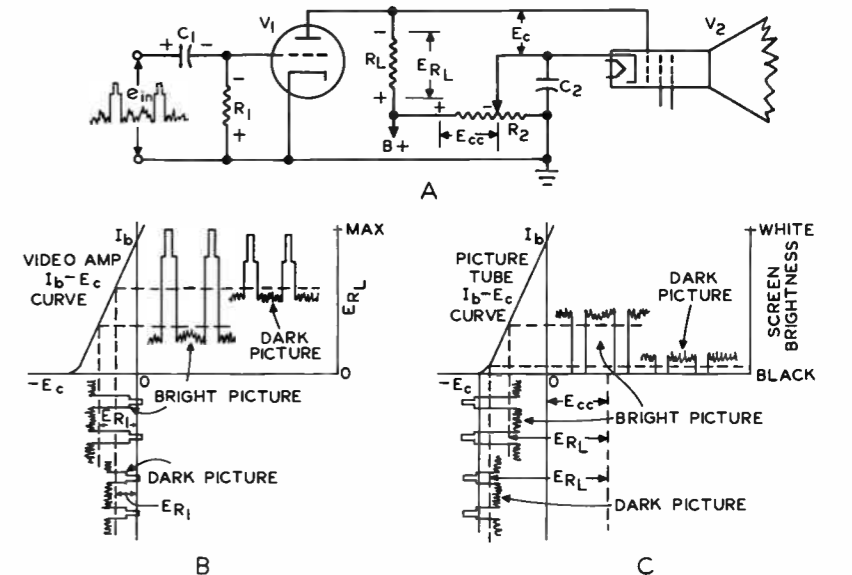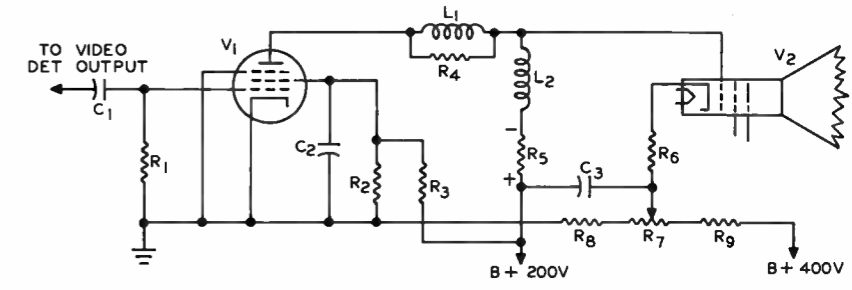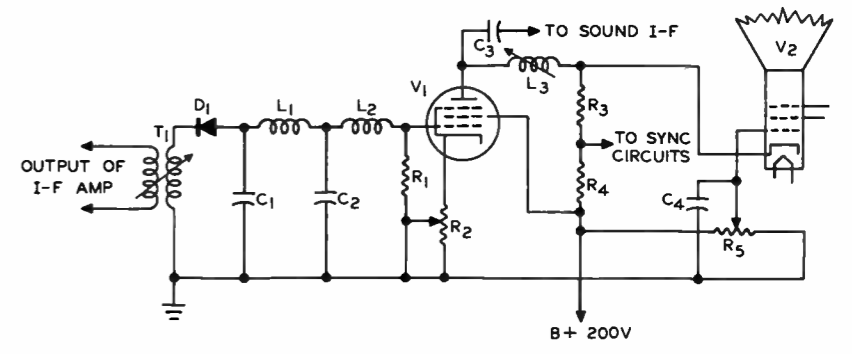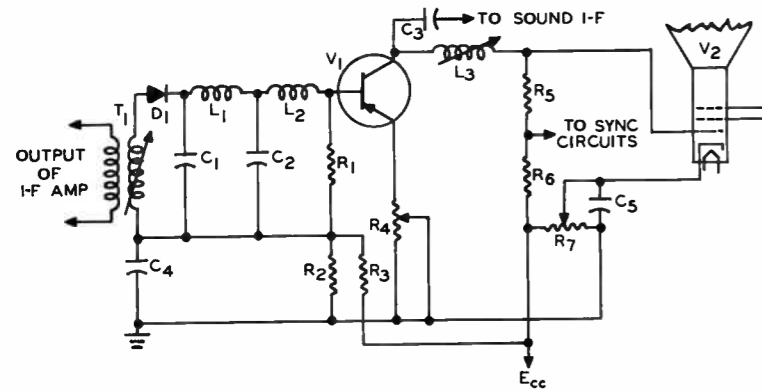
FIGURE 13

PRACTICE EXERCISE SOLUTIONS

1. In the circuit of Figure 1, resistors R_9 and R_{10} and capacitors C_6 and C_7 form an **integrating network.**

2. In the circuit of Figure 2, the V_3 stage is operated as a **sync phase inverter.**

3. In the circuit of Figure 3, resistors R_6 and R_7 and capacitors C_6 and C_7 form a **dual time constant network.**

4. In the circuit of Figure 3, C_9 and R_{14} form a **differentiating network.**

5. In the circuit of Figure 5, V_3 is cut off only when a **noise pulse** occurs.

6. TRUE.

7. FALSE. Many television receivers do not incorporate a dc restorer. In these receivers, an average background brightness level is set with the brightness control potentiometer.

8. TRUE.

9. TRUE.

10. TRUE.

SYNC CIRCUITS AND DC RESTORERS

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question, as illustrated in the example below.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

LESSON CODE

T2C-10H

Example: An instrument used by astronomers to view the stars is a

A
B ■
C
D

A. microscope, B. telescope, C. horoscope, D. periscope.

1. A B C D
In the circuit of Figure 1, the dual time constant network consisting of C_2R_2 and C_3R_3
(A) prevents the stripped sync pulses from affecting the output capacitance of V_1. (B) increases the frequency of the horizontal sync pulses. (C) separates the horizontal and vertical sync pulses. (D) prevents noise pulses from changing the bias on the sync separator.

2. A B C D
In the circuit of Figure 2, resistor R_1
(A) allows only negative going sync pulses to be applied to the grid of V_2. (B) prevents shunting the V_1 plate circuit with the input capacitance of V_2. (C) limits the plate current of V_1 between pulses. (D) prevents the sync pulses from being applied to the cathode of the picture tube.

3. A B C D
In the circuit of Figure 4, resistors R_6 and R_7 form
(A) a base bias voltage divider circuit for the V_3 stage. (B) a dual time constant network. (C) a differentiating network. (D) an integrating network.

4. A B C D
In the circuit of Figure 3, tube V_2 goes into cutoff only
(A) during noise-free periods. (B) if its cathode voltage swings negative. (C) during the sync pulse intervals. (D) when high amplitude noise pulses are present.

5. A B C D
In the circuit of Figure 3, the plate of V_1 applies the video signal with positive going pulses through C_6 and C_7. To cancel noise in this signal, negative going pulses are applied
(A) to the grid of V_3 from the plate of V_2. (B) to the plate of V_1 from the video detector. (C) to C_5 from the anode of D_1. (D) to the grid of V_2 from potentiometer R_{18}.

6. A B C D
In the circuit of Figure 5, the V_3 stage conducts only
(A) during high amplitude noise pulses. (B) when no high amplitude noise pulses are present. (C) during the vertical sync pulses. (D) during the horizontal sync pulses.

7. A B C D
In the circuit of Figure 5, the V_2 sync separator stage and the V_3 noise switch
(A) both function as sync separators. (B) are effectively connected in parallel. (C) are effectively connected in series. (D) conduct at different times.

8. A B C D
In an RC coupling circuit like that of Figure 7A, the coupling capacitor
(A) blocks the ac component of the signal. (B) passes only the dc component of the signal. (C) blocks the dc component of the signal. (D) passes both the ac and dc components of the signal.

9. A B C D
In the diode dc restorer circuit of Figure 9A, the circuit action produces a positive direct voltage across R_1 which
(A) cuts off the picture tube. (B) aids the negative bias E_{cc}. (C) opposes the negative bias E_{cc}. (D) provides a small net bias on V_2 for a dark picture signal.

10. A B C D
In the video circuits of Figure 13, loss of the dc component is prevented by
(A) coupling capacitor C_3. (B) direct coupling between stages. (C) grounding the negative output of the power supply. (D) employing a video signal which contains ac components only.

T2C-10H
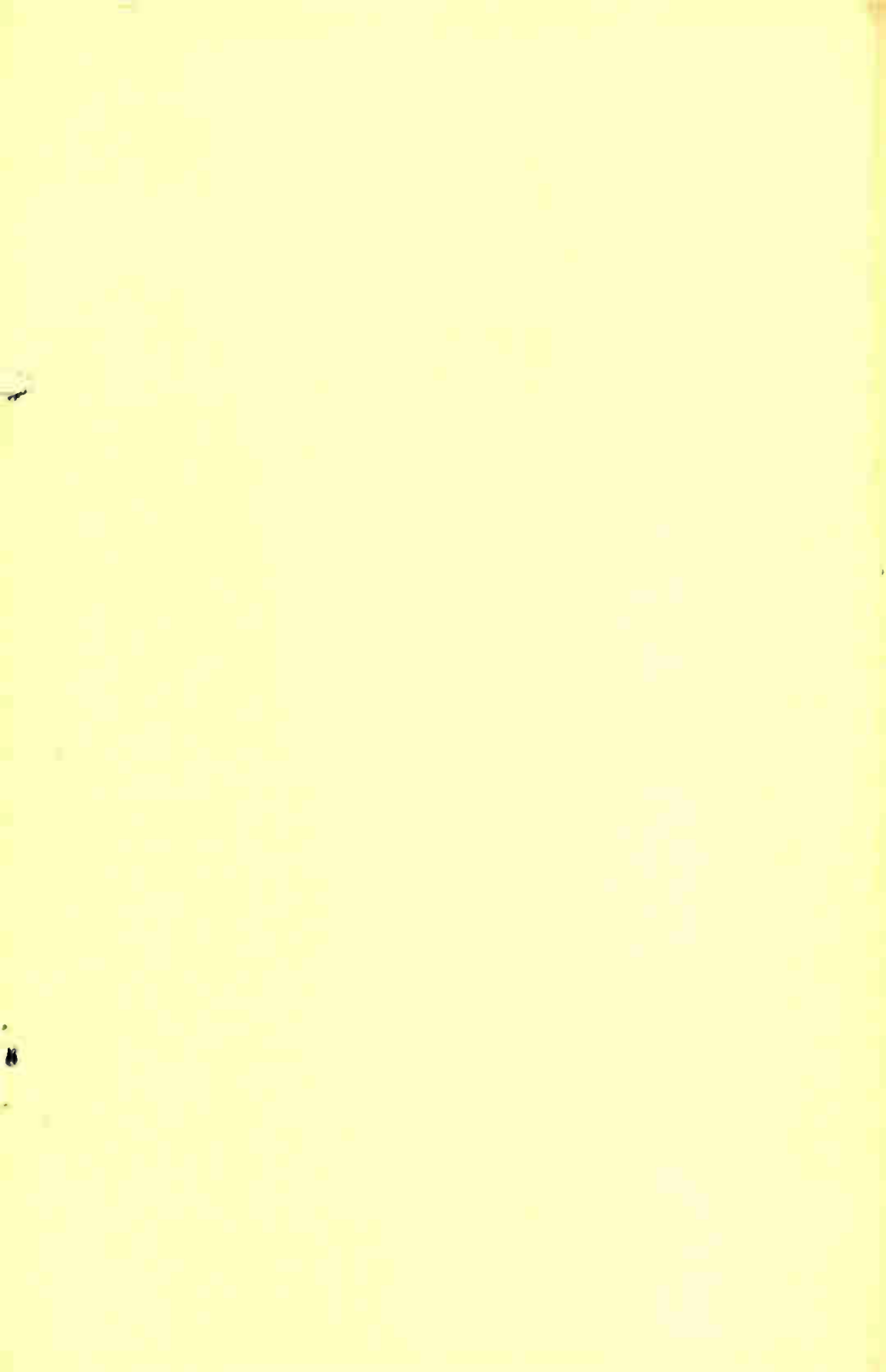
AM BROADCASTING

Lesson 4700

DeVRY INSTITUTE OF TECHNOLOGY
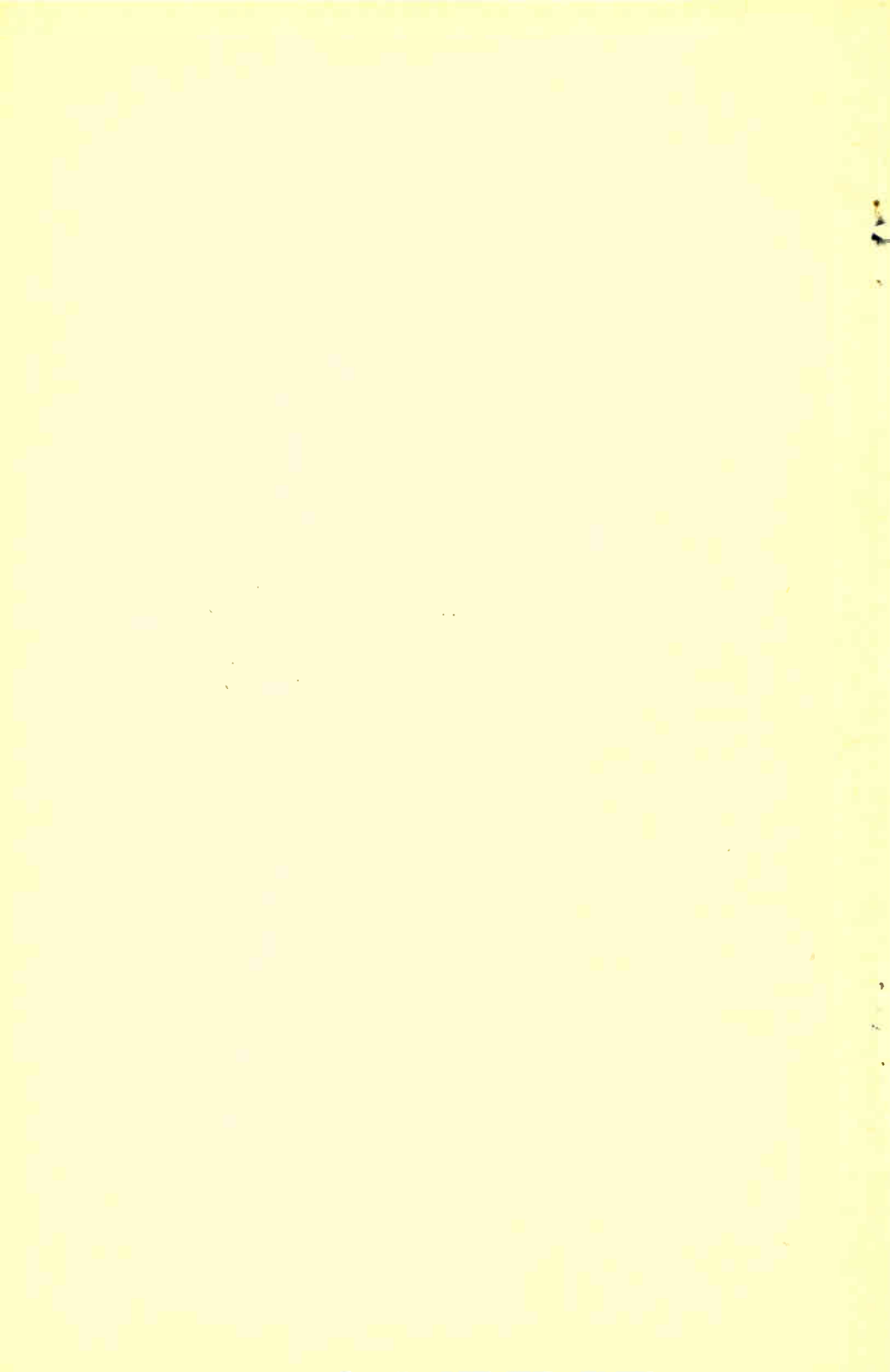
CHICAGO   PHOENIX   TORONTO

AM BROADCASTING

Revised 1968

OPPORTUNITY

3

This audio central console and twin turntables are typical of the equipment used in many broadcast stations. The console is a ten-channel dual programming unit that is completely solid state.

Courtesy Gates Radio Co.

AM BROADCASTING

CONTENTS

****

When someone doing a piece of work says, "Let it
go, that's good enough", it is generally a pretty
good sign that it is not good enough. If it were, no
one would need convincing.

                          --Dr. Frank Crane

AM BROADCASTING

The invention of the triode vacuum tube in 1907 touched off a rapid growth of the communications field. It soon became evident that a controlling agency was needed if maximum benefits were to be obtained from the increased knowledge in this area. Thus, in 1934 the Federal legislature passed a Communications Act which created the Federal Communications Commission (FCC). The purpose of the FCC is to help provide maximum service to the public, industry, business and government with minimum interference.

The FCC controls radio communications by issuance of station and operators' licenses. Even though there are very few broadcast stations compared to the hundreds of thousands of other types of stations, the broadcast stations affect millions of people. Therefore, special rules and regulations are set up for broadcast stations. This lesson is devoted to what is commonly known as AM broadcasting. Other lessons deal with FM and TV broadcasting.

STANDARD BROADCAST STATIONS

A STANDARD BROADCAST STATION is licensed for the transmission of radiotelephone emissions primarily intended to be received by the general public. It uses AM (amplitude modulation) and operates on a specified channel in the STANDARD BROADCAST BAND, which is 535-1605 kHz or kc. (The units Hertz (Hz) and cycle per second (cps) are used interchangeably.)

*　　　　*　　　　*

1. The "standard broadcast band" covers what band of frequencies?

*　　　　*　　　　*

Classes of Channels

Each channel in the Standard Broadcast Band is classified

as either a clear channel, a regional channel, or a local channel. A CLEAR CHANNEL is one which is used by a station or stations to serve a wide, interference-free area. Stations on clear channels may use up to 50 kw of operating power.

A REGIONAL CHANNEL is one on which several stations may operate with powers of 5 kw or less. It is designed to render service primarily to a principal center of population and the rural areas in the immediate vicinity.

A LOCAL CHANNEL is one on which a number of stations operate with powers of 1 kw or less. It is designed to render service to a city or town and the rural area nearby.

*   *   *

2.   What is a clear channel?

3.   What is a regional channel?

4.   What is a local channel?

*   *   *

Classes of Stations

Each station in the Standard Broadcast Band is also classified. A Class I-A station operates on a clear channel with 50 kw of power. A Class I-B station operates on a clear channel with 10 kw to 50 kw of power.

The FCC also uses the term DOMINANT STATION to describe a Class I station operating on a clear channel with an operating power of 10 kw to 50 kw. Therefore, all Class I-A and Class I-B stations are dominant stations.

*   *   *

5.   What is a dominant station?

*   *   *

The term **SECONDARY STATION** is used by the FCC to de-
scribe any station except a Class I station operating on a
clear channel. Thus, all sta-
tions except dominant stations
are considered secondary sta-
tions.

A Class II-A station operates
unlimited time on a clear
channel with .25 kw to 50 kw
of daytime power and 10 kw to
50 kw of nighttime power. A
Class II-B station operates
unlimited time on a clear chan-
nel with .25 kw to 50 kw of
power. A Class II-D station
operates daytime or limited
time on a clear channel with
.25 kw to 50 kw of power.

All dominant stations (Class I)
are protected from interfer-
ence by other stations. For
example, if a secondary sta-
tion is found to be interfering
with a dominant station, the
secondary station must take
the necessary precautions to
stop the interference. Some-
times a directional antenna
system must be used. Other
times, the secondary station
is restricted as to its hours of operation.

When an AM broadcast station must use a
directional antenna system, it is important
that the currents fed to the antenna elements
are properly phased. The antenna phasor
shown here is designed to provide the proper
phase relationship between the currents.
Courtesy Collins Radio Co.

Several other classes of stations also exist. A Class III-A
station operates on a regional channel with 1 kw to 5 kw of
operating power. A Class IV station operates on a local
channel with .1 kw to 1 kw of operating power.

Figure 1 is a chart which shows the various classes of sta-

tions, the class of channel each is allowed to use, and the permissible operating power. Notice that the nighttime operating power is different than the daytime operating power for some stations.

*   *   *

6. What is a secondary station?

7. Referring to the chart of Figure 1, what is the nighttime op-
    erating power of a Class III-B station?

*   *   *

Frequency and Bandwidth

Each standard broadcast station is assigned a specific chan-
nel, and its carrier frequency must be in the center of this
channel. The chart of Figure 2 gives the carrier frequency
assignment, the class of channel (clear, regional or local),
and the channel number.   The channel number 1 carrier
frequency is 540 kHz while the entire channel extends from
535 kHz to 545 kHz (not shown on chart). The channel num-
ber 2 carrier frequency is 550 kHz while the entire channel
extends from 545 kHz to 555 kHz.   This arrangement con-
tinues with each carrier being separated from the preced-
ing carrier by 10 kHz, and each channel being 10 kHz wide
(5 kHz on each side of the carrier frequency).   Finally,
channel number 107 occupies the 10 kHz from 1595 kHz to
1605 kHz with the carrier frequency being 1600 kHz.

*   *   *

8. What is the bandwidth of each channel in the standard broad-
    cast band?

*   *   *

Since each channel is 10 kHz wide, it is a common miscon-
ception that the transmitted signal of each station must be
limited in bandwidth to 10 kHz.   This is not true.   Where

bandwidth of the emitted signal is concerned the FCC rules state "any emission removed from the carrier by 15 kHz must be 25 dB below the level of the unmodulated carrier." Thus, the occupied bandwidth is 30 kHz or less.

Interference between stations is generally prevented by not assigning adjacent channels to a particular area. Three of the stations in the Chicago area, for example, are assigned carrier frequencies of 670 kHz, 720 kHz, and 780 kHz, respectively. No other stations are assigned between 670 kHz and 720 kHz, or between 720 kHz and 780 kHz. We see, then, that there will be no interference problem.

As a final precaution, the FCC specifies that any station illegally interfering with another station must take the necessary steps to prevent the interference. This is usually accomplished by making the antenna system directional, limiting the hours of operation, or reducing the bandwidth of the interfering signal.

*   *   *

9.   The transmission bandwidth of a standard broadcast station is limited to 10 kHz. True or False?

*   *   *

Operator Requirements

All standard broadcast stations must have a properly licensed operator on duty at all times. The operator is in charge of the transmitting apparatus. The type of license required depends upon several factors. If the station is operating with more than 10 kw of power, or is using a directional antenna system, the operator must have a first-class radiotelephone operator's license.

*   *   *

10.   Under what conditions must an operator with a first-class radiotelephone license be on duty at all times?

*   *   *

If a station is using a non-directional antenna and operating with power of 10 kw or less, operators with second-class radiotelephone and certain other lower-grade licenses may make routine transmitter adjustments. However, no maintenance or repair work may be done by holders of lower-grade operator's licenses. Also, the station must have at least one operator holding a first-class radiotelephone operator's license employed at the station. It is his primary duty to maintain and repair the transmitting equipment. At all standard broadcast stations, a complete inspection of all transmitting equipment in use must be made by the holder of a valid radiotelephone first-class operator's license at least once each day, 5 days each week, with an interval of no less than 12 hours between successive inspections.

*   *   *

11. At non-directional stations with a power of 10 kw or less, routine transmitter adjustments may be made by the holder of a second-class radiotelephone operator's license. True or False?

*   *   *

Maximum Rated Carrier Power

Each standard broadcast station is authorized to use a certain amount of carrier power as specified in the station license issued by the FCC. The holders of the station license then select a transmitter that will provide the authorized carrier power. In many cases, the license holders are permitted to use a transmitter which is capable of radiating more power than the station license authorizes.

Figure 3 is a chart showing the maximum carrier power capability of the transmitter that may be installed. For example, suppose a Class IV station has a maximum authorized power of 100 watts. The license holders may install a transmitter with a maximum rated carrier power of 250 watts. However, the actual radiated carrier power must be limited to 100 watts as specified in the station license.

For another example, suppose a Class IV station has an authorized power of 250 watts. The license holders may install a transmitter with a maximum rated carrier power of 1000 watts. Again, the actual radiated carrier power must be limited to 250 watts. Only one advantage is gained by installing a higher powered transmitter than necessary. That is, the transmitter is not being driven to the limits of its capability and less trouble will probably be encountered.

*   *   *

12. A Class II station has an authorized power of 5000 watts. What is the maximum rated carrier power permitted to be installed?

13. A Class I station with an authorized power of 25, 000 watts installs a 50, 000 watt transmitter. Is this permissible? Is it permissible to radiate the full 50, 000 watts?

*   *   *

When rating transmitters, the FCC uses even power steps of 100 watts, 250 watts, 500 watts, 1 kw, 5 kw, 10 kw, 25 kw and 50 kw. The maximum rated carrier power is determined by the sum of the power ratings of all tubes (or other output devices) used in the final r-f stage of the transmitter.

*   *   *

14. How is the maximum rated carrier power determined?

*   *   *

STATION MEASUREMENTS

As we mentioned previously, the primary purpose of the FCC is to help provide a maximum amount of radio communications with a minimum of interference. To help effect their goal, all standard broadcast stations are required to make certain measurements. The most important of these

measurements are the operating power, the percentage of modulation, and the frequency of the carrier.

Operating Power

Whenever possible, the operating power (unmodulated r-f carrier power) of a station is determined by the **DIRECT METHOD**. In an emergency where the licensed antenna system has been damaged by uncontrollable causes, or if the antenna system is being changed, the operating power may be determined on a temporary basis by the **INDIRECT METHOD**.

$$*\qquad\qquad *\qquad\qquad *$$

15. What two methods are used to measure the operating power of a station?

$$*\qquad\qquad *\qquad\qquad *$$

The direct method of determining operating power is to multiply the square of the antenna current by the antenna resistance. In the form of an equation,

Operating Power = Antenna Current^2 × Antenna Resistance

Further, the current must be measured at the operating frequency and at the same point the resistance was measured.

$$*\qquad\qquad *\qquad\qquad *$$

16. Describe the direct method of determining operating power.

$$*\qquad\qquad *\qquad\qquad *$$

A radio-frequency bridge, or other suitable method, may be used to measure antenna resistance. Measurements are taken at 5, 10, 15 and 20 kHz on each side of the operating frequency. A curve is then drawn of antenna resistance as a function of frequency to determine the actual antenna re-

sistance at the operating frequency.

The indirect method of determining operating power uses the following relationship:

Operating Power = $E_p \times I_p \times F$

where E_p and I_p are the plate voltage and plate current of the last r-f stage, and F is the proper multiplying factor as specified in the rules and regulations. The proper factors are given in the chart of Figure 4.

As an example, suppose the indirect method is being used to determine the operating power of a transmitter which has a maximum rated carrier power of 10 kw and employs plate modulation. The plate voltage of the last r-f stage is 6000 volts and the plate current is 1 ampere. The operating power is:

Operating Power = $6000 \times 1 \times .80 = 4800$ watts

*   *   *

17. In the preceding example, suppose the plate current had been 2 amperes, what would the operating power be?

*   *   *

Regardless of how the operating power is determined, each station must maintain the operating power within 5% above and 10% below the licensed power. In an emergency, the station is permitted to operate with reduced power for 10 days. In such a case, the FCC and the Engineer in Charge of the radio district must be notified immediately after the emergency develops and also upon resumption of licensed power.

Besides maintaining the operating power within the specified limits, stations employing directional antenna systems

must maintain the currents in the elements within 5% of the value specified in the license.
In the event a reduction in power is necessary, the current in each element must be reduced proportionally so the ratio remains within 5% of the original ratio. This insures that the proper directivity is maintained regardless of the amount of power being radiated.

Since the measurement of operating power is so important, the FCC requires all stations to be equipped with indicating instruments (meters) for measuring the dc plate circuit current and voltage of the last r-f stage; the r-f base current of each antenna element; and, for directional antenna systems, the r-f current at the point of common input to the directional antenna.

Some stations are permitted to install a transmitter that has greater power capabilities than the operating power authorized to the station. This transmitter may be used by stations whose operating power is 250 W, 500 W or 1000 W.
Courtesy Collins Radio Co.

The indicating instruments used to determine the operating power must meet the following specifications:

(1) The length of the scale must be at least 2.3 inches.
(2) The accuracy must be within 2% of the full scale reading.
(3) The meter must not read off scale during modulation.
(4) A thermocouple type ammeter must be used to measure antenna current.

Each of the instruments must meet various other specifications depending upon the type of meter and its use.

*   *   *

18. What is the allowable tolerance concerning operating power?

19. The currents in the elements of a directional antenna system must be kept within a certain percentage of the licensed currents.   What is this percentage?

20. A station that is using the direct method of determining operating power need not measure the dc plate voltage and current of the last r-f stage.   True or False?

*   *   *

Modulation

All standard broadcast stations are required to maintain the percentage of modulation as high as possible without over-modulating. Generally, the percentage of modulation should
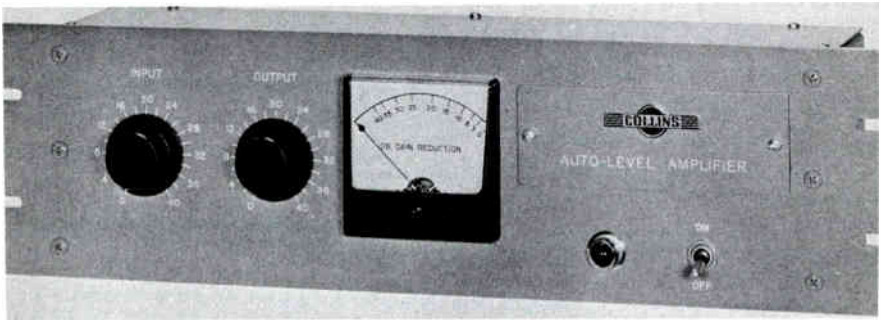
The unit shown here is a dynamic compression amplifier that allows low amplitude passages to be amplified more than high amplitude passages. In this way, the percentage of modulation is kept high.

Courtesy Collins Radio Co.

not be less than 85% on peaks of frequent recurrence. In no case, however, should the percentage of modulation exceed 100% on negative peaks of frequent recurrence.

Overmodulation on negative peaks actually causes cutoff of the carrier, distorts the signal, and produces harmonics that interfere with other stations. Since overmodulation can

be so harmful, it seems as though a simple way to prevent this condition is to reduce the percentage of modulation to a low level.

Unfortunately, an equally undesirable condition occurs with a low percentage of modulation. It must be remembered that the intelligence being transmitted is contained in the sidebands, with the carrier being a reference signal. Reducing the percentage of modulation reduces the power in the sidebands, which reduces the service area of the transmitted signal. In fact, a 1000 watt carrier modulated 100% has 500 watts of power in the sidebands. A 10,000 watt carrier modulated 30% has only 450 watts of power in the sidebands. Thus, we see that reducing the percentage of modulation defeats the purpose of having a higher powered transmitter.

*   *   *

21. What is the maximum allowable percentage of modulation on negative peaks of frequent recurrence?

*   *   *

As with operating power, the FCC requires all standard broadcast stations to continuously monitor the percentage of modulation with a modulation monitor of the type approved by the Commission. Should the modulation monitor become defective, the station may operate without it for 60 days provided that the Engineer in Charge of the radio district is notified immediately and that the modulation is monitored with a cathode ray oscilloscope or other suitable device.

*   *   *

22. The use of a modulation monitor is optional at standard broadcast stations. True or False?

*   *   *

To be approved by the FCC, the modulation monitor must

meet certain specifications. The most important of these specifications are:

1. A dc meter for setting the average rectified carrier at a specific value and to indicate changes in carrier intensity during modulation.

2. A peak indicating light, or similar device, that can be set at any predetermined value from 50 to 120 percent modulation to indicate on positive peaks and/or from 50 to 100 percent negative peak modulation.

3. A semi-peak indicator with a meter that can be switched to read either positive or negative modulation. The meter scale must be at least 2.3 inches in length, must be calibrated from 0 to 110 percent modulation, and must be calibrated in decibels below 100% with 100% modulation being 0 dB. The meter accuracy must be ± 2% (or better) for 100% modulation and ± 4% of full scale reading at any other percentage of modulation.

4. The frequency response of the monitor must be ± 0.5 dB from 30 to 10,000 Hz.

*   *   *

23. An approved modulation monitor must contain a dc meter, a peak indicating light (or other device), and a semi-peak indicating meter. True or False?

*   *   *

Carrier Frequency

Along with operating power and percentage of modulation, the frequency of the carrier is equally important in maintaining good communications. Therefore, the operating frequency of each standard broadcast station must be maintained within at least 20 Hz below to 20 Hz above the assigned frequency.

To measure the carrier frequency, each station must have in continuous operation an approved frequency monitor. Should the frequency monitor become defective, the station

may operate without it for 60 days, provided that the Engi-

FCC approved, this frequency monitor is pre-set to operate at any frequency in the Standard Broad-
cast Band. It has an accuracy of ±0.5 parts per million.

Courtesy Gates Radio Co.

neer in Charge of the radio district is notified immediately
and that the station operating frequency be measured by an
external source at least once every 7 days.

    *   *   *

24. What is the operating frequency tolerance of a standard broad-
  cast station?

    *   *   *

An approved frequency monitor must meet certain specifi-
cations, the most important of which are:

 1. An accuracy within at least 5 parts per million under
   ordinary conditions.
 2. The range of the indicating device must be at least
   ± 20 Hz of the assigned frequency.
 3. It must be calibrated to be accurately read within 1 Hz.
 4. It must be equipped with an automatic temperature

control chamber to maintain the crystal temperature within ± .05°C for an X or Y cut crystal, or ± .5°C for a low temperature coefficient crystal.

5. Means must be provided to adjust the monitor to agree with an external standard.

6. It must be capable of continuous operation without affecting the emitted carrier.

*   *   *

25. What frequency range is required of the frequency monitor?

*   *   *

TRANSMITTER REQUIREMENTS

Transmitters used by standard broadcast stations must be accepted for licensing by the FCC. To gain FCC approval the transmitter must meet certain design, construction and safety of life requirements. Some of these requirements are:

1. The maximum rated carrier power is in accordance with the chart of Figure 3.

2. Operate at the authorized power with 85 to 95% modulation.

3. Total audio frequency distortion from microphone terminals to antenna output does not exceed 5% harmonics from 0 to 84% modulation and not over 7.5% harmonics from 85 to 95% modulation. The distortion is measured with modulating frequencies of 50, 100, 400, 1000, 5000 and 7500 Hz and must include the tenth harmonic or 16,000 Hz, whichever is lower.

4. The audio frequency response from the microphone terminals to the antenna output is ± 2 dB from 100 to 5000 Hz with the response at 1000 Hz as the reference.

5. The carrier shift (current) at any percentage of modulation does not exceed 5%. Carrier shift refers to any change in the carrier power during modulation.

6. The carrier hum and extraneous noise level (exclusive of studio and microphone noises) is at least 45 dB be-

low 100% modulation for the frequency band of 30 to 20,000 Hz.

7. The transmitter must be equipped with suitable indicating instruments that are necessary for proper adjustment and operation.

8. The power output must be sufficiently variable to compensate for variation in line voltage or other factors which may affect the power output.

9. The transmitter must be equipped with automatic frequency control equipment which maintains the operating frequency within the ± 20 Hz limit.

10. Means must be provided for connection and continuous operation of approved modulation and frequency monitors.

11. The emitted signal must occupy the proper bandwidth. Any signal removed from the carrier by 15 kHz must be at least 25 dB below the unmodulated carrier level. This indicates that the occupied bandwidth is 30 kHz or less.

12. When more than 350 volts is applied to a tuned circuit, the tuning adjustment must be made from the front of the cabinet with all access doors closed.

13. The power supply condenser banks must be automatically discharged after the high voltage circuit is opened.

14. Various other precautions must be taken to help prevent injury or shock to operating personnel.

                    *   *   *

26. When modulating the carrier 90%, what is the allowable audio harmonic distortion?

27. What is the required audio frequency response from the microphone terminals to the antenna output?

28. What is carrier shift?

29. What is the maximum allowable percentage of carrier shift?

30. Carrier hum and extraneous noise must be how many dB below 100% modulation?

31. What is the maximum allowable bandwidth of the emitted signal?

*   *   *

EQUIPMENT PERFORMANCE MEASUREMENTS

All broadcast stations must use a transmitter which has
been manufactured to meet the preceding requirements.
To be sure that the transmitter continues to operate prop-
erly, the FCC requires that certain measurements be made
periodically.   These measurements are known as **EQUIP-
MENT PERFORMANCE MEASUREMENTS, or PROOF-OF-
PERFORMANCE MEASUREMENTS.**

The proof-of-performance measurements must be made at
least at yearly intervals. Also, a complete set of measure-
ments must be made during the four-month period preced-
ing the date of filing application for renewal of the station
license.

*   *   *

32. When must the proof-of-performance measurements be made?

*   *   *

The proof-of-performance measurements concern audio
frequency response, harmonic distortion, carrier shift,
hum and noise, and spurious radiations. Briefly, they are:

1. Data and curves showing audio frequency response
   from 30 to 7500 Hz for 25%, 50%, 85% and 100% (if
   obtainable) modulation. The family of curves is plotted
   with 1000 Hz as the reference frequency.
2. Data and curves for 25%, 50%, 85% and 100% modula-
   tion for fundamental frequencies of 50, 100, 400, 1000,
   5000, and 7500 Hz, showing audio frequency harmonic
   content up to tenth harmonic or 16,000 Hz, whichever
   is lower.
3. Data showing percentage of carrier shift for 25, 50,

85 and 100% modulation with a 400 Hz tone.

4. Carrier hum and extraneous noise measured as the level below 100% modulation throughout the audio spectrum.

5. Measurements or evidence showing that spurious radiations are suppressed or are not present to a degree capable of causing objectionable interference to other radio services.

*   *   *

33. What data is required by the proof-of-performance measurements?

*   *   *

LOG REQUIREMENTS

The licensee (owner) of each standard broadcast station is responsible for keeping a program log, an operating log and a maintenance log. Each log is actually kept by any competent person, who must sign the log when starting duty and again when going off duty. The logs must be kept orderly, legible, and in a suitable form with sufficient detail. Abbreviations may be used if their meaning is explained elsewhere in the log. Time entries must be in local standard or daylight saving time and indicated accordingly.

Corrections may be made only by the person originating the entry, who shall initial the correction and date it. Original data may be recorded in rough form and later transcribed into the log. In such case all portions of the original data must be retained as part of the complete log.

*   *   *

34. What types of logs must be kept by a station?

35. Who may make corrections in a log?

*   *   *

Program Log

The **PROGRAM LOG** is a chronological record of program activities of the station. It must contain information concerning programs such as: beginning and ending times; name of each program and sponsor; brief description of program — musical, comedy, speech, etc; live, recorded or network program; and name and political affiliation of any political candidate presented. Also, the program log must contain the time of each station-identification announcement, public service announcements, and pertinent information concerning commercial announcements.

*   *   *

36. Information concerning the beginning and ending times of all programs are recorded in the (a) operating log, (b) program log, (c) maintenance log.

*   *   *

Operating Log

The **OPERATING LOG** is a chronological record of technical events pertinent to the operation of the station. Some of the entries in the operating log are:

1. The time the station begins to apply power to the antenna and the time it stops.
2. Interruption of the carrier; its cause and duration.
3. Every half hour or less: plate voltage and plate current of last radio stage, antenna current, and frequency monitor reading.
4. Every day: entries of current in all legs of directional antenna system and phase relationships.
5. Any other entries required by the instrument of authorization (station license).

*   *   *

37. Interruptions of the carrier are recorded in the (a) operating log, (b) program log, (c) maintenance log.

*   *   *

Maintenance Log

The **MAINTENANCE LOG** is a chronological record of routine maintenance and repair work done on necessary equipment which is not an actual part of the transmitter. Some of the entries in the maintenance log are:

1. Weekly readings of the tower base current ammeter and the associated remote antenna ammeter. An indication must be made concerning the calibration of the remote antenna ammeter against the tower base ammeter.
2. Time and result of weekly test of auxiliary transmitter.
3. Results of frequency checks made independently of the frequency monitor.
4. Notations concerning any repairs made on the modulation monitor, frequency monitor, final stage plate voltmeter and plate ammeter, base current ammeter, and common point ammeter. Time of removal from and restoration to service must be recorded.
5. Record of tower light inspections where required.
6. Entries concerning any experimental operations.
7. Summary of the daily transmitter equipment inspection.

*   *   *

38. Tests concerning the auxiliary transmitter are recorded in the maintenance log. True or False?

*   *   *

Retention and Availability of Logs

Ordinarily, the logs of standard broadcast stations must be retained for two years. Logs containing information pertinent to a disaster or other incident being investigated by the FCC must be retained until the FCC gives permission, in writing, to destroy them. All logs must be made available upon request by an authorized representative of the FCC.

*   *   *

39. Under ordinary conditions, how long must station logs be retained?

*   *   *

ANTENNA REQUIREMENTS

Since air travel has become so common, any structure that has considerable height may present a hazard to aircraft.
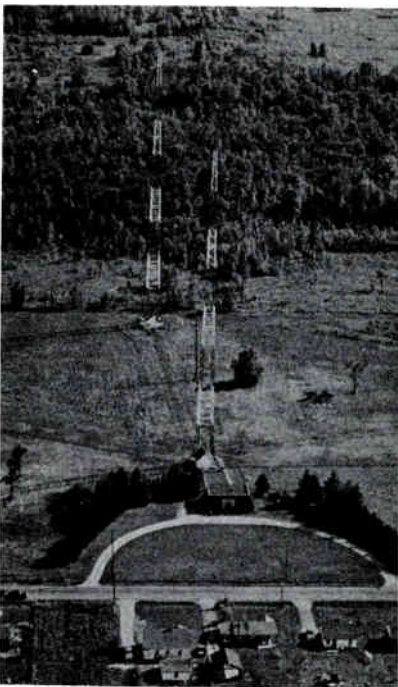
The twin antenna towers pictured here illustrate the need for painting alternate sections light and dark.
Courtesy Radio Station WKZO

Therefore, to minimize the hazard presented by the erection of an antenna, certain rules and regulations must be followed concerning height, aeronautical study, painting, and lighting. Details concerning these aspects of an antenna are contained in Part 17, Volume 1 of the FCC Rules and Regulations. A very brief outline follows.

Aeronautical Study

Proposed antenna structures over 500 feet in height above the ground will require special aeronautical study irrespective of their location to determine whether or not the structure represents a hazard to air navigation.

Proposed antenna structures from 170 feet to 500 feet in height above the ground will not require special aeronautical study except in the immediate vicinity of airports and approach areas, in areas of established coastal corridors, and in certain civil airways

and air traffic control areas.

Proposed antenna structures 170 feet and under in height above the ground will not require special aeronautical study except in the immediate vicinity of airports and approach areas.

Painting

Antenna structures must be painted when they require special aeronautical study or when they exceed 170 feet in height above the ground. When painting is required, the antenna structure must be painted with alternate bands of orange and white. Additional specifications are contained in the FCC Rules and Regulations.

   *   *   *

40. Antenna structures less than 170 feet in height need never be painted. True or False?

   *   *   *

Lighting

The FCC Rules and Regulations concerning lighting of antenna structures is very rigidly enforced. Some of these rules are:

1. In most vicinities, antenna structures up to and including 150 feet in height above the ground need no lighting.
2. In the vicinity of airports and approach areas, antenna structures up to and including 150 feet in height above the ground must be lighted by at least two 100 watt lamps enclosed in aviation red obstruction light globes.
3. Antenna structures over 150 feet up to and including 300 feet in height above the ground must be lighted at the top by a flashing red beacon consisting of two 500 watt or 620 watt lamps. The approximate midpoint of

the structure height must be lighted by at least two 100 watt lamps enclosed in aviation red obstruction light globes.

4. Antenna structures over 300 feet in height must be lighted at the top with a flashing red beacon. At various other points, red obstruction lights and/or flashing red beacons may be required. Details for required lighting of antenna structures over 300 feet may be found in the FCC Rules and Regulations, Vol. 1, Part 17.

5. All lights must burn continuously from sunset to sunrise unless otherwise specified.

6. The beacon flashing mechanism must cause not more than 40 flashes per minute nor less than 12 flashes per minute with the off time being one-half the on time.

7. A light sensitive device may be used to turn off the lights during the day and turn them on at night.

<p style="text-align:center">*   *   *</p>

41. In most vicinities, antenna structures must be lighted when they exceed a certain height. What is this height?

<p style="text-align:center">*   *   *</p>

AURAL BROADCAST STL AND IR STATIONS

An aural broadcast STL (Studio-to-Transmitter-Link) station is a special UHF station that is used by a standard broadcast station for the transmission of aural program material from the studio to the transmitter.

An aural broadcast IR (Intercity Relay) station is a special UHF station that is used to transmit aural program material between broadcasting stations. The transmitter of either an STL or IR station may be multiplexed to provide for the transmission of operational communications in addition to the aural program material. Neither station may be operated, however, solely for the transmission of operational communications such as cues, orders, etc.

*   *   *

42. What is the purpose of an STL station?

*   *   *

Aural broadcast STL and IR stations are assigned a band of
frequencies between 942-952 MHz. The band contains 19
channels, with each channel being 500 kHz wide. The center
frequency of the first channel is 942.5 MHz, with the center
frequency of each successive channel being 500 kHz higher
than the preceding one. This 500 kHz spacing continues so
the center frequency of the 19th channel is 951.5 MHz.

*   *   *

43. On what frequency band do STL (Studio-to-Transmitter Link)
and IR (Intercity Relay) stations operate?

*   *   *

Other important features of these stations are:

1. Frequency modulation must be employed.
2. A directional antenna must be employed.
3. The authorized operating power is only enough to ren-
der satisfactory service.
4. The holder of any class of commercial radio operator
license may operate the station.

BROADCAST STATION FACILITIES

Figure 5 is a block diagram of the facilities found in a typi-
cal standard broadcast station. The five blocks on the left
— microphones, turntables, tape machines, network, and
remote pickup receiver — are sources of audio. Although
not all stations have all of these sources, most stations do.

The studio control console — the next block — is the heart
of the control room. One or more of the input signals, as
desired, are selected and amplified to the proper level.

The console allows instantaneous switching from one source to another or a gradual fade from one source to another.

The studio ond studio control equipment shown here are part of a large AM broadcast station. The control console in the foreground permits complete control of the microphone.

Courtesy CBS Rodio Network

Also, any of the input signals can be monitored while another signal is being amplified and fed to the transmitter. This allows the operator to switch from one signal to another with proper timing.

*   *   *

44. What is the basic purpose of the studio control console?

*   *   *

From the console, the desired signal is fed to telephone

lines which carry it to the transmitter. The transmitter may be located a number of miles from the studio. This is especially true of high powered stations authorized to operate in large communities. In Chicago, for example, station WBBM has its studios located in the heart of the city while the antenna and the transmitter are located in a western suburb about 20 miles away.

The signal from the console may also be fed to an STL transmitter at the studio location which radiates the signal by a directional antenna to an STL receiver at the main transmitter location. The audio signals from the STL receiver and the telephone lines are fed to the control section of the transmitter.

In the transmitter control section, the desired signal is selected, amplified, and fed to the limiter which limits the peak amplitude of the signal. From the limiter, the audio signal is finally fed to the transmitter. In the transmitter, the r-f carrier signal is generated and amplified to the proper level. Also, the audio signal is built up to the proper level and used to modulate the carrier. The modulated r-f output of the transmitter is then fed to the antenna and radiated. Also, samples of the signal are fed to the frequency monitor and the modulation monitor as required by the FCC Rules and Regulations.

SUMMARY

The entire frequency spectrum is considered to be the property of all the people and should be used in the best interests of all the people. Since the signals from standard broadcast stations are probably heard by more people than are the signals from any other type of station, it is important that interference-free communications be maintained. All of the requirements imposed upon standard broadcast stations are aimed at producing this situation. It is the duty of the Federal Communications Commission (FCC) to enforce these requirements.

IMPORTANT DEFINITIONS

CLEAR CHANNEL - A channel used by a station or stations to serve a wide, interference-free area.

DIRECT METHOD - A method of determining operating power. It is the square of the antenna current multiplied by the antenna resistance.

DOMINANT STATION - A Class I station operating on a clear channel.

EQUIPMENT PERFORMANCE MEASUREMENTS - A group of transmitter equipment measurements concerning audio frequency response, harmonic distortion, carrier shift, hum and noise, and spurious radiations. Also called PROOF-OF-PERFORMANCE MEASUREMENTS.

INDIRECT METHOD - A method of determining operating power. It uses the product of the plate voltage and plate current of the final r-f stage, and a specified multiplying factor to allow for the efficiency of the stage.

LOCAL CHANNEL - A channel used by a station of 1 kw or less. It renders service to a city or town and the rural area nearby.

MAINTENANCE LOG - A chronological record of maintenance and repair work done on necessary equipment which is not an actual part of the transmitter.

OPERATING LOG - A chronological record of technical events pertinent to the operation of the station.

PROGRAM LOG - A chronological record of program activities of the station.

IMPORTANT DEFINITIONS (Continued)

PROOF-OF-PERFORMANCE MEASUREMENTS - An alter-
nate term for EQUIPMENT PERFORMANCE MEAS-
UREMENTS.

REGIONAL CHANNEL - A channel used by stations with
operating power of 5 kw or less. It renders service
primarily to a principal center of population and the
rural areas in the immediate vicinity.

SECONDARY STATION - Any station except a dominant sta-
tion.

STANDARD BROADCAST BAND - The band of frequencies
extending from 535 kHz to 1605 kHz.

STANDARD BROADCAST STATION - A station licensed for
the transmission of radiotelephone emissions primar-
ily intended to be received by the general public.

STUDENT NOTES

PRACTICE EXERCISE SOLUTIONS

1. 535 to 1605 kHz

2. One used by a station or stations to render service over a wide area.

3. One on which several stations may operate with powers of 5 kw or less.

4. One on which a number of stations may operate with powers of 1 kw or less.

5. A Class I station operating on a clear channel with an authorized power of 10 kw to 50 kw.

6. A secondary station is any station except a dominant station.

7. .5 kw to 1 kw

8. 10 kHz

9. False -- The transmission bandwidth is 30 kHz, providing there is no interference with other stations.

10. When a station is operating with more than 10 kw of power or uses a directional antenna, a first-class radiotelephone operator must be on duty at all times.

11. True

12. 10,000 watts

13. Yes, it is permissible to install a 50,000 watt transmitter. No, it is not permissible to radiate the full 50,000 watts since the authorized power is only 25,000 watts.

14. By the sum of the power ratings of all tubes (or other output devices) used in the final r-f stage.

15. the direct and indirect methods

16. The direct method consists of multiplying the square of the antenna current by the antenna resistance. The current must be measured at the operating frequency and at the same point the resistance was measured.

CLASS OF STATION	CLASS OF CHANNEL USED	PERMISSIBLE POWER
CLASS I-A	CLEAR	50 KW
CLASS I-B	CLEAR	10 KW TO 50 KW
CLASS II-A	CLEAR	.25 KW TO 50 KW (DAY) / 10 KW TO 50 KW (NIGHT)
CLASS II-B AND II-D	CLEAR	.25 KW TO 50 KW
CLASS III-A	REGIONAL	1 KW TO 5 KW
CLASS III-B	REGIONAL	.5 KW TO 5 KW (DAY) / .5 KW TO 1 KW (NIGHT)
CLASS IV	LOCAL	.1 KW TO 1 KW (DAY) / .1 KW TO .25 KW (NIGHT)

FIGURE 1

CLASS OF STATION	MAXIMUM POWER AUTHORIZED TO STATION	MAXIMUM RATED CARRIER POWER PERMITTED TO BE INSTALLED
CLASS IV	100 WATTS	250 WATTS
	250, 500 OR 1000 WATTS	1000 WATTS
CLASS III	500 OR 1000 WATTS	1000 WATTS
	5000 WATTS	5000 WATTS
CLASS II	250, 500 OR 1000 WATTS	1000 WATTS
	5000 OR 10,000 WATTS	10,000 WATTS
	25,000 OR 50,000 WATTS	50,000 WATTS
CLASS I	10,000 WATTS	10,000 WATTS
	25,000 OR 50,000 WATTS	50,000 WATTS

FIGURE 3

FACTOR (F)	METHOD OF MODULATION	MAXIMUM RATED CARRIER POWER	CLASS OF AMPLIFIER
.70	PLATE	.1KW TO 1KW	----
.80	PLATE	5KW AND OVER	----
.35	LOW LEVEL	.1KW AND OVER	B
.65	LOW LEVEL	.1KW AND OVER	BC
.35	GRID	.1KW AND OVER	----

FIGURE 4

4700

FREQ (kHz)	CLASS	CHANNEL	FREQ (kHz)	CLASS	CHANNEL
540	C	1	1080	C	55
550	R	2	1090	C	56
560	R	3	1100	C	57
570	R	4	1110	C	58
580	R	5	1120	C	59
590	R	6	1130	C	60
600	R	7	1140	C	61
610	R	8	1150	R	62
620	R	9	1160	C	63
630	R	10	1170	C	64
640	C	11	1180	C	65
650	C	12	1190	C	66
660	C	13	1200	C	67
670	C	14	1210	C	68
680	C	15	1220	C	69
690	C	16	1230	L	70
700	C	17	1240	L	71
710	C	18	1250	R	72
720	C	19	1260	R	73
730	C	20	1270	R	74
740	C	21	1280	R	75
750	C	22	1290	R	76
760	C	23	1300	R	77
770	C	24	1310	R	78
780	C	25	1320	R	79
790	R	26	1330	R	80
800	C	27	1340	L	81
810	C	28	1350	R	82
820	C	29	1360	R	83
830	C	30	1370	R	84
840	C	31	1380	R	85
850	C	32	1390	R	86
860	C	33	1400	L	87
870	C	34	1410	R	88
880	C	35	1420	R	89
890	C	36	1430	R	90
900	C	37	1440	R	91
910	R	38	1450	L	92
920	R	39	1460	R	93
930	R	40	1470	R	94
940	C	41	1480	R	95
950	R	42	1490	L	96
960	R	43	1500	C	97
970	R	44	1510	C	98
980	R	45	1520	C	99
990	C	46	1530	C	100
1000	C	47	1540	C	101
1010	C	48	1550	C	102
1020	C	49	1560	C	103
1030	C	50	1570	C	104
1040	C	51	1580	C	105
1050	C	52	1590	R	106
1060	C	53	1600	R	107
1070	C	54			

FIGURE 2

4700
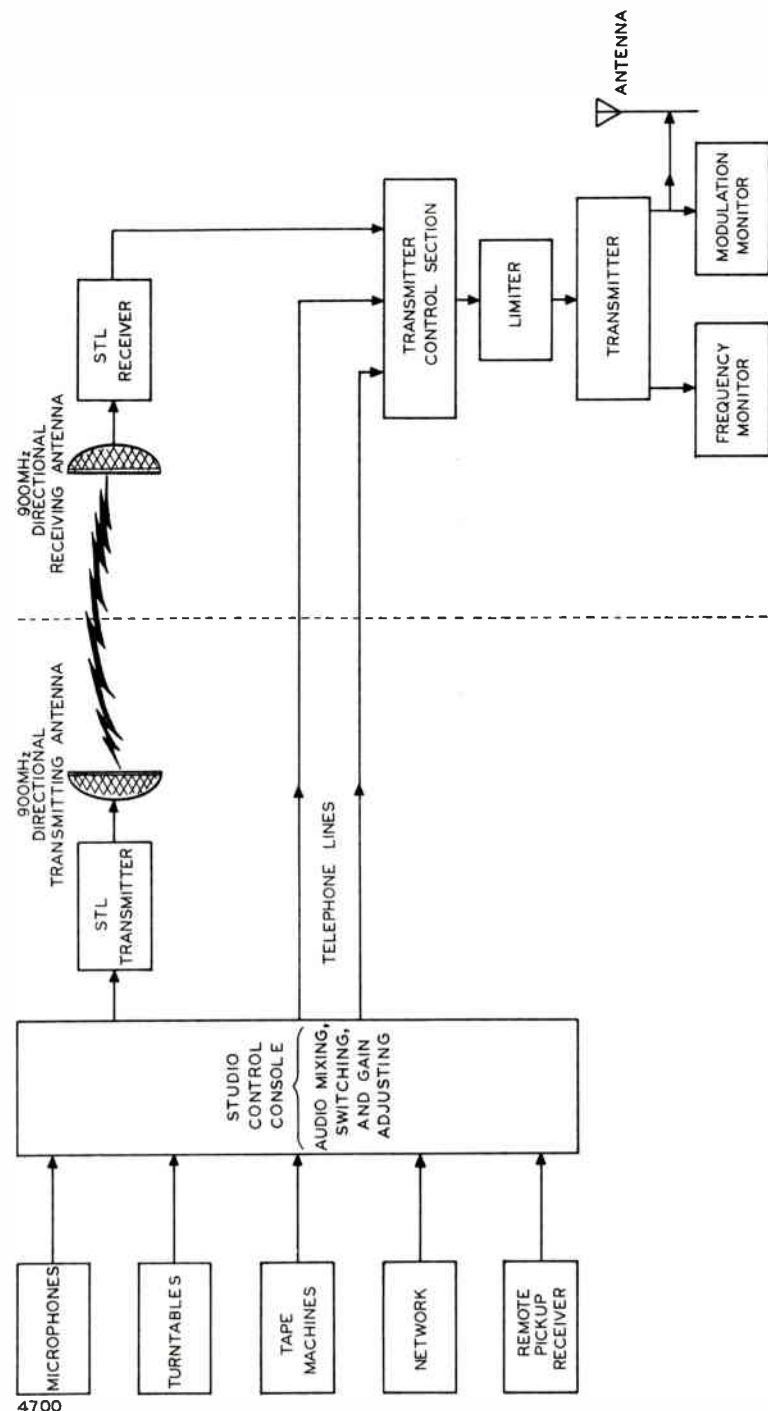
FIGURE 5

17. 9600 watts -- Operating power $= E_p \times I_p \times F = 6000 \times 2 \times .80$
$= 9600$ watts

18. +5% and -10% of the licensed power

19. 5%

20. False -- All stations must measure dc plate voltage and current of the last r-f stage regardless of the method used to determine operating power.

21. 100%

22. False -- All stations must have a modulation monitor in operation.

23. True

24. ±20 Hz of the assigned frequency

25. At least 20 Hz below to 20 Hz above the assigned frequency.

26. From 85% to 95% modulation, the allowable harmonic distortion is 7.5%.

27. ± 2 dB between 100 and 5000 Hz as compared to the response at 1000 Hz

28. A change in carrier power when the carrier is modulated.

29. 5%

30. 45 dB

31. 30 kHz

32. At yearly intervals. One such set must be made during the four-month period preceding the date of filing application for renewal of station license.

33. Overall audio frequency response, audio frequency harmonic distortion, percentage of carrier shift, percentage of hum and extraneous noise, and spurious radiations.

34. A program log, an operating log, and a maintenance log.

35. The person originating the entry may make corrections.

36. (b) program log.

37. (a) operating log.

38. True

39. 2 years

40. False -- Antenna structures less than 170 feet in height may require painting if they are a possible hazard to aircraft.

41. 150 feet

42. An STL station is used to transmit program material from studio to transmitter.

43. 942-952 MHz

44. To select the desired audio input signal and amplify it to the proper level.

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question, as illustrated in the example below.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

LESSON CODE

4700A

Example: Shoes are usually worn on the
(A) hands. (B) feet. (C) ears. (D) lips.

1. In the Standard Broadcast Band, the transmitted signal of each station is limited in bandwidth to
(A) 30 kHz. (B) 20 kHz. (C) 40 kHz. (D) 10 kHz.

2. To perform all technical duties at a standard broadcast station, the operator must hold a
(A) radiotelephone second-class license. (B) radiotelegraph second-class license. (C) radiotelephone first-class license. (D) radiotelegraph first-class license.

3. The frequency tolerance for the carrier of a standard broadcast transmitter is
(A) 20 kHz. (B) 2 kHz. (C) 200 Hz. (D) 20 Hz.

4. For a standard broadcast transmitter, the percentage of modulation
(A) should always be 100%. (B) should be kept between 30% and 85%. (C) should not exceed 100% on negative peaks of frequent recurrence. (D) should not exceed 100% on positive peaks of frequent recurrence.

5. Under normal conditions, the operating power of a standard broadcast station must be kept within
(A) ± 20% of the licensed power. (B) plus 5% and minus 10% of the licensed power. (C) plus 10% and minus 5% of the licensed power. (D) 85% and 100% of the licensed power.

6. At a standard broadcast station, the antenna current must be logged
(A) every week. (B) every day. (C) every hour. (D) every half hour.

7. An antenna structure 250 feet in height above the ground
(A) need not be lighted. (B) must be lighted at the top with red obstruction lights. (C) must be lighted at the top with a flashing red beacon but needs no additional lighting. (D) must be lighted at the top with a flashing red beacon and at the approximate midpoint by red obstruction lights.

8. Aural broadcast STL and IR stations
(A) use amplitude modulation. (B) are assigned a channel 30 kHz wide. (C) must use 1 kw of operating power. (D) must use a directional antenna.

9. Proof-of-performance measurements
(A) must be made at least at yearly intervals. (B) concern only the percentage of modulation and the frequency of the carrier. (C) are a check on the accuracy of the frequency monitor. (D) must be made in a thirty day period preceding the date of filing for renewal of the station license.

10. At a standard broadcast station, the modulation and frequency monitors
(A) are operated one day each week. (B) are optional equipment. (C) must be checked against FCC standards each day. (D) are in operation continuously with the transmitter.

4700A
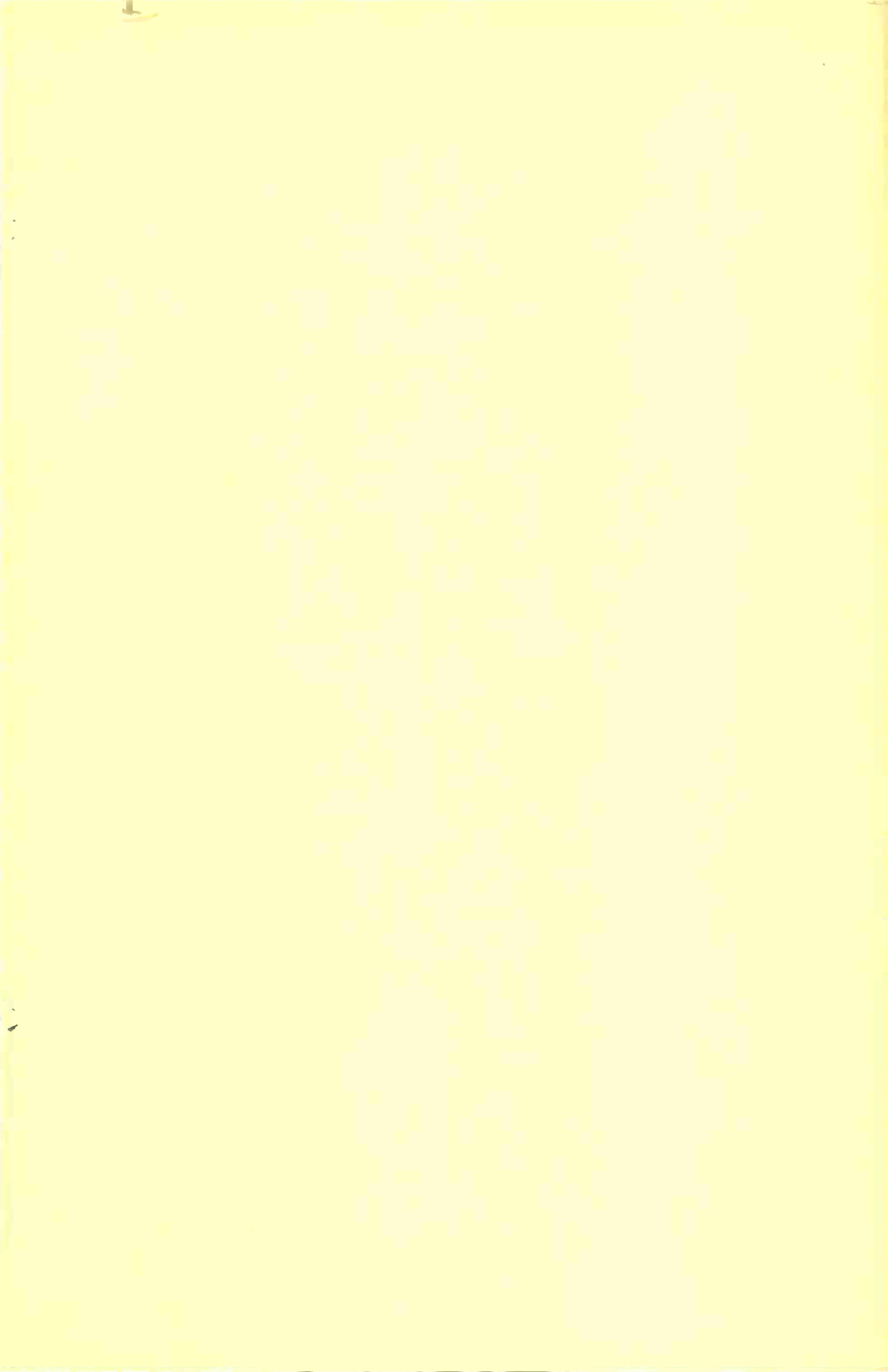
FM BROADCASTING

Lesson 4703

DeVRY INSTITUTE of TECHNOLOGY

FM BROADCASTING

Revised 1968

OPPORTUNITY

4
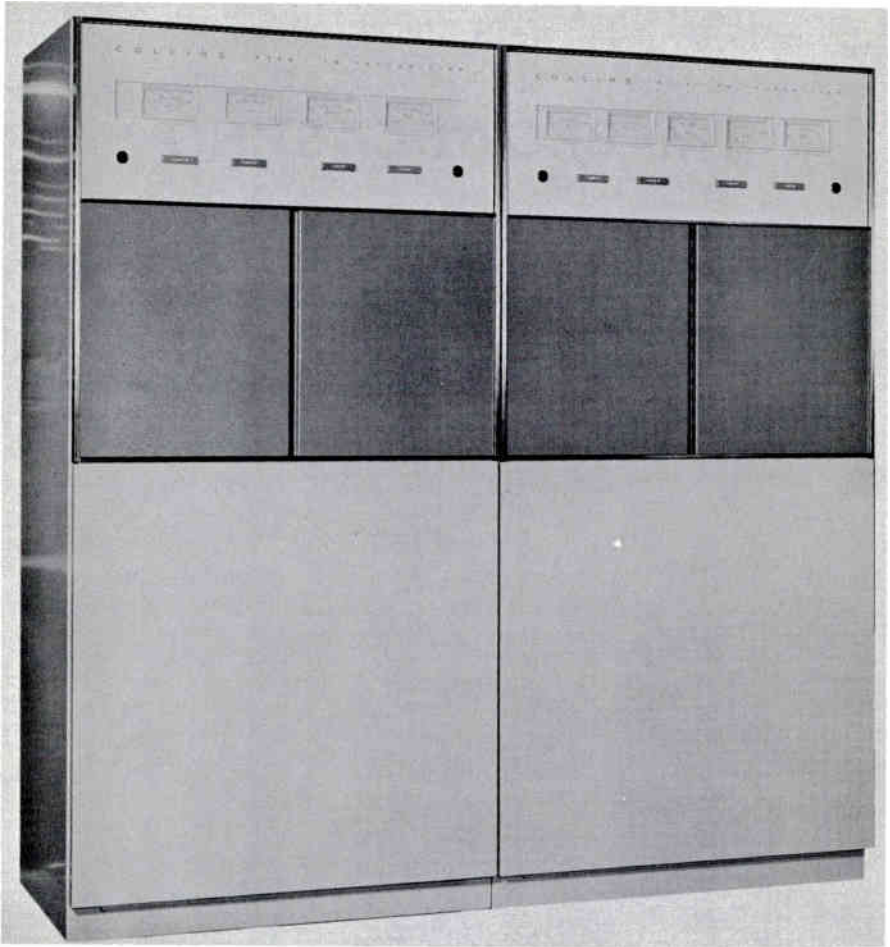
A complete FM broadcast transmitter. The left unit houses a direct FM exciter and 250 watt driver. The right unit houses a 5 kw single-stage transmitter.

Courtesy Collins Radio Co.

FM BROADCASTING

CONTENTS

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The secret of happiness is not in doing
what one likes, but in liking what one
has to do.
                                    --James M. Barrie

FM BROADCASTING

The primary purpose of any type of aural broadcasting is to transmit intelligence or information. To do this the carrier must be changed in some way by the audio signal. The first method used was to vary the amplitude of the r-f carrier signal by the audio signal. Quite naturally, it was called amplitude modulation (AM).

The basic AM system that was first used in the early 1900's is still used today and is quite good. It does have some disadvantages, however. One of these is its susceptibility to noise signals. Most types of noise—both man-made and natural—amplitude modulate an r-f carrier. Since the desired information also amplitude modulates the r-f carrier, it is very difficult for a receiver to distinguish between the desired and undesired modulation. There are some special anti-noise circuits which can be incorporated into an AM receiver, but they only reduce the noise—not eliminate it.

By using relatively low radio frequencies, high power, and a limited bandwidth, AM stations provide limited fidelity signals for good reception at long distances.

As the population of the United States became more concentrated in the urban areas, there arose a need for short-range, high fidelity, low-noise broadcasting. This need was recognized by E. H. Armstrong and he began to experiment with frequency modulation. In 1937, his experimental FM station proved highly successful and FM broadcast stations were licensed by the FCC shortly thereafter.

An FM BROADCAST STATION is licensed for the transmission of radiotelephone emissions primarily intended to be received by the general public. It uses frequency modulation and operates on a channel in the FM broadcast band. The FM BROADCAST BAND is a band of frequencies 20 MHz wide which extends from 88 to 108 MHz. An FM BROAD-

CAST CHANNEL is a band of frequencies 200 kHz wide. The center frequency of the first channel is 88.1 MHz and the center frequency of each successive channel is 200 kHz higher than the preceding one. The center frequency of the last channel is 107.9 MHz. Refer to the chart of Figure 1 for a complete listing of all 100 channels.

*   *   *

1. What frequency band is used by FM broadcast stations?

*   *   *

CLASSES OF CHANNELS

The first 20 channels (201-220) are non-commercial educational FM channels. Technicalities concerning the use of these channels are discussed later in the text.

The two classes of channels for commercial FM broadcasting are Class A and Class B-C. There are 20 Class A channels, while the remaining 60 channels are Class B-C.

*   *   *

2. What are the two classes of channels for commercial FM broadcasting?

*   *   *

CLASSES OF STATIONS

There are three classes of stations in the FM broadcast band -- Class A, Class B and Class C. Class A stations operate on a Class A channel and are designed to render service to a relatively small community, city, or town, and the surrounding rural area. The minimum ERP (Effective Radiated Power) of a Class A station is 100 watts (-10 dBk) while the maximum ERP is 3 kw (4.8 dBk). The term "dBk" means "decibels above or below 1 kw". Therefore, 3 kw is 4.8 dB above 1 kw. EFFECTIVE RADIATED POWER

is the antenna power multiplied by either the antenna power gain or the square of the antenna field gain.

*   *   *

3. What is the basic purpose of a Class A FM broadcast station?

*   *   *

The coverage of a Class A station cannot exceed the coverage obtained from a 3 kw ERP and an antenna height of 300 feet above average terrain. When the antenna height exceeds 300 feet, the ERP must be reduced accordingly.

*   *   *

4. What is the maximum ERP of a Class A FM broadcast station?

5. When a Class A station has an ERP of 3 kw, what is the maximum allowable antenna height above average terrain?

*   *   *

Class B stations operate on Class B-C channels and are designed to render service to a sizeable community, city, or town. The minimum ERP of a Class B station is 5 kw (7 dBk) while the maximum ERP is 50 kw (17 dBk). The coverage of a Class B station cannot exceed the coverage obtained with an ERP of 50 kw and an antenna height above average terrain of 500 feet. When the antenna height exceeds 500 feet, the ERP must be reduced accordingly.

*   *   *

6. What is the basic purpose of a Class B FM broadcast station?

7. What is the maximum ERP of a Class B FM broadcast station?

*   *   *

Class C stations operate on Class B-C channels and are designed to render service to a large community, city or

town, and a large surrounding area. The minimum ERP of a Class C station is 25 kw (14 dBk) while the maximum ERP is 100 kw (20 dBk). The coverage of a Class C station cannot exceed that obtained with an ERP of 100 kw and antenna height of 2000 ft above average terrain. When the antenna height exceeds 2000 feet, the ERP must be reduced accordingly.

*   *   *

8.   When a Class C station has an ERP of 100 kw, what is the maximum allowable antenna height above average terrain?

*   *   *

FREQUENCY ASSIGNMENTS

Getting back to the chart of Figure 1, we see that the first channel is channel 201. The center frequency of this channel is 88.1 MHz. This is the assigned carrier frequency

Since all FM broadcast stations have a specified frequency assignment, a frequency monitor is required. This unit provides continuous frequency monitoring regardless of modulation percentage and is adjustable to cover any channel in the 88-108 MHz band.

Courtesy McMartin Industries, Inc.

of the channel. The second channel is channel 202 and the assigned carrier frequency is 88.3 MHz. Since each channel has a bandwidth of 200 kHz, channel 201 extends from

88.0 MHz to 88.2 MHz, and channel 202 extends from 88.2 MHz to 88.4 MHz. The remaining channels occupy successive bandwidths of 200 kHz with the carrier frequency being the center of the channel. The 100th channel (channel 300) occupies 200 kHz from 107.8 MHz to 108 MHz, with the carrier frequency being 107.9 MHz as indicated.

*   *   *

9. What is the bandwidth of each channel in the FM broadcast band?

*   *   *

Channels 201 to 220 are used by non-commercial educational FM broadcast stations. Starting with channel 221, the remaining 80 channels are assigned to commercial FM broadcast stations. The Class A channels are fairly evenly distributed throughout the entire band and are limited to 20 in number. Since Class A stations have a maximum ERP of only 3 kw, the area of coverage is rather small. Because of this, Class A stations on the same channel need be separated by only 65 miles.

*   *   *

10. Referring to Figure 1, which channels are used by educational FM stations?

*   *   *

With 20 channels for educational stations and 20 channels for Class A stations, there are 60 channels remaining for use by Class B and Class C stations. Due to the power authorization, Class B stations on the same channel must be separated by 150 miles or more; Class C stations on the same channel must be separated by 180 miles or more.

*   *   *

11. What is the minimum separation between two Class B stations on the same channel?

*   *   *

OPERATOR REQUIREMENTS

When the transmitter power output (not the ERP) of an FM broadcast station is over 25 kw, a radio operator holding a valid radiotelephone first-class operator license must be on duty during all hours of operation.

When the transmitter power output is 25 kw or less, the radio operator on duty may hold a lesser license. Under these conditions the adjustments of the transmitter made by the operator are limited to:

(1) Those necessary to turn the transmitter on and off.
(2) Adjustments of external controls as may be necessary to compensate for voltage fluctuation in the power supply.
(3) Adjustments of external controls to maintain modulation of the transmitter within the prescribed limits.

Also, the licensee of the station must employ at least one operator who holds a first-class radiotelephone license. The holder of the first-class license must perform transmitter maintenance and be immediately available to correct conditions of improper operation beyond the scope of authority of the lesser grade operator on duty.

*   *   *

12. An FM broadcast station with an ERP of 25 kw or less need not employ any operators holding a first-class radiotelephone license. True or False?

*   *   *

OPERATING POWER

The **OPERATING POWER** of an FM broadcast station is the actual output power of the transmitter and is determined by either the direct or indirect method. Using the direct method, the operating power is measured at the output terminals of the transmitter while operating into a dummy load of

substantially zero reactance and a resistance equal to the transmission line characteristic impedance. The transmitter must be unmodulated during this measurement. Also, the direct plate voltage and current of the last r-f stage, and the transmission line current, must be measured and compared with similar readings taken when the dummy load is replaced by the antenna. Both sets of readings must be in substantial agreement.

Using the indirect method, the operating power is the product of the plate voltage and the plate current of the last radio stage, and an efficiency factor, F, as follows:

$$\text{Operating Power} = E_p \times I_p \times F$$

where the efficiency factor, F, has been established by the manufacturer and accepted by the Commission (FCC).

The operating power must be maintained as close as possible to the authorized power and must not be less than 90% nor more than 105% of the authorized power except during an emergency. In this event, the FCC and the Engineer in Charge of the radio district must be notified immediately.

This power output stage (above) and driver (lower left) provide an operating power of 5 kw to 7.5 kw. The power output stage is pre-tuned by the manufacturer to a specific frequency in the FM broadcast bond.

Courtesy Gates Radio Company

When determined by the direct method, the transmitter operating power must be monitored by a transmission line meter which reads proportional to voltage, current, or power at the transmitter output terminals.

*   *   *

13. What is an acceptable method for measuring the operating power of an FM broadcast station?

14. What is the allowable tolerance for operating power?

*   *   *

EFFECTIVE RADIATED POWER (ERP)

Although transmitters are rated as to their operating power, FM broadcast stations are licensed for effective radiated power (ERP). The ERP means the product of the antenna power (transmitter output power less transmission line loss) times the antenna power gain or the square of the antenna field gain.

For example, an FM transmitter has a power output of 20 kw, the transmission line is 85% efficient and the antenna power gain is 2.3. The ERP is

$$ERP = 20 \text{ kw} \times .85 \times 2.3$$
$$ERP = 39.1 \text{ kw}$$

*   *   *

15. What is effective radiated power (ERP)?

16. The output of the transmitter of an FM station is 1 kw, the transmission line efficiency is 80%, and the antenna power gain is 3.5. What is the ERP?

*   *   *

Since it is standard practice to employ a horizontally polarized antenna system, the ERP authorized refers to the horizontally polarized radiation. However, if desired, a vertically polarized supplemental antenna system may be used. The additional ERP required for the vertically polarized system may not exceed the ERP authorized for the horizontally polarized system.

To illustrate, assume that a station using only a horizontally polarized antenna system is licensed for ERP of 2.5 kw. This station may add a vertically polarized antenna system and feed it with sufficient power to obtain an additional ERP of 2.5 kw.

*   *   *

17. An FM broadcast station may use only a vertically polarized antenna system.   True or False?

*   *   *

MODULATION

When a carrier is being amplitude modulated it is a very simple matter to determine the percentage of modulation. For example, when the amplitude of the carrier varies from twice its unmodulated amplitude to zero, the percentage of modulation is 100%.

Where FM is concerned, there is no such simple method for determining the percentage of modulation.   Therefore, the FCC has stated that a carrier deviation (frequency swing) of ±75 kHz is 100% modulation for an FM broadcast station.   A reduction in carrier deviation produces a linear reduction in percentage of modulation.   That is, a carrier deviation of 37.5 kHz is 50% modulation.

*   *   *

18. What is 100% modulation for an FM broadcast station?

*   *   *

Normally, the percentage of modulation should be held between 85% and 100% on peaks of frequent recurrence. In no case should it exceed 100% on peaks of frequent recurrence. In some cases, where necessary to avoid objectionable loudness, the modulation may be reduced to whatever level is

necessary, even if this is considerably less than 85% on peaks of frequent recurrence.

*   *   *

19.   On peaks of frequent recurrence, what are the normal limits of modulation percentage?

*   *   *

The transmitter employed by an FM broadcast station must have means for the connection and continuous operation of
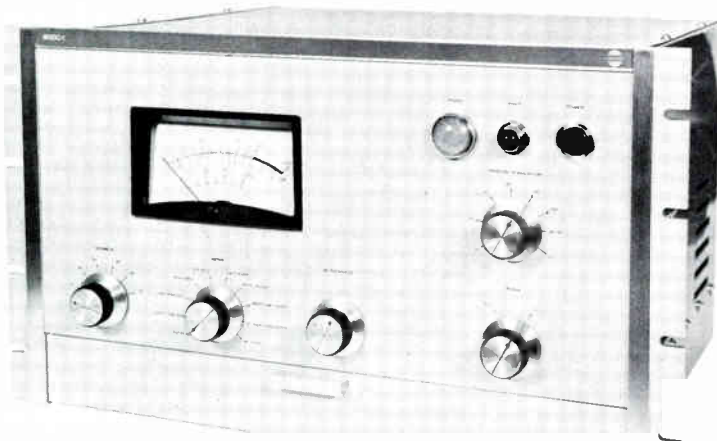
This modulation monitor meets all FCC standards for FM stereo multiplex programming. It includes a meter plus a peak limit indicator light.

Courtesy Collins Radio Co.

an approved modulation monitor that meets the following specifications:

(1) A modulation peak indicating device (usually a light) that can be set at any predetermined value from 50% to 120% modulation and for either positive or negative swings (that is, above or below the transmitter center frequency).

(2) A semi-peak indicating meter that can be switched to read either positive or negative swings.

(3) The percentage of modulation reading must be accu-
rate within ±5%.

(4) The frequency response should be within ±1/2 dB
from 50 to 15,000 Hz.

(5) There should be no appreciable power absorbed from
the transmitter.

(6) There should be no degrading effect on the operation
of the transmitter.

*   *   *

20. What accuracy is required of the modulation monitor used in
an FM broadcast station?

*   *   *

BANDWIDTH

For an FM broadcast station, the FCC rules and regulations
state that any emission (radiated signal) removed from the
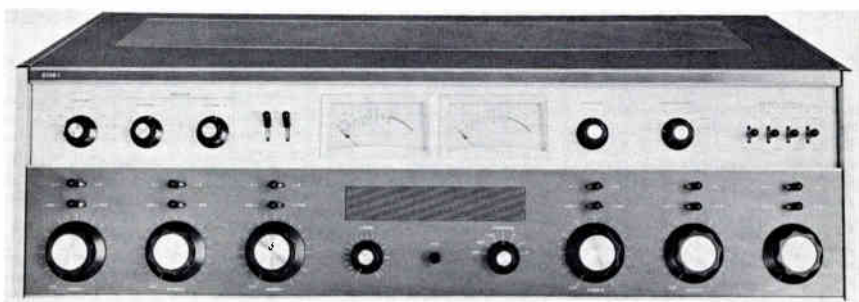
To obtain the proper bandwidth, a high quality stereo speech input console is needed. This unit has
a frequency response of ±1 dB from 30 to 15,000 Hz.

Courtesy Collins Radio Co.

carrier by 120 kHz must be at least 25 dB below the level
of the unmodulated carrier. In effect, this means that the
occupied bandwidth of the emitted signal is 240 kHz or less.

The audio frequency response of FM transmitting equipment
should be relatively flat from 50 to 15,000 Hz. When a

15,000 Hz audio signal has sufficient amplitude to cause 100% modulation, a carrier deviation of ±75 kHz occurs. Under these conditions the modulation index is 5 and the number of significant sideband pairs produced is 8. Thus, the emitted signal requires 120 kHz on each side of the carrier for a total bandwidth of 240 kHz.

Previously we stated that the bandwidth of each FM broadcast channel was 200 kHz. Since the emitted signal may occupy a bandwidth of 240 kHz, an overlap may occur into each of the two adjacent channels. To prevent this overlap from causing undesirable interference, the FCC does not allocate adjacent channels to the same area.

*   *   *

21. What is the maximum bandwidth of the signal emitted by an FM broadcast station?

*   *   *

FREQUENCY TOLERANCE

For FM broadcast stations, the center frequency of the transmitter must be maintained within ±2000 Hz of the assigned frequency. Further, the transmitter must be provided with means to automatically maintain the assigned center frequency within the allowable tolerance. The transmitter must also be provided with a connection for the continuous operation of an approved frequency monitor that meets the following specifications:

(1) It must have an accuracy of at least ±1000 Hz under normal conditions of temperature, humidity, etc.

(2) The indicating device must have a frequency range of at least 2000 Hz below to 2000 Hz above the assigned center frequency.

(3) The scale of the indicating device must be calibrated to be read accurately within at least 100 Hz.

(4) Means must be provided for adjustment of the monitor indication to agree with an external standard.

(5) It must be capable of continuous operation with no ill effects on the operation of the transmitter.

*   *   *

22. What is the frequency tolerance for the carrier of an FM broadcast station?

23. What is the frequency range of the indicating device of the frequency monitor used by an FM broadcast station?

*   *   *

EQUIPMENT PERFORMANCE MEASUREMENTS

Since it is very important that transmitting equipment be kept in proper operating condition, the licensee of each FM broadcast station is required to make certain equipment performance measurements at least at yearly intervals. One set of measurements must be made during the four month period preceding the date of filing application for renewal of station license. The required measurements are:

(1) Audio frequency response from 50 to 15,000 Hz for approximately 25%, 50% and 100% modulation. Audio frequencies of 50, 100, 400, 1000, 5000, 10,000 and 15,000 Hz must be used.

(2) Audio frequency harmonic distortion for 25%, 50% and 100% modulation using frequencies of 50, 100, 400, 1000 and 5000 Hz. Also, audio frequency harmonic distortion for 100% modulation using frequencies of 10,000 and 15,000 Hz. The allowable distortion varies from 2.5% to 3.5%, depending upon the audio frequency being used.

(3) From 50 to 15,000 Hz, the output noise level that causes frequency modulation. The noise level must be 60 dB below 100% modulation.

(4) From 50 to 15,000 Hz, the output noise level that causes amplitude modulation. The noise level must be 50 dB below 100% modulation.

*   *   *

24. What is the required audio frequency response of the FM broadcast transmitting system?

25. What is the allowable audio frequency harmonic distortion for FM broadcasting?

26. What is the maximum FM noise level?

27. What is the maximum AM noise level?

*   *   *

OTHER TRANSMITTER REQUIREMENTS

In addition to specifications concerning operating power, percentage of modulation, bandwidth, carrier frequency tolerance, and audio frequency performance, FM broadcast

A fully transistorized audio processor used between the limiting amplifier and the FM transmitter to allow maximum modulation without fear of overmodulation.

Courtesy Gates Radio Co.

transmitters must meet other specifications. For example, the audio equipment must contain a pre-emphasis circuit that has the characteristics of a series inductance-resistance network having a time constant of 75 microseconds.

The transmitter must be provided with the necessary instruments for measuring and adjusting the operating power.

It also must be designed for the connection of all monitors.

A number of transmitter specifications pertain to the safety of the operators. For example, when more than 350 volts is required in a circuit, the tuning adjustments must be made from the front of the panels with all access doors closed. Also, when the access door is opened, all voltages must be automatically reduced to less than 350 volts within 2 seconds after the access door is opened.

*   *   *

28. FM transmitters are designed without regard for the safety of the operator. True or False?

*   *   *

LOG REQUIREMENTS

The licensee of each FM broadcast station is required to maintain program, operating and maintenance logs. The required entries are basically the same as for an AM station.

*   *   *

29. What logs must be maintained by each FM broadcast station?

*   *   *

FACSIMILE

An FM broadcast station may cease its usual transmission and transmit simplex facsimile for one hour between 7 A.M. and midnight. Between midnight and 7 A.M., simplex facsimile may be transmitted the entire time. Upon securing authorization, multiplex operation (regular FM plus facsimile) is allowed at any time.

Some of the engineering standards for facsimile operation are as follows:

(1) Either amplitude modulation or frequency (frequency-shift) modulation may be used.

(2) The frequency range of the modulated subcarrier must be between 22 and 28 kHz. This sets the subcarrier frequency at 25 kHz.

(3) Negative modulation must be used. That is, for amplitude modulation of the subcarrier, maximum subcarrier amplitude and maximum radio frequency swing on black; for frequency modulation of the subcarrier, highest instantaneous frequency of the subcarrier on black.

(4) In simplex operation, the modulation of the main FM carrier should not exceed 30%.

(5) In multiplex operation, the modulation of the main FM carrier should not exceed 5%.

*   *   *

30. For facsimile operation, what type of modulation may be used?

31. For facsimile operation, what is the frequency range of the modulated subcarrier?

*   *   *

SUBSIDIARY COMMUNICATIONS AUTHORIZATION (SCA)

A Subsidiary Communication Authorization (SCA) is a secondary type of license which is issued only to licensees of FM broadcast stations and cannot exist apart from this license. Loss of the FM broadcast license automatically terminates the SCA license.

The SCA license allows the transmission of programs which are of interest primarily to limited segments of the public wishing to pay subscription fees. Background music and detailed weather forecasting are typical services available.

The SCA license also allows the transmission of signals which are directly related to the operation of FM broadcast

stations. For example, relaying of broadcast material to other FM and standard broadcast stations, remote cueing

This FM Modulation – SCA Monitor has separate indicoting meters for main chonnel modulotion, subchannel frequency, and subchannel modulation.

Courtesy McMartin Industries, Inc.

and order circuits, and remote control telemetering functions associated with authorized STL operation. SCA operations are permitted at any time the main channel is programmed.

*   *   *

32. An SCA license may be obtained independently of any other license. True or False?

*   *   *

A daily operating log of SCA operation must be kept which contains the following information:

(1) The time the subcarrier generator is turned on.
(2) The time modulation is applied to the subcarrier.
(3) The time modulation is removed from the subcarrier.
(4) The time the subcarrier generator is turned off.

Some of the technical standards governing SCA operation are as follows:

(1) Frequency modulation must be used for the SCA subcarrier.

(2) When monophonic FM broadcasting is being used, the SCA subcarrier must be kept within the range of 20 kHz to 75 kHz, and modulation of the main carrier by the SCA subcarrier must not exceed 30%.

(3) When stereophonic FM broadcasting is being used, the SCA subcarrier must be kept within the range of 53 kHz to 75 kHz, and modulation of the main carrier by the SCA subcarrier must not exceed 10%. In this case the SCA subcarrier is usually 67 kHz with a deviation of ±7.5 kHz.

*   *   *

33. What type of modulation is used with the SCA subcarrier?

34. When an FM broadcast station IS NOT engaged in stereophonic broadcasting, what is the frequency range of the SCA subcarrier?

35. When an FM broadcast station is engaged in stereophonic broadcasting, what is the frequency range of the SCA subcarrier?

36. When an FM broadcast station is engaged in stereophonic broadcasting, modulation of the main carrier by the SCA subcarrier is limited to what percentage?

*   *   *

STEREOPHONIC BROADCASTING

The present system of stereophonic broadcasting by FM broadcast stations was made effective by the FCC as of June 1, 1961. Stereo FM broadcasting is made possible by a **MULTIPLEX TRANSMISSION** system that allows several signals to simultaneously modulate the r-f carrier and yet retains the identity of each modulating signal.

A simple block diagram of the stereophonic system is shown in Figure 2. The output signals from a left and a right microphone are amplified and fed to an L+R adder. The right audio signal (+R) is phase inverted to -R, then added to the L signal in an L-R adder. A 19 kHz oscillator is doubled to obtain the 38 kHz stereophonic subcarrier. This subcarrier signal, along with the L-R audio signal, is fed to

A fully transistorized FM Stereo Monitor which provides channel separation of 40 dB. These meters allow simultaneous readings of left, right and total modulation.

Courtesy McMartin Industries, Inc.

a balanced modulator. In the balanced modulator, the 38 kHz stereophonic subcarrier is amplitude modulated by the L-R audio signal. The characteristics of a balanced modulator circuit cause the stereophonic subcarrier to be suppressed but allow the sidebands to be produced. Thus, the output of the balanced modulator is a double-sideband suppressed-carrier signal which we will call the L-R sidebands.

The L+R main channel signal and the L-R stereophonic side-bands contain all of the audio information and are fed to the FM transmitter. In addition, a 19 kHz pilot subcarrier (for receiver synchronization) is fed to the FM transmitter. All three of these signals (the L+R main channel, the L-R

stereophonic sidebands, and the 19 kHz pilot) are now used to frequency modulate the r-f carrier in a conventional manner.

*   *   *

37. In stereo FM broadcasting, the main channel modulating signal is the (a) L+R, (b) L-R signal.

38. What is the frequency of the pilot subcarrier in stereo FM broadcasting?

39. What is the frequency of the stereophonic subcarrier?

40. What type of modulation is used with the stereophonic sub-carrier?

*   *   *

The L+R main channel signal is a simple audio signal which extends from 50 Hz to 15,000 Hz. The L-R sidebands actually extend from 23 kHz to 53 kHz, but contain audio information from 50 Hz to 15,000 Hz. The 19 kHz pilot subcarrier is a sine wave that is used to synchronize the receiver subcarrier oscillator.

*   *   *

41. The sideband components of the stereophonic subcarrier (the L-R sidebands) occupy a specific band of frequencies. What is this band of frequencies?

*   *   *

Some of the stereophonic transmission standards are:

(1) The modulating signal for the main channel must consist of the sum of the left and right signals. (This is the L+R audio signal.)

(2) A pilot subcarrier of 19,000 Hz, ±2 Hz, must frequency modulate the main carrier from 8% to 10%. (This is the 19 kHz signal that is used to synchronize the receiver stereo subcarrier oscillator.)

(3) The stereophonic subcarrier must be the second har-
    monic of the pilot subcarrier. (This is the 38 kHz
    stereophonic subcarrier that is suppressed in the
    balanced modulator.)
(4) The modulating signal for the stereophonic subcarrier
    must be equal to the difference of the left and right
    signals. (This is the L-R audio signal.)
(5) Amplitude modulation of the stereophonic subcarrier
    must be used.
(6) When only a left or right signal exists, the L+R main
    channel signal must not cause more than 45% modu-
    lation of the r-f carrier. When only a left or right
    signal exists, the L-R stereophonic sidebands must
    not cause more than 45% modulation of the r-f car-
    rier. (This means that modulation of the r-f carrier
    by the two modulating signals cannot exceed 90%. The
    remaining 10% modulation is reserved for the 19 kHz
    pilot subcarrier.)
(7) When an SCA subcarrier is also used, the 45% fig-
    ures in the preceding paragraph (6) must be reduced
    to approximately 40%. (This allows the r-f carrier
    to be modulated 10% by the SCA subcarrier.)
(8) Crosstalk between the main channel and the stereo-
    phonic subchannel must be kept at least 40 dB below
    90% modulation. (This provides good separation of
    the two signals and gives a good stereo effect at the
    receiver.)

STL AND IR STATIONS

Studio-Transmitter-Link (STL) and Intercity Relay (IR)
stations are used by FM broadcast stations in exactly the
same way they are used by standard (AM) broadcast sta-
tions.

STATION FACILITIES

Where a standard (AM) broadcast station is concerned, the
transmitter and the antenna are usually separated from the
studios because of the large amount of space required for
the antenna.

Where an FM broadcast station is concerned, the antenna may be mounted on top of the same building that houses the transmitter and the studios. On the other hand, the antenna may be located on a tall tower that is separated from the studios. The transmitter is always located relatively close to the antenna.

Studio facilities for an FM broadcast station are about the same as for an AM station. Both types of station need turntables, tape players, an audio console, microphones, etc. The biggest difference lies in the fact that audio equipment for an FM station must have a wider frequency response (50-15,000 Hz) than audio equipment for an AM station (50-7500 Hz).

*   *   *

42. The audio console in an FM broadcast station is similar to the audio console in an AM broadcast station. True or False?

*   *   *

NON-COMMERCIAL EDUCATIONAL FM BROADCAST STATIONS

Non-commercial educational FM broadcast stations (which we shall call educational FM stations) use the first 20 channels (201 to 220) of the FM broadcast band as indicated in Figure 1. The stations are divided into four classes — Class A, Class B, Class C and Class D.

Stations with more than 10 watts transmitter output power, but not more than 3 kw ERP, are Class A stations. With an ERP of more than 3 kw, the station falls into the Class B or Class C category. A Class D station operates with 10 watts or less of transmitter output power.

*   *   *

43. How many classes of non-commercial educational FM broadcast stations are there? List them.

44. What is the power limitation of a Class D station?

                *   *   *

Educational FM stations which operate with more than 10 watts of transmitter output power (all stations except Class D) must abide by most of the same rules and regulations as do commercial FM broadcast stations.

Because of their low power output (10 watts or less), Class D educational FM stations do not have to meet the same

This FM stereo rebroadcast receiver is especially useful for educational FM stations. It is designed to receive an FM stereo broadcast and to feed certain FM transmitters to allow a direct rebroadcast without any intermediate equipment.

Courtesy McMartin Industries, Inc.

technical specifications as do the other stations. For example, a Class D station may hire an operator who holds a second-class radiotelephone or radiotelegraph license to do maintenance work. No first-class license holders are required to be on duty at any time.

                *   *   *

45. What are the operator requirements for a Class D station?

                *   *   *

The frequency tolerance of the carrier of a Class D station

is ±3 kHz instead of the usual 2 kHz. In addition, the carrier frequency does not have to be continuously monitored. After installation, it need be measured only if there is reason to believe that the carrier frequency has drifted beyond the allowable tolerance or if equipment changes are made.

*   *   *

46.   What is the frequency tolerance of the carrier of a Class D station?

*   *   *

Where power is concerned, Class D stations must keep their radiated power less than 5% above the authorized power. Where other performance of equipment is concerned, Class D stations are not required to meet specifications regarding frequency response, distortion, hum and noise, etc. They are merely required to maintain the equipment in a condition that will provide satisfactory broadcast service.

SUMMARY

Licenses for FM broadcast stations are issued to suit the best interests of the general public. The various rules and regulations which must be observed are designed to allow the greatest number of people to enjoy interference-free reception. To accomplish this purpose, the people involved in the technical operation and maintenance must have a good understanding of the station requirements. As a result, the FCC requires that the majority of the station technical personnel who are responsible for its operation be holders of a radiotelephone first-class operator license.

IMPORTANT DEFINITIONS

EFFECTIVE RADIATED POWER(ERP) - The antenna power multiplied by either the antenna power gain or the square of the antenna field gain.

FM BROADCAST BAND - The band of frequencies extending from 88 to 108 MHz.

FM BROADCAST CHANNEL - A band of frequencies 200 kHz wide and located in the FM broadcast band. The center frequency of the first channel is 88.1 MHz and the center frequency of the last (100th) channel is 107.9 MHz.

FM BROADCAST STATION - A station employing frequency modulation in the FM broadcast band and licensed primarily for the transmission of radiotelephone emissions intended to be received by the general public.

MULTIPLEX TRANSMISSION - The transmission of two or more signals within a single channel. As applied to FM broadcast stations, multiplex transmission means the transmission of facsimile or other signals in addition to the regular broadcast signals.

OPERATING POWER - The output power of the transmitter.

PRACTICE EXERCISE SOLUTIONS

1. 88-108 MHz

2. Class A and Class B-C channels

3. Render service to a relatively small community.

4. 3 kw (4.8 dBk)

5. 300 ft

6. A Class B station renders service to a sizeable community.

7. 50 kw (17 dBk).

8. 2000 ft

9. 200 kHz

10. channels 201 to 220

11. 150 miles

12. False -- At least one operator must have a first-class radio-telephone license.

13. Either the direct or indirect method may be used.

14. 90% to 105% of authorized power.

15. ERP is the antenna power multiplied by the antenna power gain or the square of the antenna field gain.

16. $1000 \times .8 \times 3.5 = 800 \times 3.5 = 2.8$ kw

17. False -- The vertically polarized antenna system is supplemental to the horizontally polarized antenna system.

18. A frequency swing of ±75 kHz is 100% modulation in FM broadcasting.

19. Modulation is limited to not less than 85% and not more than 100%.

FREQ (MHz)	CLASS	CHANNEL	FREQ (MHz)	CLASS	CHANNEL
88.1	E	201	98.1	B-C	251
88.3	E	202	98.3	A	252
88.5	E	203	98.5	B-C	253
88.7	E	204	98.7	B-C	254
88.9	E	205	98.9	B-C	255
89.1	E	206	99.1	B-C	256
89.3	E	207	99.3	A	257
89.5	E	208	99.5	B-C	258
89.7	E	209	99.7	B-C	259
89.9	E	210	99.9	B-C	260
90.1	E	211	100.1	A	261
90.3	E	212	100.3	B-C	262
90.5	E	213	100.5	B-C	263
90.7	E	214	100.7	B-C	264
90.9	E	215	100.9	A	265
91.1	E	216	101.1	B-C	266
91.3	E	217	101.3	B-C	267
91.5	E	218	101.5	B-C	268
91.7	E	219	101.7	A	269
91.9	E	220	101.9	B-C	270
92.1	A	221	102.1	B-C	271
92.3	B-C	222	102.3	A	272
92.5	B-C	223	102.5	B-C	273
92.7	A	224	102.7	B-C	274
92.9	B-C	225	102.9	B-C	275
93.1	B-C	226	103.1	A	276
93.3	B-C	227	103.3	B-C	277
93.5	A	228	103.5	B-C	278
93.7	B-C	229	103.7	B-C	279
93.9	B-C	230	103.9	A	280
94.1	B-C	231	104.1	B-C	281
94.3	A	232	104.3	B-C	282
94.5	B-C	233	104.5	B-C	283
94.7	B-C	234	104.7	B-C	284
94.9	B-C	235	104.9	A	285
95.1	B-C	236	105.1	B-C	286
95.3	A	237	105.3	B-C	287
95.5	B-C	238	105.5	A	288
95.7	B-C	239	105.7	B-C	289
95.9	A	240	105.9	B-C	290
96.1	B-C	241	106.1	B-C	291
96.3	B-C	242	106.3	A	292
96.5	B-C	243	106.5	B-C	293
96.7	A	244	106.7	B-C	294
96.9	B-C	245	106.9	B-C	295
97.1	B-C	246	107.1	A	296
97.3	B-C	247	107.3	B-C	297
97.5	B-C	248	107.5	B-C	298
97.7	A	249	107.7	B-C	299
97.9	B-C	250	107.9	B-C	300

FIGURE 1

4703

FIGURE 2

4703
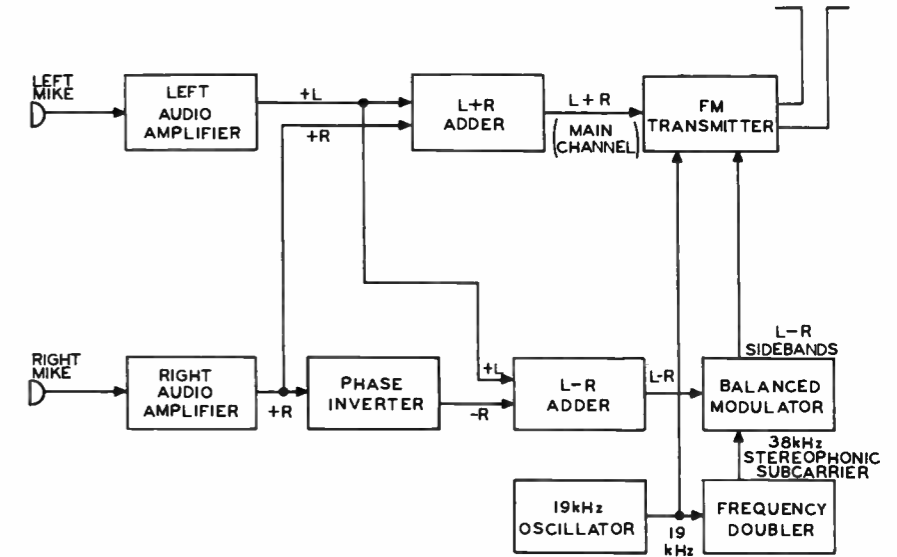
20. ±5%

21. 240 kHz

22. ±2000 Hz of the assigned frequency

23. 2000 Hz below to 2000 Hz above the assigned center frequency

24. 50 Hz to 15,000 Hz

25. 2.5% to 3.5%, depending upon the audio frequency being used

26. 60 dB below 100% modulation

27. 50 dB below 100% amplitude modulation

28. False

29. Program, operating, and maintenance logs.

30. Either AM or frequency shift may be used.

31. 22 to 28 kHz

32. False -- An SCA license is issued only to the licensee of an FM broadcast station.

33. FM

34. 20 to 75 kHz

35. 53 to 75 kHz

36. 10%

37. (a) L+R

38. 19 kHz

39. 38 kHz

40. AM

41. 23 kHz to 53 kHz

42. True

43. There are four classes: Class A, B, C and D.

44. 10 watts or less

45. The operator may hold a second-class radiotelephone or radiotelegraph license.

46. ±3 kHz

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question, as illustrated in the example below.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

LESSON CODE

4703A

Example: An animal noted for its exceptionally long neck is the
(A) rhinoceros. (B) giraffe. (C) elephant. (D) hippopotamus.

1. When the transmitter power output of an FM broadcast station is over 25 kw, (A) one operator on duty must hold a second-class radiotelephone license. (B) one operator on duty must hold a first-class radiotelephone license. (C) maintenance work may be made by an operator who holds a third-class radiotelephone license. (D) two operators must be on duty at all times.

2. Where FM broadcast stations are concerned, the effective radiated power (ERP) (A) is always less than the transmitter power output. (B) is equal to the antenna power multiplied by 2. (C) is the transmitter operating power. (D) is the antenna power multiplied by the antenna power gain.

3. For an FM broadcast station, 100% modulation (A) causes a 50% increase in average power output. (B) is a carrier deviation of ±75 kHz. (C) is forbidden by the FCC. (D) occurs when the carrier frequency varies from zero to twice its unmodulated frequency.

4. For an FM broadcast station, the occupied bandwidth of the emitted signal is (A) 240 kHz or less. (B) 200 kHz or less. (C) 15,000 Hz. (D) 150 kHz or less.

5. For an FM broadcast station, the center frequency of the transmitter (A) must be kept within ±2000 Hz of the assigned frequency. (B) has a frequency tolerance of ±1%. (C) must be monitored once each day. (D) may be anywhere within the 200 kHz band.

6. The audio frequency response of FM broadcast equipment (A) is not specified by the FCC. (B) is measured from 50 to 15,000 Hz. (C) is the same as for AM broadcast equipment. (D) is measured only at 100% modulation.

7. Technical standards governing SCA operation require (A) amplitude modulation of the SCA subcarrier. (B) 50% modulation of the main carrier by the SCA subcarrier. (C) the SCA subcarrier to be 50 kHz during stereophonic FM broadcasting. (D) frequency modulation of the SCA subcarrier.

8. The L-R sidebands of a stereophonic FM broadcast (A) are obtained by frequency modulating a 38 kHz subcarrier. (B) extend from 23 kHz to 53 kHz. (C) are obtained by amplitude modulating a 19 kc pilot subcarrier. (D) must not cause more than 10% modulation of the main carrier.

9. The 38 kHz stereophonic subcarrier (A) produces the L+R signal. (B) is used as the receiver synchronizing signal. (C) is frequency modulated to produce the L-R sidebands. (D) is suppressed in the balanced modulator.

10. A Class D educational FM station (A) may operate with an ERP of 3 kw. (B) is allowed a carrier frequency tolerance of ±3000 Hz. (C) must continuously monitor the carrier frequency. (D) must meet all the same technical specifications as FM stations of other classes.
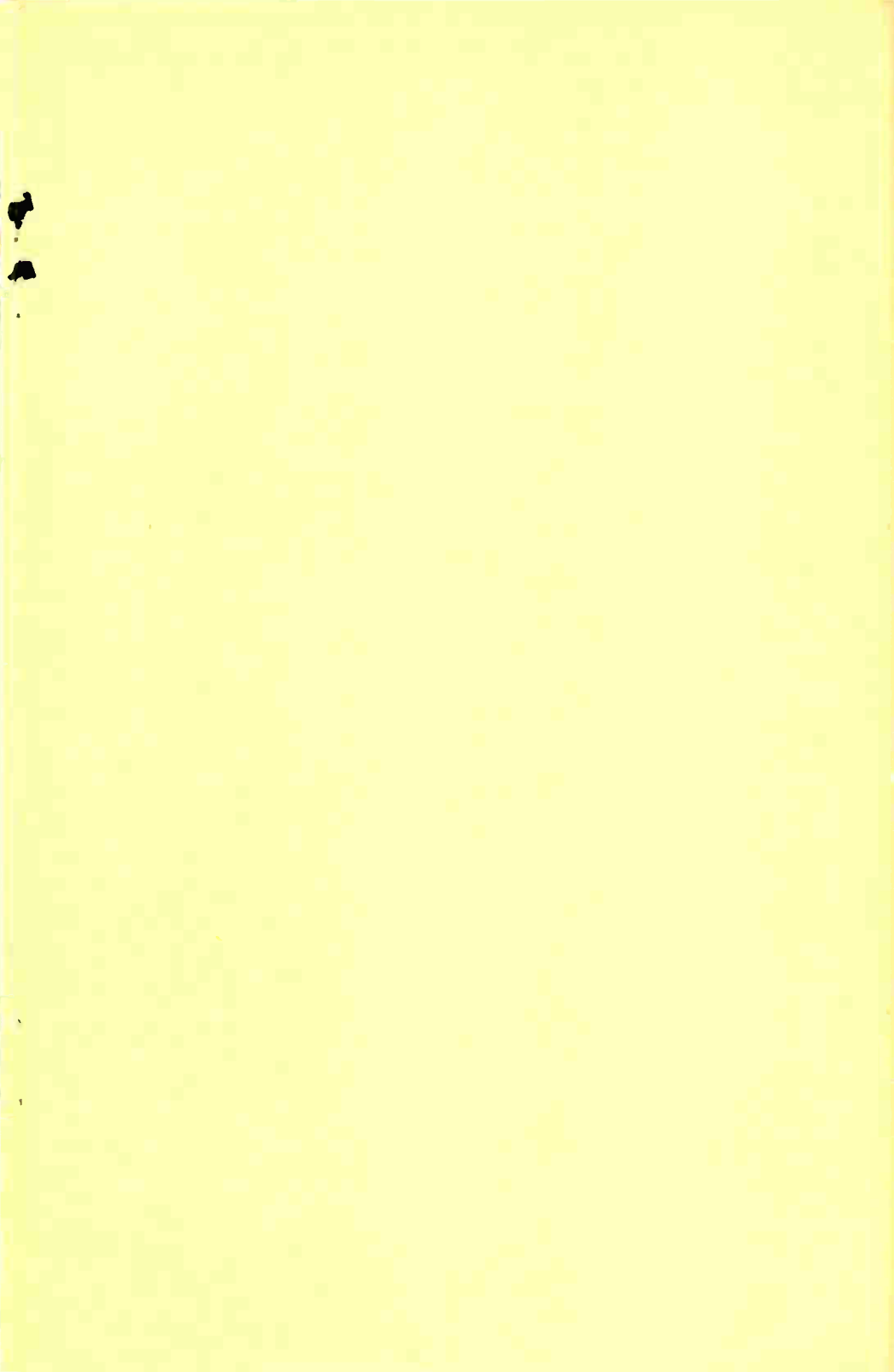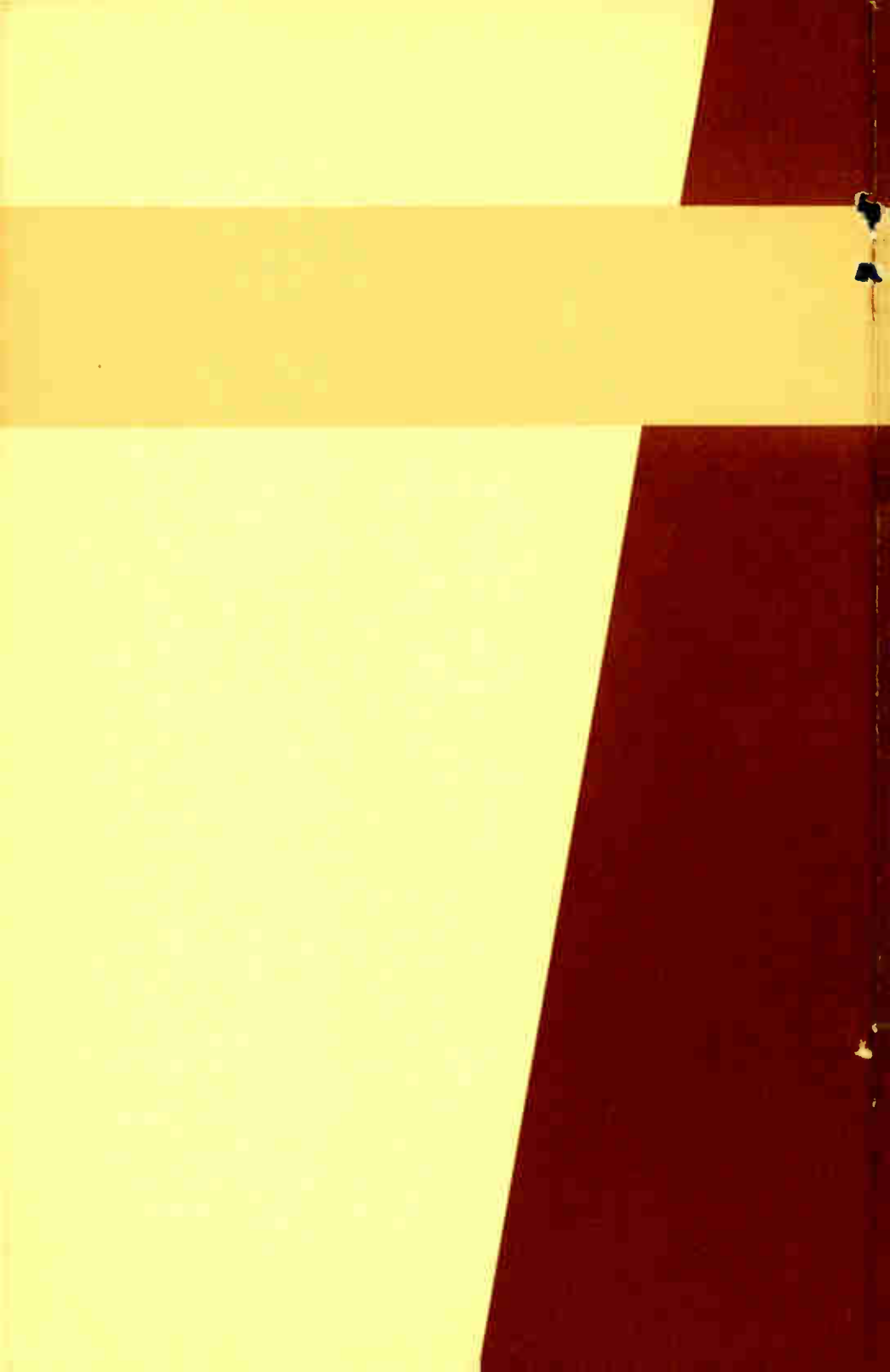
MICROPHONES

Lesson 4712

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OPPORTUNITY

3
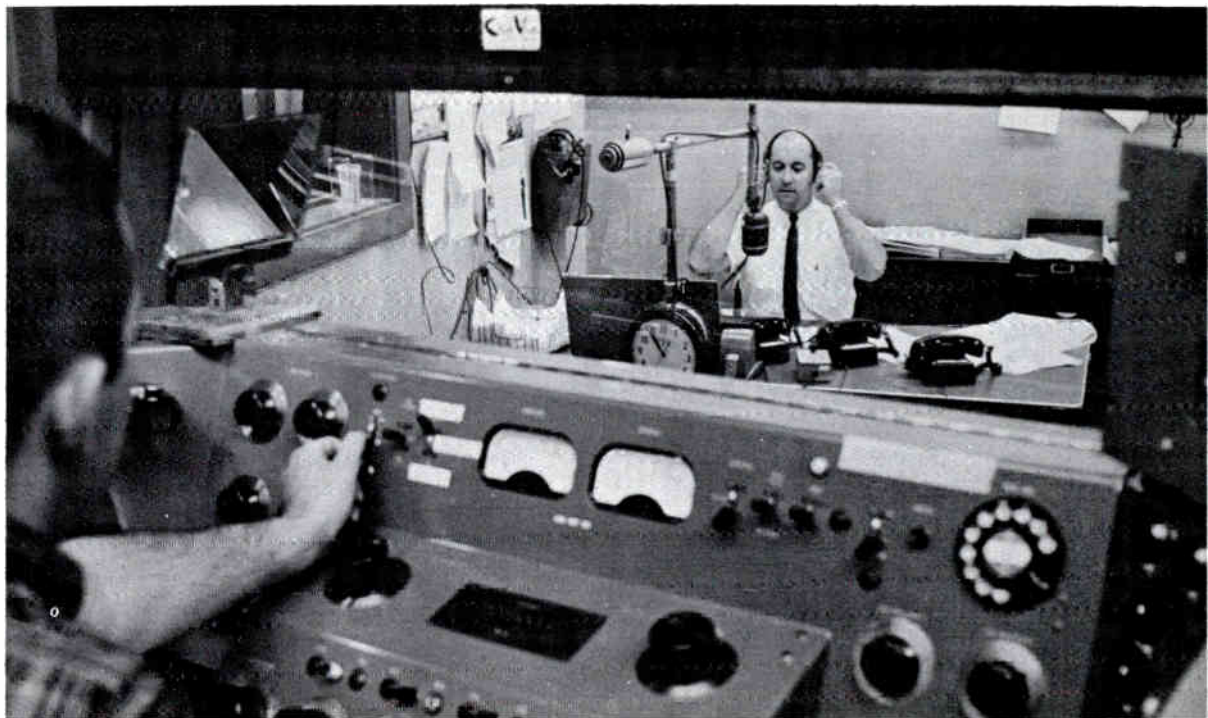
A central room view of a radio broadcast studio. The announcer speaks into a boom-mounted microphone, which is controlled by the operator at the audio console in the control room. The control room personnel use microphones to communicate with the announcer, who wears headphones for this purpose.

Courtesy WGN Radio

MICROPHONES

CONTENTS

****

TRIUMPH is just TRY with a little OOMPH.
--Sonik

MICROPHONES

A **MICROPHONE** is an input transducer used to convert sound energy to electric energy. This electric energy may be amplified and used to modulate a transmitter or drive a recorder. A knowledge of **SOUND** and **ACOUSTICS** will help you to understand the operation and uses of microphones. Therefore, this lesson describes some of the important principles of sound and acoustics, as well as the principles and characteristics of various types of microphones and the equipment used with microphones.

SOUND

Sound is produced by any vibrating body in contact with some medium capable of conducting the vibration. Vibrations of a given level in the frequency range from about 20 hertz (cycles per second) to about 20,000 hertz are audible, or can be heard by the normal human ear. Thus, the vibrational frequencies from 20 Hz (hertz) to 20,000 Hz are called the **AUDIO FREQUENCIES.**

Two properties of a medium that determine how well it will conduct sound are its elasticity and its density. **ELASTICITY** is the springlike quality of a material, or the tendency of the material to return to its original size or shape after being deformed. **DENSITY** is a measure of the number of molecules of a medium per given volume of the medium.

The greater the elasticity and the lower the density of a medium, the faster sound will travel through it. For example, sound travels at about 1088 feet per second (ft/sec) in air at 32°F, and it travels at about 4165 ft/sec in hydrogen gas (less dense than air and essentially the same elasticity) at 32°F. Although liquids and solids are denser than air, they are much more elastic than air. Thus, sound generally travels faster in liquids and solids than in air.

*   *   *

1. The frequencies between 20 Hz and 20,000 Hz are called the
    _____ frequencies.

2. What two properties of a medium determine how well it will
    conduct sound?

*   *   *

Sound can be transmitted through water, gases, metals and
many other types of material. However, we are primarily
interested in sound traveling through the air. Figure 1
shows the sound waves set up around a vibrating string, as
viewed from the end of the string. The vibration disturbs
air molecules near the string. These air molecules, in
turn, disturb other air molecules a little farther away from
the string, and so on. These waves move out from the
string in all directions.

As shown in Figure 1, the air molecules bunch up and thin
out in step with the vibrations of the string. That is, the
vibrating string compresses a large number of molecules
into a given space to form what are called COMPRESSIONS.
The spaces between the compressions contain fewer air
molecules than normal and form what are called RARE-
FACTIONS. Thus, the sound from the vibrating string is
transmitted by the air to a distant point (such as point A in
Figure 1) as a series of compressions and rarefactions.

As indicated in Figure 1, the distance between compressions
is the WAVELENGTH of the sound. The wavelength is in-
versely proportional to the frequency of the sound. That is,
the shorter the wavelength, the higher the frequency, and
the longer the wavelength, the lower the frequency.

*   *   *

3. A sound wave is made up of a series of_____and

    _____.

*   *   *

The compressions and rarefactions making up a sound wave have the ability to do work. For example, they may vibrate the diaphragm of a microphone. The ability of sound to do work is its **ACOUSTIC ENERGY.** The vibrating string in Figure 1 produces a certain amount of acoustic energy. If the amplitude of vibration of the string is made larger (say, by plucking the string harder), the string produces a greater amount of acoustic energy.

*   *   *

4. What is acoustic energy?

*   *   *

Acoustic energy may be divided into two components: the **PRESSURE COMPONENT** and the **VELOCITY COMPONENT.** The compressions and rarefactions of a sound wave represent variations in air pressure above and below normal atmospheric pressure: 14.5×10^{-6} pounds per square inch or one **MICROBAR.** These pressure variations make up the pressure component.

The instantaneous rate at which the pressure component changes is the velocity component. This is because the rate of change of air pressure at a given point determines the instantaneous velocity of air molecules at that point as the molecules vibrate about their rest positions in accordance with the sound.

*   *   *

5. The two components of acoustic energy are_____and _____.

*   *   *

Sounds differ from each other in three fundamental ways: loudness or intensity, pitch or frequency, and tone quality or waveform. These three properties make it possible for our ear to detect the difference between sounds coming from various sources.

Intensity and Loudness

The **INTENSITY** of a sound is the amount of acoustic energy
that flows through a given area each second. Thus, sound
intensity is usually given in units of watts per square centi-
meter (watts/cm^2).

Sound travels away from a sound source in all directions.
Therefore, the acoustic energy flows from a source in all
directions. Thus, any given
point receives only a small
part of the total acoustic ener-
gy produced by the sound
source. This causes the in-
tensity of the sound to vary in-
versely as the square of the
distance between the sound
source and the sound receiver.
For example, the sound re-
ceived one mile from a sound
source is only one-fourth as
intense as the sound received
a half-mile from the same
sound source.

R=RADIUS OF SOUND SHELL
A=INTERCEPTED AREA
I=ACOUSTICAL INTENSITY

This three-dimensional model illustrates the
variation of acoustical intensity with distance
from a point source of sound. The energy is
distributed over a greater area as distance in-
creases, and thus the intensity of the sound
varies inversely as the square of the distance
from the source.

The **LOUDNESS** of a sound, as
heard by the human ear, de-
pends on the intensity of the
sound as it enters the ear.
The intensity of the faintest sound that the normal ear can
detect, called the threshold of hearing, is 10^{-16} watt/cm^2.
The intensity at which most people begin to experience
physical pain, called the threshold of pain, is 10^{-4} watt/cm^2
or 10^{12} times the threshold of hearing.

Since the human ear responds logarithmically to sounds of
varying intensity, the loudness of a sound is usually given
in terms of decibels (dB) above the threshold of hearing.
Loudness is related to intensity by the following expression:

$$L = 10 \log \frac{I}{I_o} \qquad (1)$$

where   L is loudness in dB,

I is the intensity of the sound in $watt/cm^2$, and

I_o is the threshold of hearing (10^{-16} $watt/cm^2$).

The loudness levels of a number of common sounds are given in the table of Figure 2.

*   *   *

6. You measure the intensity of a sound to be 1 $watt/cm^2$. Calculate the loudness level of this sound. Will this sound cause physical discomfort to those who hear it?

*   *   *

Pitch and Frequency

The **PITCH** of a sound is determined by the rate of vibration of the sound source or the **FREQUENCY** of the sound wave. The standard piano keyboard covers a frequency range of from 27.5 Hz to 4186 Hz. Many other musical instruments, in addition to human voices, fall within the frequency range of the piano. This is shown in Figure 3.

The piano covers a wide range of pitches. Each key on the piano has a different note or pitch. Each key is assigned a letter from A through G. Each time a letter is repeated, it marks the beginning of a new octave. Each octave represents a doubling of pitch. For example, the pitch of the second A at the left in Figure 3 is twice the pitch of the A at the far left. That is, the frequency of the second A (55 Hz) is twice the frequency of the first A (27.5 Hz).

Tone Quality and Waveform

Notice in Figure 3 that many instruments are able to produce sound of the same pitch. For example, the piccolo, flute, clarinet, violin and trumpet each can produce a note

of 698.46 Hz. However, this note sounds quite different
when it is played on each of the five instruments mentioned.
This is due to the **TONE QUALITY** of each instrument.

Instruments produce overtones of the frequency to which
they are tuned. These over-
tones occur at multiples of the
fundamental frequency. Thus,
for a string vibrating at 20 Hz,
the first overtone is 2 x 20 Hz
or 40 Hz, the second overtone
is 3 x 20 Hz or 60 Hz, etc.
This results in a complex
sound wave consisting of the
fundamental plus its overtones.

The overtones affect the
WAVEFORM of the sound.
The exact waveform depends
on the number of overtones
and the intensity of each over-
tone. Each instrument pro-
duces its own particular num-

A comparison of the waveforms of sounds of the
same frequency produced by various sources.
These waveforms differ because of their har-
monic contents.

ber of overtones of various intensities. Thus, each instru-
ment produces a different waveform and sounds different.

MICROPHONE CHARACTERISTICS

Three important characteristics of microphones are output
level, frequency response, and directivity. The first of
these characteristics, **OUTPUT LEVEL,** is the ratio of
electrical power output to a given sound pressure input in
watts per microbar (watts/microbar). The output level of
a microphone is usually expressed in terms of decibels be-
low a reference level of one milliwatt per microbar or 10^{-3}
watt/microbar of input (at the rated impedance of the micro-
phone).

The actual output of a given microphone (as compared to
the output level) depends on the acoustic energy of the sound

source and the distance between the microphone and the source. The output level of a microphone may be calculated as follows:

$$D = 10 \log \frac{1}{1_o} \qquad (2)$$

where   D is the microphone output level in dB,

        1 is the output level of the microphone in watts per microbar, and

        1_o is the reference level (1 milliwatt/microbar or 10^{-3} watt/microbar).

For example, if the output level of a microphone is 10^{-8} watt/microbar, then the microphone's output level in dB is

$$D = 10 \log \frac{1}{1_o} = 10 \log \frac{10^{-8} \text{ watt/microbar}}{10^{-3} \text{ watt/microbar}}$$

$$= 10 \log \frac{10^{-8}}{10^{-3}} = 10 \log 10^{-5} = 10 \,(-5)$$

$$= -50 \text{ dB}$$

*   *   *

7.   The output level of a microphone you are testing is 10^{-6} watt/microbar. What is the output level of this microphone in dB?

*   *   *

Another important characteristic of a microphone is its **FREQUENCY RESPONSE.** The frequency response of a microphone indicates its ability to convert sounds of various frequencies into output variations of voltage or current. If the microphone output does not vary more than a few decibels (the dB variations permissible depend on the application and operating conditions) in a given frequency range, the microphone is said to be "flat" in that range. This, of course, assumes the same sound level at all frequencies.

For example, the microphone represented by the response curve of Figure 4A is flat from 20 Hz to 10,000 Hz.

It is usually desirable that the response curve of a microphone does not contain ragged peaks as in the response curve of Figure 4B. Many broadcast transmitters (such as single sideband) automatically limit their output, so that the radiated power does not exceed the limit set by the FCC. If there are ragged peaks in the frequency response curve of a microphone, the peaks will determine maximum output. Thus, the average output will be far below that which is permissible.

In some communications applications a microphone with a flat frequency response from 60 Hz to 8000 Hz, for example, is adequate. In other applications, such as professional recording, a microphone with a wide, flat frequency response of from 20 Hz or lower to 20,000 Hz or higher is necessary.

An omnidirectional microphone designed for use in TV, AM and FM broadcasting and professional recording. The frequency response is from 40 Hz to 20,000 Hz.
Courtesy Shure Brothers, Inc.

A third important characteristic of a microphone is its DIRECTIVITY. The directivity of a microphone is its ability to pick up sounds from different directions.

The pickup characteristics of a typical OMNIDIRECTIONAL MICROPHONE for three frequencies are shown by the three patterns in the graph of Figure 5A. 0° is the direction directly in front of the microphone. 0 dB (indicated by the circle next to the outside circle) is arbitrarily chosen as the

maximum intensity level picked up by the microphone. Each succeeding circle, moving toward the center, indicates a 5 dB reduction in output.

This microphone receives 1 kHz sounds equally well from all directions, as shown by the solid line pattern. This is also true to a lesser extent at 5 kHz, which is represented by the dashed line pattern. However, the pickup becomes quite unidirectional (one-directional) at 10 kHz, which produces the dotted line pattern. For example, point A in Figure 5A shows that the output level at 10 kHz is -10 dB (down 10 dB) in the 105° direction.

Figure 5B shows the directivity characteristics of a typical CARDIOID MICROPHONE. The word cardioid refers to the heart-shaped directivity characteristics of this microphone. ("Cardioid" comes from the Greek "kardia" meaning heart.) The pickup of a cardioid microphone is somewhat unidirectional at all frequencies.

Finally, Figure 5C shows the pickup characteristics of a typical BIDIRECTIONAL MICROPHONE. The bidirectional microphone receives sound equally well from either front (0°) or rear (180°). However, it picks up practically no sound from either side.

A device capable of adding a highly unidirectional pickup characteristic to any microphone is the PARABOLIC REFLECTOR, a cross-section of which is shown in Figure 6. The shape of the reflector is such that sounds traveling parallel to the axis are all focused to one point. The microphone is placed at this point so it receives all the sound energy focused at it by the reflector.

Reflectors are often used in outdoor recording or broadcasting situations. For example, they are very popular for sound pickup at football games and similar events. At a football game, the sound man on the sidelines can aim the reflector at the players and pick up the quarterback's signals and other sounds of the game that would otherwise be drowned out by the crowd noise.

MICROPHONE TYPES

All microphones have the same general purpose: to produce variations of electrical energy when they are subjected to variations of acoustical energy. Various types of microphones can be classified according to how they are affected by acoustical energy and how they produce variations of electrical energy. First, let's consider the ways in which microphones may be affected by acoustical energy. From this standpoint there are two main classes of microphones: pressure microphones and velocity microphones.

A **PRESSURE MICROPHONE** is one in which the pressure components of sound waves actuate the operating mechanism. Dynamic, piezoelectric, condenser, and carbon types are all forms of pressure microphones. The dynamic and piezoelectric microphones contain generating elements. The condenser and carbon microphones do not generate an output. Rather, their properties of capacitance and resistance, respectively, vary in accordance with the pressure component of a sound. These variations control a bias voltage or current produced by a separate power supply.

A **VELOCITY MICROPHONE** is one in which the velocity components of sound waves actuate the operating mechanism. A velocity microphone contains a generating element similar to that of the dynamic pressure microphone.

Dynamic Microphone

A microphone that operates by the principle of electromagnetic induction is the **DYNAMIC MICROPHONE**. Figure 7A is a cross-sectional view of a simplified dynamic microphone. The diaphragm is a thin, dome-shaped object that will yield to slight variations in pressure. A lightweight, cylindrical coil form is attached to the hollow side of the diaphragm (see Figure 7A). This assembly is suspended over one pole of a permanent magnet by the diaphragm. The diaphragm is mounted within a ring support that rests on the other pole of the permanent magnet as in Figure 7A.

In a dynamic microphone, the diaphragm vibrates in step with the acoustic energy striking the diaphragm. This causes the coil attached to the diaphragm to cut the flux lines between the poles of the permanent magnet. By elec- tromagnetic induction, this cutting induces an emf across the coil that also varies in step with the incoming sound waves. Thus, the dynamic microphone is a form of gen- erator: it converts mechan- ical and acoustical energy to electrical energy.

It is interesting to note that the construction and operation of the dynamic microphone is similar to that of a speaker. Signal currents in the voice coil of a speaker set up a vary- ing magnetic field that inter- acts with the field of the per- manent magnet. This inter- action causes the diaphragm to vibrate in step with the signal and, thus, produce acoustical energy. Because of the simi-

A unidirectional dynamic microphone for studio use. This microphone can be mounted on a boom, or in a desk mount as shown here. Courtesy Shure Brothers, Inc.

larity in operating principles, a single moving coil element is used as a speaker and a microphone in many intercoms and walkie-talkies.

*   *   *

8. What is the operating principle of a dynamic microphone?

9. If the dynamic microphone acts as a generator, then the dy- namic speaker acts as a _____.

*   *   *

The construction of the dynamic microphone in Figure 7A

is relatively simple. However, a practical dynamic micro-
phone must contain a number of mechanical refinements for
good operation.   For example, something must be done
about the mechanical resonant characteristics of the micro-
phone, which tend to produce poor frequency response.

Figure 7B shows a cross-sectional view of a practical
microphone.   When sound waves cause the diaphragm to
vibrate, it will tend to vibrate at its natural resonant fre-
quency, which is determined by the mass and the stiffness
of the diaphragm.   If the mechanical resonance of the dia-
phragm occurs in the audio frequency range, the speech or
music variations at the output of the microphone will be
distorted.   Thus, the dynamic microphone is usually de-
signed such that the mechanical resonant frequency of the
diaphragm is above the audio frequency range.

The frequency response of a typical dynamic microphone
for high quality recording and broadcast use may be from
20 cps to 20,000 Hz.   The ruggedness and good frequency
response of the dynamic microphone make it one of the pre-
ferred types in recording and broadcast work.

<div align="center">*   *   *</div>

10. Why are most microphone diaphragms designed such that
    their natural resonant frequencies are above the audio range?

<div align="center">*   *   *</div>

A typical dynamic microphone produces a low output voltage
(about 0.01 volt is typical).   Therefore, an amplifier is
normally used with a dynamic microphone.   The dynamic
microphone has a low impedance.   To obtain maximum
power transfer, the amplifier must present a low input im-
pedance to the dynamic microphone.   A common emitter
transistor amplifier such as the one shown in Figure 8A has
a low input impedance, which meets the impedance match-
ing requirements of many dynamic microphones.   On the
other hand, a conventional tube amplifier has a high input

impedance.   Thus, a transformer of suitable turns ratio is

normally used to couple a dy-
namic microphone to a com-
mon cathode tube amplifier as
in Figure 8B.

Some microphones have built-
in impedance matching trans-
formers.   However,   these
built-in transformers are used
to convert the physical imped-
ance of the generating or con-
trolling element to a standard
high impedance (hi-Z) or low
impedance (lo-Z) value.   If
the amplifier to be used has a
different input impedance than
the one presented by the inter-
nal microphone transformer,
an additional matching trans-
former may be required to
match the microphone to the
amplifier.   In addition to
built-in impedance matching

An omnidirectional dynamic microphone for
broadcasting of both music and speech. This
microphone has an output impedance of 150
ohms.

Courtesy Gates Radio Company

transformers, some microphones have built-in amplifiers.

*   *   *

11. Why is a transformer usually used to couple a dynamic micro-
     phone to a grounded cathode tube amplifier?

*   *   *

Piezoelectric Microphone

A number of crystalline substances have the ability to pro-
duce electric current or voltage when pressure is applied.
For example, if mechanical pressure is applied to a crys-
tal mounted between two electrodes, a voltage will appear
across the electrodes.   This property is called piezoelec-
tricity, and it is the operating principle of the PIEZOELEC-
TRIC MICROPHONE.

*   *   *

12. The operation of a crystal microphone depends on (a) the
    piezoelectric effect, (b) the photoelectric effect, (c) elec-
    tromagnetic induction.

*   *   *

Two major classes of piezoelectric microphones are the
crystal microphone and the ceramic microphone. In a
CRYSTAL MICROPHONE, the mechanical pressure is the
result of sound waves striking the crystal element, and the
resultant voltage is used as the signal for an amplifier.
Rochelle salts are widely used crystal microphone generat-
ing elements. For the same applied pressure they produce
a higher output voltage than other crystal elements.

Most microphone elements are made up of two Rochelle salt
crystal slabs adjacent to one another. This is known as a
BIMORPH ELEMENT. The advantages of bimorph elements
over single crystal elements are: a bimorph element can
be made in a more convenient shape, it is affected less by
temperature variations, and it is a more sensitive element.

*   *   *

13. What are the advantages of a bimorph crystal element over a
    single-crystal element?

*   *   *

There are two types of crystal microphones: the directly
actuated type and the diaphragm actuated type. In the di-
rectly actuated type, sound pressure acts directly on the
crystal. In the diaphragm actuated type, the sound pres-
sure acts on a diaphragm which is mechanically coupled to
the crystal.

A cross-sectional view of a directly actuated crystal micro-
phone, or sound cell, is shown in Figure 9. A thin bimorph
crystal element with a metal foil electrode is attached to
each side of a bakelite frame. The bimorph element is in

an air-tight chamber that allows the element to vibrate freely in step with acoustic energy variations.

When sound waves approach the microphone, the two sections of the bimorph element vibrate in phase with each other to produce an output voltage that follows the variations of

CRYSTAL AND DRIVE PIN ASSEMBLY

DIAPHRAGM

DAMPING PLATE AND ACCOUSTIC DAMPING MATERIAL ASSEMBLY

GRILLE

CASE TOP

TERMINAL LUGS

CASE BOTTOM

CABLE AND STRAIN RELIEF ASSEMBLY

STAND AND NECK CORD ASSEMBLY
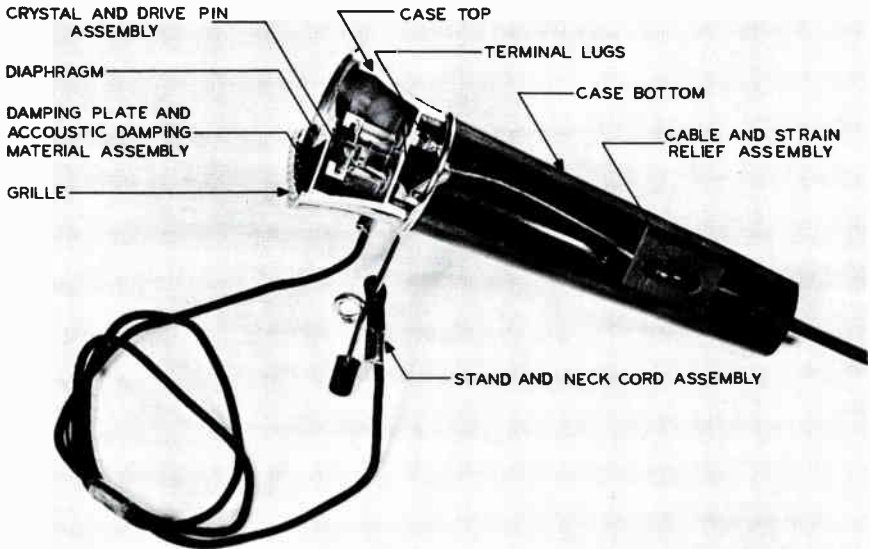
A cutaway view of a high impedance crystal microphone with the parts identified. This unit is equipped with a neck cord such as those used in interviews.

Courtesy American Microphone Manufacturing Co.

the incoming sound waves. However, mechanical shocks are not likely to produce in-phase voltages. Thus, the output of a sound cell is relatively noise free.

Sound cells are usually designed so their natural resonant frequency is in the ultrasonic range. As a result, there are no unwanted resonant peaks in the upper audio frequencies, so the microphone provides good high frequency response. The output voltage of a single sound cell is very low, and the impedance is very high. However, by connecting sound cells in series and parallel, it is possible to

produce a wide range of output voltages and impedances.

Figure 10 shows a cross-sectional view of a diaphragm-actuated crystal microphone. The conical diaphragm in Figure 10 effectively amplifies the incoming sound pressure by focusing it on a small area. Thus, more force per small area is exerted on the crystal element than is applied to the diaphragm. This is also greater than that which is exerted on the element in a sound cell for the same sound pressure. Thus, the output is greater than that of a sound cell. However, the frequency response is more ragged than that of the sound cell.

The impedance of a crystal microphone is quite high, so an amplifier must present a high input impedance to this type of microphone. The transistor amplifier in the common emitter circuit of Figure 11A has a lower input impedance than desired. Therefore, this circuit requires a transformer for efficient coupling of the crystal microphone to the amplifier. A common cathode tube amplifier has a high input impedance and meets the impedance matching requirements of the crystal microphone without any transformer.

The crystal microphone has a very high resistance to direct current. Therefore, resistor R_1 in Figure 11B is used to complete the grid-cathode bias circuit.

A **CERAMIC MICROPHONE** is similar to the crystal microphone in its characteristics. A ceramic microphone uses a ceramic element of barium titanate in place of the Rochelle salt element of the crystal microphone. The ceramic element is not as greatly affected by temperature and humidity variations as the crystal element.

*   *   *

14. The impedance matching conditions for a ceramic microphone are just the reverse of those for a dynamic microphone. True or False?

*   *   *

Condenser Microphone

The **CONDENSER MICROPHONE** is basically a variable capacitor. This variable capacitor is made up of a lightweight metal diaphragm and a fixed metal backplate with air as the dielectric. The construction of a condenser microphone is illustrated in Figure 12. A dc voltage must be applied to this type of microphone since it does not contain a generating element as the dynamic or piezoelectric type does.

*   *   *

15. The condenser microphone is a variable_____.

*   *   *

Figure 13 shows a typical condenser microphone circuit.
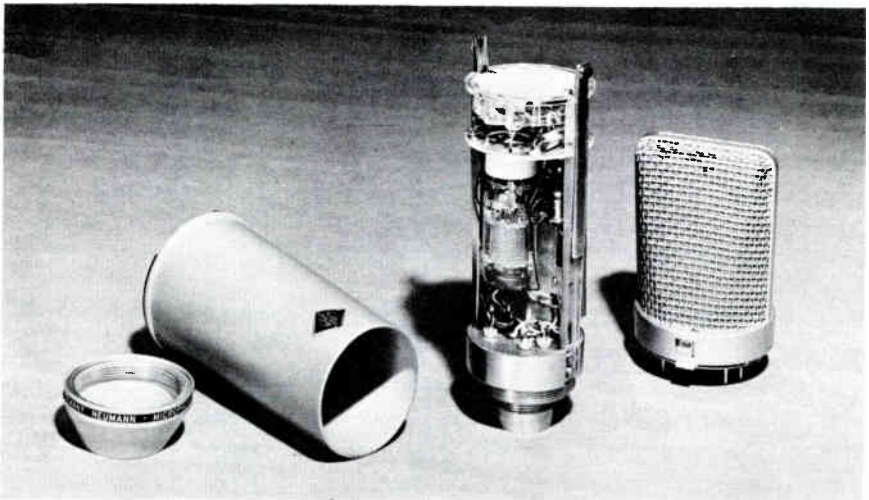
This high quality condenser microphone, designed for studio use, includes a built-in amplifier. The unit is disassembled in this photograph to show the amplifier arrangement.

Courtesy Gotham Audio Corporation

Condenser microphone M_1 is connected in series with resistor R_1 and dc microphone bias supply E_M. When the

circuit is closed, the condenser microphone charges to the bias voltage value. Then, as variations of sound pressure move the diaphragm, the capacitance of the microphone changes. As the capacitance of the microphone changes, the voltage across the microphone also changes. Thus the capacitance of the microphone controls the bias voltage.

To see how this occurs, let's look at the expression for voltage across a capacitor:

$$E = kQd \qquad (3)$$

where   E is the capacitor voltage,
          k is a constant determined by the area of the capacitor plates,
          Q is the charge on the capacitor, and
          d is the distance between the plates.

When the microphone diaphragm (one plate of the capacitor) moves, the distance d changes. However, k does not change, and the charge Q cannot change rapidly. Therefore, a change of distance between the plates causes a change of voltage across the capacitor. For example, when a rarefaction strikes the diaphragm, the diaphragm moves away from the backplate and d increases, causing E to increase. Similarly, when a compression strikes the diaphragm, the diaphragm moves toward the backplate and d decreases, causing E to decrease.

If the diaphragm moves or vibrates at an audio rate, the voltage across the capacitor varies at an audio rate. Thus, an ac voltage of audio frequency is produced and applied to the grid of tube V_1 in Figure 13. This voltage corresponds to the incoming sound waves.

*   *   *

16. The voltage across the plates of a condenser microphone will (a) increase, (b) decrease when the diaphragm is activated by a compression.

*   *   *

Carbon Microphone

A **CARBON MICROPHONE** is essentially a variable resistor, and not a generating element. Like the condenser microphone, the carbon microphone needs a dc bias supply to produce an output signal.

There are two types of carbon microphones: the single-button type and the double-button type. Figure 14 shows a cross-sectional view of a single-button carbon microphone. The conical diaphragm is supported at its outer edge, so that the curved central portion projects into a cup filled with carbon granules. The resistance of the carbon cup depends on how densely the carbon granules are packed. The more densely packed the carbon granules, the lower the resistance of the carbon cup.

When a rarefaction hits the diaphragm, the carbon granules become less densely packed than normal and the resistance increases, causing the bias current to decrease. When a compression hits the diaphragm, the carbon granules become more tightly packed and the resistance decreases, causing the bias current to increase. Thus, the base current of the transistor amplifier in Figure 15A or the secondary voltage of the transformer in Figure 15B varies in step with the incoming sound waves.

*   *   *

17. When a compression strikes the diaphragm of a single-button carbon microphone, the resistance of the carbon cup (a) increases, (b) decreases.

*   *   *

As the diaphragm returns to its rest position after being depressed, the air in the space behind the diaphragm becomes rarified and holds back on the diaphragm. This loading of the diaphragm is controlled by the pressure equalization hole. The lower the frequency of an incoming sound wave, the more time the air has to escape through the

pressure equalization hole.   Thus, the reduction in back pressure is proportional to the period of the incoming sound wave.   This improves the low frequency response of the microphone.   Even with this improvement, however, the frequency response of the single-button carbon microphone is quite limited and very ragged.

*   *   *

18. The pressure equalization hole in the diaphragm of a single-button carbon microphone improves the (a) high frequency response, (b) low frequency response.

*   *   *

Since the impedance of a single-button carbon microphone is low, this microphone normally presents the same matching problems as the dynamic microphone.   However, the output developed by a carbon microphone may be as high as 1 volt.   Because of this high output, the microphone is sometimes coupled directly to the input of a tube amplifier.

*   *   *

19. The matching conditions for a single-button carbon microphone are just the reverse of those for a dynamic microphone.   True or False?

*   *   *

Figure 16 shows a cross-sectional view of a double-button carbon microphone.   This type of microphone uses two buttons or cups of carbon.   The backplate of Figure 16 is the main supporting member of the microphone, and it is hollowed out to provide a damping chamber that prevents excessive vibration of the unit.   The rear button assembly is supported by a circular metal disk that is connected mechanically (but not electrically) to the rear of the backplate. This disk is electrically connected to the rear button assembly.

A thin, circular metal diaphragm is clamped securely be-

tween the backplate and the clamping ring.   The diaphragm
is stretched tightly by the stretching ring.   This stretched
condition improves the high frequency response of the diaphragm.

A carbon microphone used primarily in voice transmission, as in mobile communications.
Courtesy Shure Brothers, Inc.

The front button assembly in Figure 16 is held in place by a bridge-like structure connected mechanically to the clamping ring. The bridge-like structure is electrically connected to the front button assembly.

The electrical circuit of a double-button carbon microphone feeding an amplifier is shown in Figure 17. The two carbon cups are connected in a push-pull arrangement through the center tap of transformer T_1. When there is no sound input, the currents through the two cups are equal in magnitude but opposite in direction. The resulting fluxes in the transformer neutralize each other.

When sound waves passing through the bridge strike the diaphragm, the resistance of one cup increases, while the resistance of the other decreases. The resulting current variations produce a push-pull action in the primary of transformer T_1. The fluctuating field in the primary induces a voltage in the grid circuit of V_1 that varies in step with the incoming sound waves.

This push-pull arrangement of the double-button type provides less distortion and a smoother frequency response than can be obtained with the single-button microphone.

*   *   *

20. The diaphragm of a double-button carbon microphone is
    stretched to improve the microphone's (a) low frequency
    response, (b) high frequency response.

*   *   *

Because each tiny carbon granule is separate from each
other one, arcing continually occurs between the granules
in a carbon microphone. Some-
times this arcing may cause
excessive heat, which may
fuse the carbon granules to-
gether. The carbon granules
in the fused state form nothing
more than a fixed resistor.
Thus, the current through the
button remains constant, and
no signal is developed across
the input of the amplifier.

In addition to arcing, other
causes of carbon fusing or
packing are: opening the mi-
crophone when there is current
flowing through it, jarring the
microphone while it is in use,
allowing moisture to accumu-
late in the element, and shout-
ing into the microphone.

Velocity Microphone

A bidirectional velocity microphone used for
interviews, combined pickup of instrumental
groups, and similar applications.
Courtesy Shure Brothers, Inc.

A microphone in which the
electric response corresponds
to the velocity component of a sound is called a VELOCITY
MICROPHONE. Figure 18 shows two cross-sectional views
of a velocity microphone. The metallic-ribbon generating
element is suspended between the pole pieces of two per-
manent magnets. Because of this construction, the velocity

microphone has a pickup characteristic similar to the bi-directional characteristic shown in Figure 5C.

Like the dynamic type, the velocity microphone operates by the principle of electromagnetic induction. Incoming sound waves cause the metallic ribbon to vibrate in the magnetic field. This induces a voltage in the ribbon that varies in step with the incoming sound waves.

Since the resistance of the ribbon is but a fraction of an ohm, the matching conditions for a velocity microphone are essentially those of the dynamic microphone. The velocity microphone also has the wide frequency response needed for high quality recording and broadcasting.

*   *   *

21. The characteristics and matching conditions of a velocity microphone are very similar to those of a dynamic microphone. True or False?

*   *   *

MICROPHONE RATINGS

Now that you have studied microphone characteristics and types you should be able to appreciate the ratings that most manufacturers give for their microphones. These ratings include: classification (type and directivity), frequency response, output level, and impedance. Typical microphone ratings are listed for a few microphones in the table of Figure 19.

The microphones in the table of Figure 19 are representative of the various types discussed earlier. The omnidirectional condenser microphone has a frequency response of 20 Hz to 20,000 Hz, an output level of -50 dB, and an impedance of 600 ohms. This microphone is of high quality as compared to the omnidirectional carbon microphone, which has a frequency response of 95 Hz to 6000 Hz. The carbon microphone, however, has the advantage of a rela-

tively high output level (-30 dB). This output level is actually 100 times that of the condenser microphone.

Data such as that in Figure 19 is very useful in selecting a microphone for a given application, or in selecting equipment for use with a given microphone. For example, if high fidelity reproduction is the main requirement, and sound level is no problem, the velocity or condenser microphone would be a good choice. Where high sensitivity is the main consideration, and frequency response is not too critical, the best choice would probably be the carbon microphone, or perhaps the dynamic microphone.

*   *   *

22. Referring to the table of Figure 19, the output level of the carbon microphone is_____dB above the output level of the ceramic microphone.

*   *   *

MICROPHONE COUPLING EQUIPMENT

We have seen that the output of a microphone usually must be amplified before it is useful. Cables, impedance matching transformers, and equalizers are devices commonly used to couple microphones to amplifiers.

Microphone Transmission Lines

Figure 20 shows a type of cable commonly used to connect a remote microphone to the input of an audio amplifier. The stranded wire which serves as one conductor of the cable is surrounded by two layers of braided cotton insulation. There is a braided copper shield around these layers of braided cotton. The braided copper shield is used as the ground connection of the cable. It is covered by a thick layer of rubber insulation. The copper shield is normally grounded at the equipment to prevent stray fields from inducing undesirable noise voltages in the inner copper wire.

*   *   *

23. Why are microphone transmission lines shielded?

*   *   *

Because of its construction, shielded microphone cable or
transmission line exhibits a capacitive effect. The stranded

A condenser microphone in a suspension type mount. The element (left end) is covered by a "blast
filter" to prevent sharp sounds from overloading the microphone. The shielded cable at the right
connects the microphone to its auxiliary units.

Courtesy Siemens American, Inc.

wire and the copper shield form the two plates of a capaci-
tor, and the layers of insulation between them form the di-
electric. The longer the cable, the larger the area of the
"plates". Thus, the longer the cable, the greater the ca-
pacitive effect.

As the length of the cable and/or the frequency of the trans-

mitted signal increases, the capacitive reactance of the transmission line decreases. Thus, while all audio signals are attenuated by a long transmission line of given length, the relatively high frequency signals are more sharply attenuated than the low frequency signals. An increase in the spacing between the stranded wire and the copper shield will decrease the cable's capacitive effect. However, there are practical limits to the diameters of microphone cables.

*   *   *

24. What causes a shielded cable to act as a capacitance?

*   *   *

Figure 21 shows an equivalent circuit for the coupling of a microphone to the input of a tube amplifier by a microphone transmission line. The generator symbol at the left represents the property of the microphone to generate a signal voltage E_M. R_M represents the internal impedance of the microphone, C the capacitance of the transmission line, and R_{IN} the input impedance of the amplifier. For maximum power transfer, we make $R_{IN} = R_M$.

With the circuit of Figure 21, we will investigate two conditions of signal loss due to the cable capacitance. First, if R_M is a high impedance as in a ceramic microphone; and second, if R_M is a low impedance as in a dynamic microphone.

If R_M is high, R_{IN} would normally be high also, to obtain maximum power transfer from microphone to amplifier. However, at high frequencies the capacitance C of the cable presents a low reactance which shunts R_{IN}. Under this condition, most of the voltage E_M developed by the microphone is lost across the high impedance of R_M, and very little appears across the amplifier input impedance R_{IN}. This loss is greatest at high frequencies and least at low frequencies. Therefore, the capacitance of the cable causes a decrease in high frequency output. If the values of R_M

and R_{IN} are hundreds of thousands of ohms, even compara-
tively low capacitance cable can cause severe losses.

*   *   *

25. In coupling a high impedance microphone to a grounded cath-
ode tube amplifier, the capacitive reactance of the shielded
cable causes a sharp attenuation of the_____frequencies.

*   *   *

Now let's consider a microphone with low internal imped-
ance R_M. In a low impedance microphone, R_M might have
a value from 50 ohms up to 500 or 600 ohms. For maximum
transfer of energy, R_{IN} would be a similar value. The re-
actance of capacitance C is now much less important. Un-
less this reactance decreases to a value of 1000 ohms or
so, it can be neglected. This means a much longer cable
can be used before capacitance becomes bothersome.

*   *   *

26. In coupling a low impedance microphone to an amplifier with
low input impedance, the capacitive reactance of the shielded
cable can usually be neglected, if it remains above approxi-
mately 1000 ohms at the signal frequencies. True or False?

*   *   *

Impedance Matching Transformers

The ideal choice for very long lines is a transmission line
having a characteristic impedance matched to the micro-
phone and also the load: for example, a 50 ohm micro-
phone connected to a 50 ohm line which, in turn, connects
to an amplifier with 50 ohms input impedance. When a
transmission line is terminated with resistance equal to its
characteristic impedance, it reflects the same impedance
to the source (the microphone). This produces maximum
energy transfer and minimum high-frequency loss.

It is possible to obtain low impedance advantages with some

fairly high impedance microphones through impedance
matching transformers. In
such cases we use transform-
ers to match the line to the
microphone and load. For ex-
ample, suppose we wish to
couple a 50,000 ohm micro-
phone to a 50 ohm line. To do
this, we use a transformer
with a turns ratio of

$$\sqrt{50,000/50} = \sqrt{1000} = 32.$$

Notice, the turns ratio is equal
to the square root of the ratio
of the impedances we wish to
match.

The transformer of this exam-
ple would be used as a step-
down transformer from micro-
phone to line. A similar trans-
former could be used at the
output end of the line to match
an amplifier with an input
impedance of 50,000 ohms. In
this case, however, the trans-

This dynamic microphone provides a choice
of three output impedances: 50 Λ, 250 Λ, or
high impedance.

Courtesy Electra-Voice, Inc.

former would be reversed to act as a step-up transformer.

Equalizers

Line losses can be compensated for, to some extent, by a
circuit called an EQUALIZER. An equalizer is a network
that can be adjusted to give desired frequency characteris-
tics. By the use of R, L and C components, the equalizer
can attenuate the lows to the same degree that the cable ca-
pacitance attenuates the highs. With such an arrangement,
the highs and lows may have the same relative intensities
with which they left the microphone. This usually results
in a loss at all frequencies, so additional amplification may
have to be added.

A typical equalizer circuit is shown in Figure 22. Here the LC network resonates near the high end of the desired frequency range, where the line normally causes attenuation (for example, 10,000 Hz). When variable resistor R is completely shorted by the sliding contact, the LC network offers a very high impedance at 10,000 Hz, but shunts the lower frequencies. As R increases, the effect of the LC network decreases, and the low frequencies are attenuated less. Thus, the setting of resistor R controls the attenuation curve of the equalizer.

*   *   *

27. An equalizer is a network that gives the effect of boosting the frequencies that are normally attenuated by line losses. True or False?

*   *   *

ACOUSTICS

It is the job of the microphone to produce an electrical output that is a faithful reproduction of the sound input. However, a microphone cannot overcome distortion produced in the sound as it travels from the source to the microphone. Only the effective application of the principles of acoustics can reduce such distortions. ACOUSTICS is the science that deals with the production, conduction, and control of sound. We have already seen that sound is produced by vibrating bodies, and that sound is conducted by elastic media. Now, we will discuss some methods of controlling sound.

When sound waves strike a surface, they may be absorbed, conducted or reflected by the surface. If sound waves of a relatively high frequency are reflected from a surface, the angle the reflected waves make with a line perpendicular to the surface (angle of reflection) will be equal to the angle the original waves make with the same perpendicular line (angle of incidence). This is shown in Figure 23.

Almost every type of surface reflects sound to some degree.

These reflections are the major cause of most acoustic problems encountered in recording and broadcast studios. Some reflections produce echoes. It has been found by experiment that a distinct, separate echo is heard if the reflected wave reaches the ear 0.1 second after the direct wave. Echoes sometimes result in confusion and loss of intelligibility when a person is speaking. However, a certain amount of echoing may enhance the sound of music.

Since the speed of sound is approximately 1130 ft/sec at room temperature, a sound must cover a round-trip distance of 1130 ft/sec × 0.1 sec = 113 ft to be perceived as an echo. Therefore, the one-way distance is 56.5 feet. Thus, in general the maximum distance from a speaker to the opposite wall of a room cannot exceed 56.5 feet if loss of intelligibility is to be minimized. Larger rooms may be used for speaking if they are acoustically correct.

<div align="center">*   *   *</div>

28. If loss of intelligibility is to be minimized, the distance from a speaker to the opposite wall of a room cannot exceed_____ feet.

<div align="center">*   *   *</div>

The echoing action of a room does not stop after one echo; the echo just decreases in intensity. Multiple echoes are called REVERBERATIONS. The time required for the intensity of a sound to drop 60 dB after the original sound has stopped is called REVERBERATION TIME. Long reverberation time gives a room a "live" atmosphere, while short reverberation time gives a room a "dead" atmosphere.

<div align="center">*   *   *</div>

29. The reverberation time of a room is the time required for the intensity of a sound to drop_____dB after the original sound has stopped.

<div align="center">*   *   *</div>

The reverberation time of a room or studio may be altered

by the placement of sound absorbing panels in strategic lo-
cations. In other cases, the studio may be specially de-
signed with walls set at a slant to each other (rather than
set perpendicular or parallel) to reduce reflections.

MICROPHONE PLACEMENT

Even in an acoustically corrected studio, the type of micro-
phone being used and the microphone placement both have a
bearing on the quality of broadcast or recorded sound. The
following paragraphs illustrate a few typical microphone
placement problems.

The conversation of people on a "talk" program or a panel
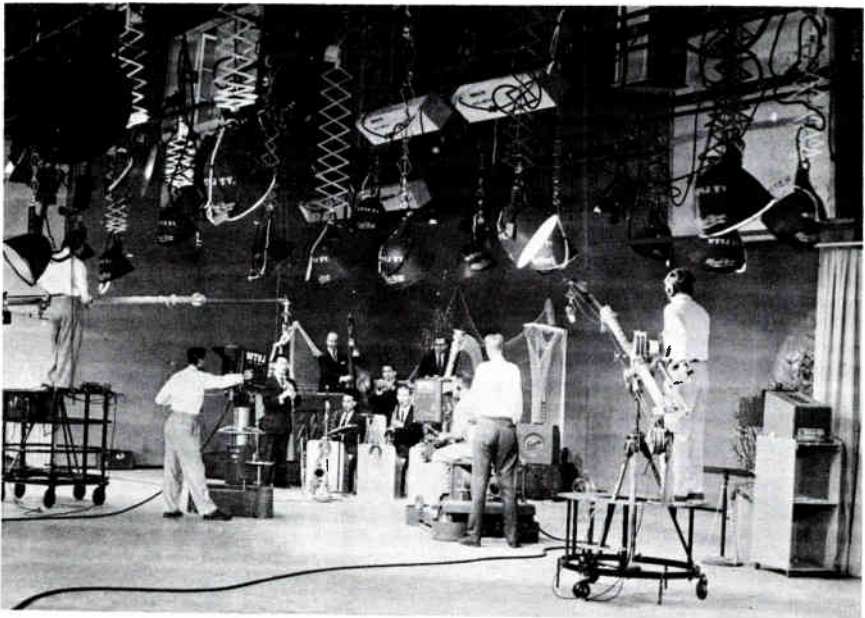
TV viewers rarely see "behind-the-scenes" activity such as that shown in this photograph. Camera-
men pick up the visual part of the program while the audio men operate the mike booms to pick up
the sounds of this small orchestral group.

Courtesy Station WTVJ

discussion program may be picked up in several ways. For

example, each member of the group may have his own microphone. However, such an arrangement may be impractical. Another arrangement is shown in Figure 24A. Here a bidirectional microphone is used to pick up the conversation from two sides of a large coffee table at which the conversants are seated. In another case, Figure 24B shows two unidirectional microphones each picking up one side of a debate.

The pickup of piano tones is an interesting problem. The bass tones, played at the low frequency end of a grand piano keyboard, are usually produced with greater amplitude than the treble tones. Thus, if a microphone is centered on the piano, the bass notes are dominant in the reproduction. To compensate, the microphone should be placed nearer the treble side of the piano as in Figure 25.

The microphone pickup of orchestral music presents quite a problem because of the varied conditions associated with instrumental groups. Instrumental groups range in size from trios and quartets to symphony orchestras with more than a hundred musicians. To further complicate the problem, these instrumental groups may be playing in a radio or television studio, an auditorium, or an outdoor location such as a bandshell. In spite of these complications, a few simple rules of microphone placement apply to most cases.

In general, percussion instruments are louder than brasses, brasses are louder than woodwinds, and woodwinds are louder than strings. Under these conditions, two general methods of orchestral pickup are normally applied to microphone placement. One of these methods is illustrated in Figure 26, where a single microphone provides the major pickup of an orchestra's music. This microphone is usually suspended from a boom and situated above the conductor.

When the entire orchestra is playing, the boom microphone provides adequate pickup. However, during soft passages or solos the boom microphone's pickup may be weak. In such cases, accent microphones located near the soloist or

strings provide the extra pickup necessary for good listen-
ing. Proper balance between the boom microphone and the
accent microphones is made by volume control adjustments
in the control room.

The other commonly used method of orchestral pickup is
illustrated in Figure 27. Here a separate microphone is
used for each general group of instruments (an additional
microphone may sometimes be used for the piano alone).
Thus, the orchestral balance, in this case, is obtained by a
combination of microphone placement and volume control.
The orchestral balance is not determined only by the indi-
vidual volume control of each microphone.

The possible solutions to some of the problems of micro-
phone placement encountered in working with choirs and
choral groups are illustrated in Figure 28. Figure 28A
shows a typical arrangement of such groups. This arrange-
ment is unsatisfactory for microphone pickup, because it is
impossible to obtain a balanced pickup from such an arrange-
ment. Since the tenors and basses are placed behind the
women, the female voices predominate (however, this may
be desirable in some cases).

The arrangement shown in Figure 28B overcomes this dif-
ficulty by placing each section of the choir an equal distance
from a microphone. Even with the arrangement of Fig-
ure 28B, many church choirs are weak in male voices.
Thus, the arrangement shown in Figure 28C allows the
operator to adjust the volume of the male voices and balance
the group's sound.

Figure 29 shows a soloist and an orchestra. Two micro-
phones are used, so that the operator may balance the ar-
rangement by controlling the volume of each microphone.
Furthermore, if two bidirectional microphones are placed
such that their directional patterns are perpendicular to
each other, the soloist microphone will pick up very little
orchestra music, and the orchestra microphone will pick
up very little solo music.

SUMMARY

Sound is produced by a vibrating body in contact with an elastic medium which will conduct the sound energy to a sound receiver. Sounds differ from each other in three fundamental ways: intensity, pitch and tone quality.

A microphone is an input transducer that converts sound energy to electric energy. There are two major types of microphones: pressure and velocity types.

Pressure microphones include dynamic, piezoelectric, condenser and carbon types. The dynamic microphone is a form of electric generator. Sound waves striking the diaphragm cause a coil, attached to the diaphragm, to cut flux lines. This induces an emf across the coil which varies according to the sound waves. The frequency response of the dynamic microphone is very good. The moving coil of a dynamic microphone presents a low output impedance.

Crystal and ceramic microphones operate by the piezoelectric effect. When the crystal or ceramic element is subjected to pressure, a voltage is developed across the element. Ceramic microphones are preferred over crystal types because they are not affected as much by temperature and humidity variations. In general, piezoelectric microphones have a good high frequency response and a high output impedance.

A condenser microphone is, as its name implies, a variable condenser or capacitor. The diaphragm forms one plate, a backplate forms the other plate, and air serves as the dielectric. The voltage across the plates of the condenser microphone is directly proportional to the distance between the diaphragm and the backplate. Thus, sound waves striking the diaphragm cause the voltage across the plates to vary with the sound waves.

Single-button and double-button carbon microphones act as variable resistors. The diaphragm controls the pressure

on carbon granules contained in a cup or button. When the carbon granules are compressed and released, the total resistance of the cup decreases and increases, respectively. Thus, sound waves striking the diaphragm cause current through the carbon cup to vary with the sound waves. The frequency response of a single-button carbon microphone is poor, but the output is relatively high. The double-button carbon microphone generally produces less distortion than the single-button type.

A velocity microphone is one in which the electric response corresponds to the difference in sound pressure on the opposite sides of a narrow metallic strip called a ribbon. Velocity microphones such as the ribbon microphones generally have bidirectional pickup characteristics.

In coupling microphones to amplifiers, shielded cable is used to prevent the addition of hum and other noise to the signal. This shielded cable or transmission line exhibits a capacitance that causes attenuation of higher frequency signals traveling along the line. Low impedance line is used for coupling low impedance microphones to amplifiers with low input impedance.

When high impedance microphones must be used with long lines, impedance matching transformers are used with a low impedance line, because high impedance line sharply attenuates the high frequencies. Normally, a step-down transformer is used from microphone to line, and a step-up transformer is used from line to amplifier. An equalizer circuit can also be used to compensate for some line losses.

Good sound reproduction requires careful placement of microphones with respect to the sound source. Also, the acoustics of the area in which the sound is being developed must be taken into consideration.

IMPORTANT DEFINITIONS

ACOUSTIC ENERGY - [uh KOO: stik] - The ability of sound to do work.

ACOUSTICS - [uh KOO: stiks] - The science that deals with the production, conduction, and control of sound.

AUDIO FREQUENCIES - The range of frequencies from about 20 to 20,000 Hz which can be heard by the normal human ear.

BIDIRECTIONAL MICROPHONE - [BIGH di REK shun'l] - A microphone that picks up sound equally well from the front and back, but picks up practically no sound from either side.

BIMORPH ELEMENT - [BIGH morf] - A sensitive crystal element made up of two slabs of crystal adjacent to each other.

CARBON MICROPHONE - A microphone in which the sensory element consists of a cup (or cups) of carbon granules, which serves as a variable resistance when sound waves cause the granules to become more densely and less densely packed.

CARDIOID MICROPHONE - [KAR di oyd] - A microphone that has a heart-shaped directivity pattern, providing maximum pickup of sound from the front, diminishing to almost no pickup from the rear.

CERAMIC MICROPHONE - [si RAM ik] - A type of piezo-electric microphone, in which variations of pressure applied to a ceramic element cause a voltage to be developed.

IMPORTANT DEFINITIONS (Continued)

COMPRESSIONS - In an analysis of sound transmission, the areas where a large number of molecules are compressed due to vibrations of a sound producing instrument.

CONDENSER MICROPHONE - A microphone in which the sensory element consists of movable and fixed plates, which serve as a variable capacitance when the movable plate is activated by sound waves.

CRYSTAL MICROPHONE - A type of piezoelectric microphone, in which variations of pressure applied to a crystal element cause a voltage to be developed.

DENSITY - The number of molecules of a given material per given volume of the material.

DIRECTIVITY - [di rek TIV i tee] - The ability of a microphone to pick up sounds from particular directions.

DYNAMIC MICROPHONE - A microphone which operates on the principle of electromagnetic induction, generating a voltage when a coil cuts a magnetic field.

ELASTICITY - [i lass TISS i tee] - The tendency of a body to return to its original size or shape after having been stretched, compressed, or deformed.

EQUALIZER - [E kwuhl eyez'r] - A circuit designed to level the frequency response of a unit, usually by attenuating the stronger frequencies.

FREQUENCY - The rate of vibration of sound energy.

FREQUENCY RESPONSE - That characteristic of a microphone which indicates its ability to convert sounds of various frequencies to output variations of voltage or current.

IMPORTANT DEFINITIONS (Continued)

INTENSITY - The rate at which acoustic energy flows through a unit area.

LOUDNESS - The magnitude of sound, as heard by the human ear, which is related to the intensity of the sound entering the ear.

MICROBAR - [MIGH kroh bar] - A unit of sound wave pressure which is equal to 14.5×10^{-6} pounds per square inch.

MICROPHONE - [MIGH kruh fohn] - A device that converts sound energy to electric energy.

OMNIDIRECTIONAL MICROPHONE - [ahm ni di REK shun'l] A microphone that receives sounds equally well from all directions.

OUTPUT LEVEL - The ratio of a microphone's power output to a given sound pressure input.

PARABOLIC REFLECTOR - [PAYR uh BAHL ik] - A dish-shaped object used to focus sound onto a microphone and thus provide a highly directional pickup pattern.

PIEZOELECTRIC MICROPHONE - [PEEZ oh i LEK trik] - A microphone which operates on the principle of piezo-electricity, wherein variations of pressure on a crystalline substance cause a voltage to be developed.

PITCH - The effect of the frequency of sound waves on the ears.

PRESSURE COMPONENT - The component of acoustic energy related to the pressure variations created by the compressions and rarefactions.

IMPORTANT DEFINITIONS (Continued)

PRESSURE MICROPHONE - A microphone in which the variations in pressure, caused by the sound waves, actuate the operating mechanism. Dynamic, piezo-electric, condenser, and carbon types are forms of pressure microphones.

RAREFACTIONS - [RAYR i FAK shuns] - In an analysis of sound transmission, the spaces between compressions where there are relatively few molecules.

REVERBERATION - [re VER ber AY sh'n] - The continued reflection of sound; a multiple echo.

REVERBERATION TIME - The time required for the intensity of a sound to drop 60 dB after the original sound has stopped.

SOUND - Vibrational energy which produces the sensation of hearing when it reaches the human ear.

TONE QUALITY - The property of sound waves which depends on the number of harmonics present and on their prominence.

VELOCITY COMPONENT - The instantaneous rate at which the pressure component of acoustic energy changes.

VELOCITY MICROPHONE - A microphone in which the electric response corresponds to the velocity component of the sound.

WAVEFORM - The shape of a sound wave, as determined by the overtones or harmonic content of the wave.

WAVELENGTH - The distance between compressions of a sound wave.

ESSENTIAL SYMBOLS AND EQUATIONS

D - output level   (dB)
d - distance between plates   (cm)
E - voltage   (volts)
I - intensity   (watts/cm^2)
I_0 - threshold of hearing   (10^{-16} watt/cm^2)
k - a constant determined by the
    area of the plates in a
    condenser microphone
L - loudness   (dB)
l - output level   (watts/microbar)
l_0 - reference level   (10^{-3} watt/microbar)
Q - charge   (coulombs)

$$L = 10 \log \frac{I}{I_0} \qquad (1)$$

$$D = 10 \log \frac{l}{l_0} \qquad (2)$$

$$E = kQd \qquad (3)$$

STUDENT NOTES

PRACTICE EXERCISE SOLUTIONS

1. audio

2. elasticity and density

3. compressions, rarefactions

4. Acoustic energy is the ability of a sound wave to do work.

5. pressure, velocity

6. 160 dB

$$L = 10 \log \frac{I}{I_0} = 10 \log \frac{1}{10^{-16}}$$

$$= 10 \log 10^{16} = 10 \times 16 = 160 \text{ dB}$$

The people who hear this sound will experience considerable pain, because this sound is 40 dB above the threshold of pain (120 dB).

7. -30 dB

$$D = 10 \log \frac{1}{I_0} = 10 \log \frac{10^{-6} \text{ watt/microbar}}{10^{-3} \text{ watt/microbar}}$$

$$= 10 \log 10^{-3} = 10(-3) = -30 \text{ dB}$$

8. The dynamic microphone operates on the principle of electromagnetic induction: when a coil cuts a magnetic field, a voltage is induced in the coil.

9. motor -- A dynamic microphone converts acoustical (mechanical) to electrical energy, and thus is a form of generator. A dynamic speaker converts electrical energy to acoustical (mechanical) energy, and thus is a form of motor.

10. If the natural resonant frequency of a diaphragm occurs in the audio range, speech and music inputs to the microphone will be distorted at the output.

4712
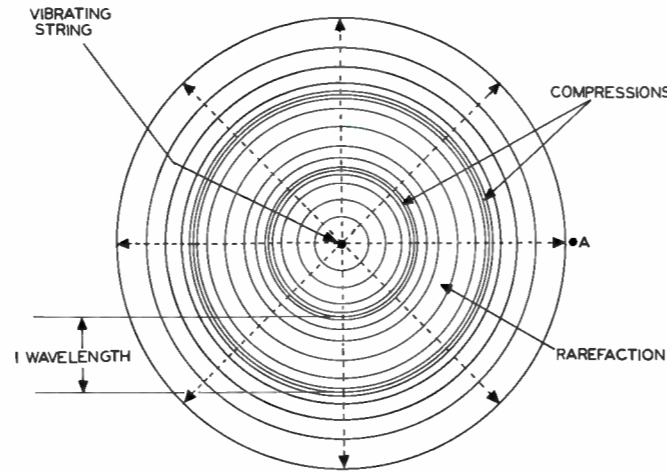
FIGURE 1

TYPE OF SOUND	LOUDNESS (dB)
THRESHOLD OF HEARING	0
WHISPER	10-20
QUIET OFFICE	20-40
AUTOMOBILE	40-50
CONVERSATION	60
HEAVY STREET TRAFFIC	70-80
ELEVATED TRAINS, RIVETERS	90-100
THUNDER	110
THRESHOLD OF PAIN	120

FIGURE 2
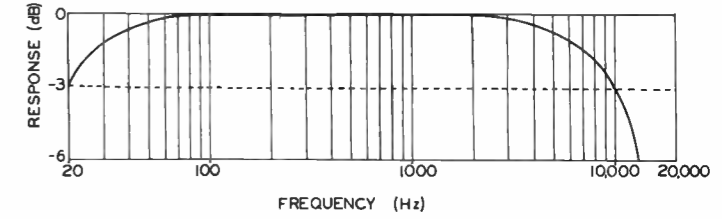
A
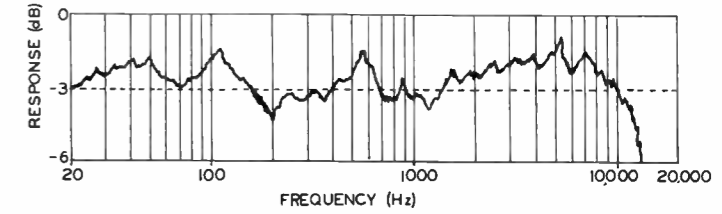
B

FIGURE 4
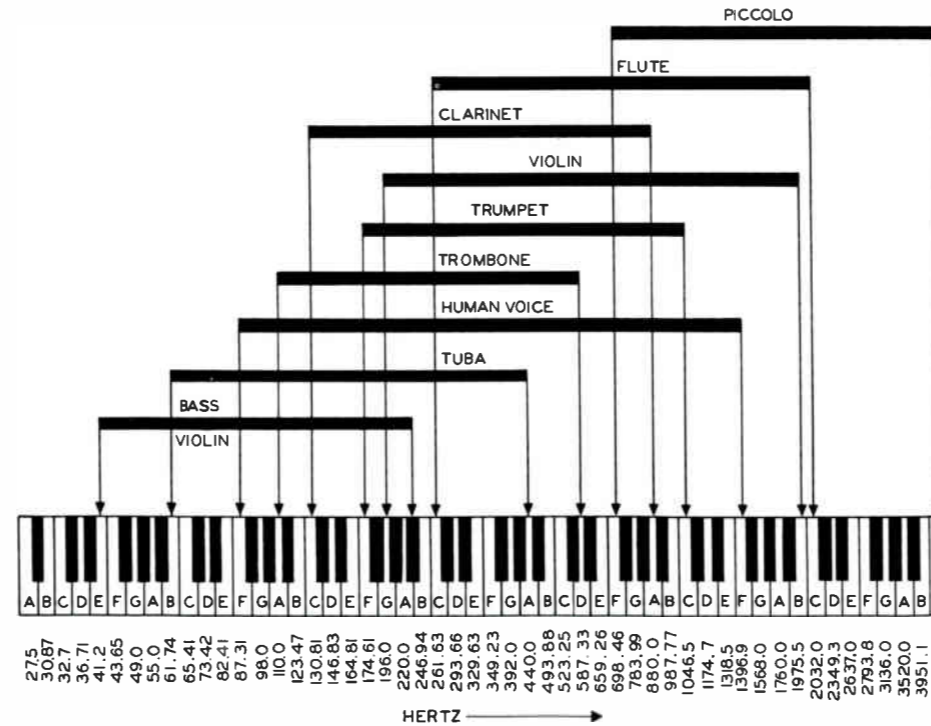
FIGURE 3
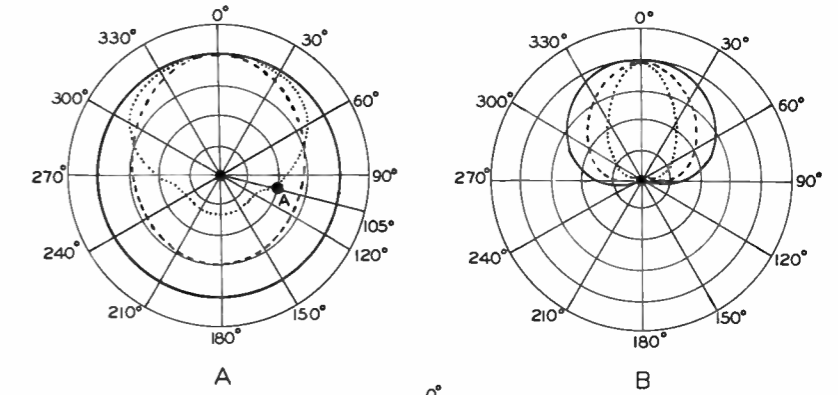
A

B
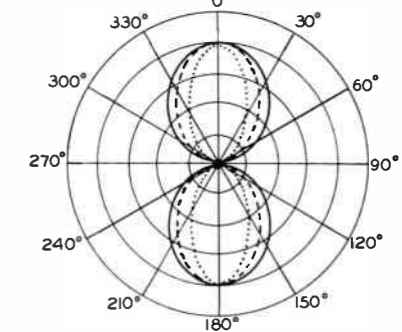
C

FIGURE 5

FIGURE 6

FIGURE 7

FIGURE 8

4712
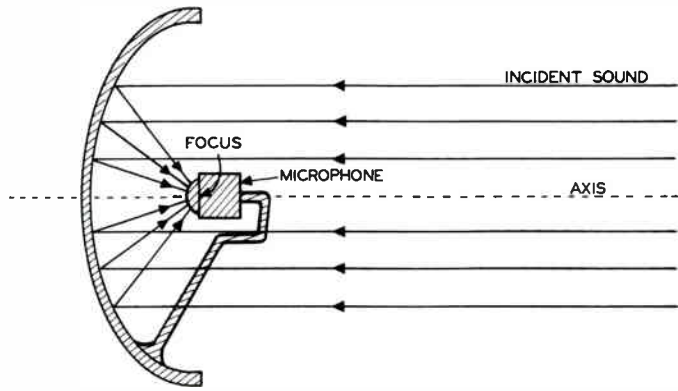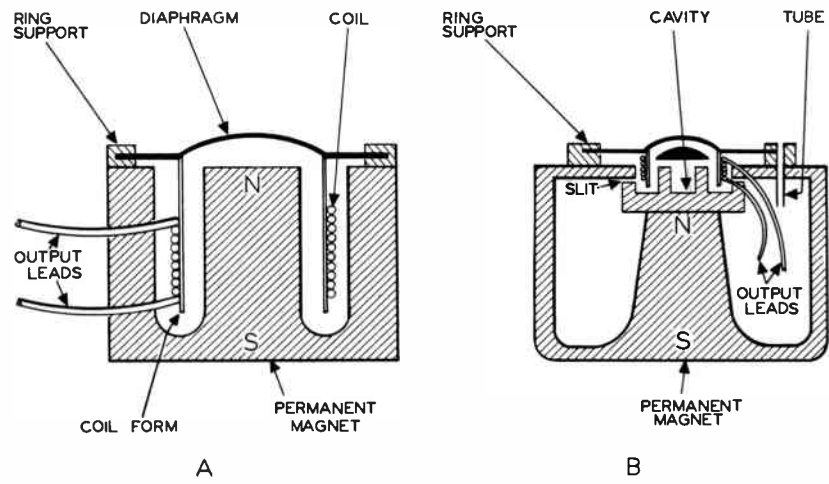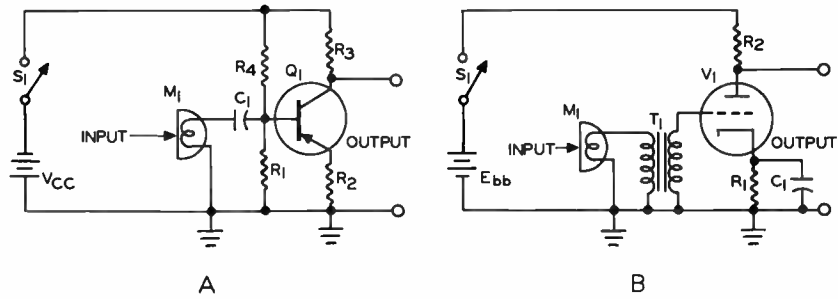
PRACTICE EXERCISE SOLUTIONS (Continued)

11. The impedance of a dynamic microphone is usually very low, and the input impedance of a grounded cathode tube amplifier is very high. Thus, for maximum power transfer, these devices must be matched by a transformer.

12. (a) the piezoelectric effect.

13. A bimorph element:
    (a) lends itself to more efficient size and shape,
    (b) is affected less by temperature and pressure variations, and
    (c) is more sensitive than a single-crystal element.

14. True

15. capacitor or condenser

16. (b) decrease

17. (b) decreases

18. (b) low frequency response.

19. False -- Since the impedance of a carbon microphone is normally low, the matching conditions for a carbon microphone are the same as those for a dynamic microphone.

20. (b) high frequency response.

21. True

22. 30 -- (-30 dB) - (-60 dB) = -30 dB + 60 dB = 30 dB

23. Microphone transmission lines are shielded to prevent undesirable noise voltages from being added to the voice or music signal before it reaches the amplifier.

24. The capacitive effect of the shielded cable is due to its construction. That is, the copper wire and the copper shield form the plates of the capacitance, and the insulation between the wire and shield forms the dielectric.
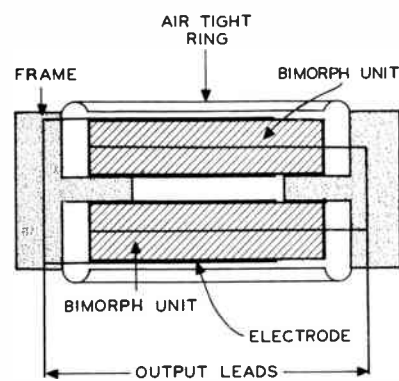
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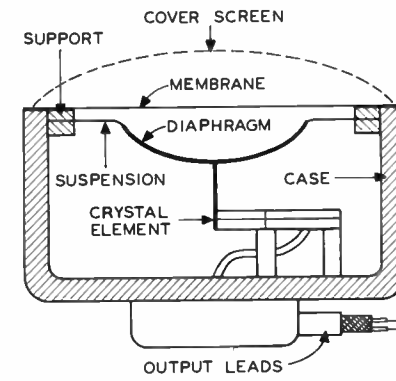
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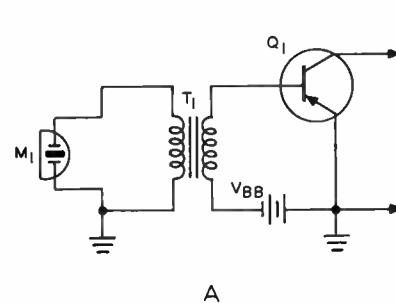
A
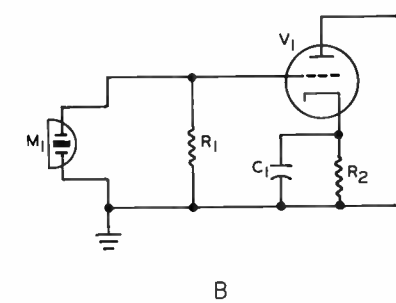
B

FIGURE 11
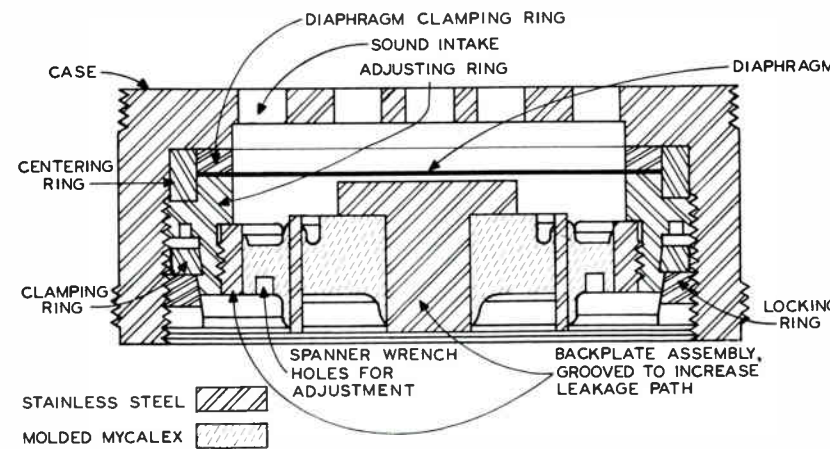
FIGURE 12

4712
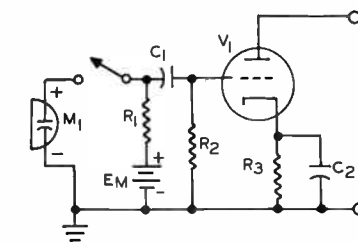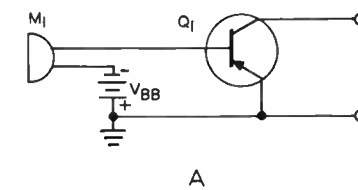
FIGURE 13

A
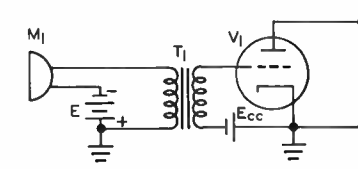
B

FIGURE 15
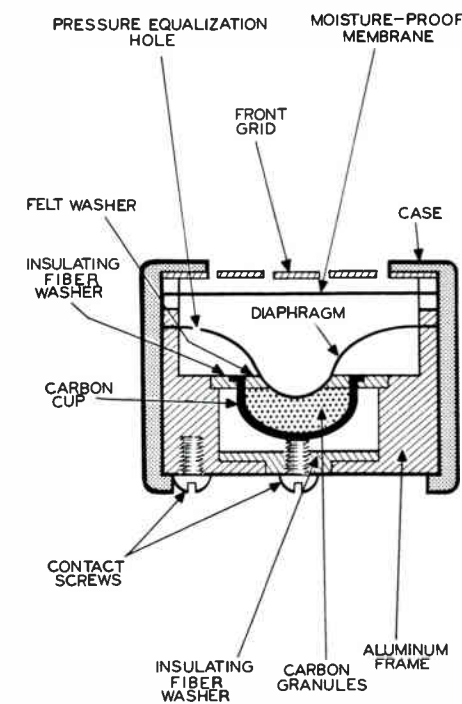
FIGURE 14

FIGURE 16

4712
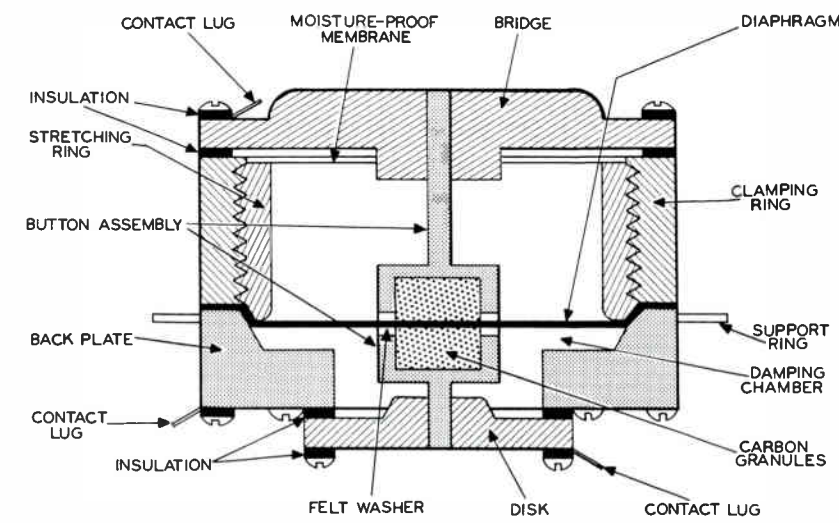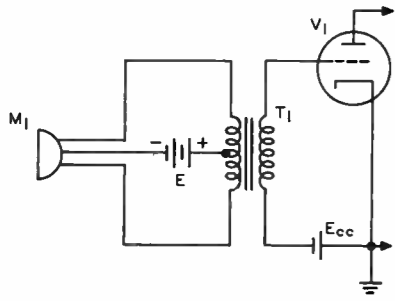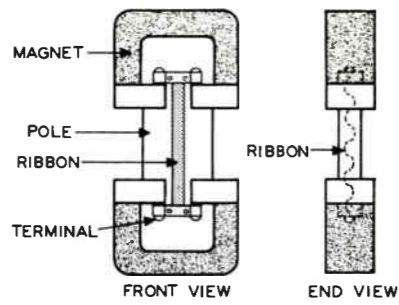
FIGURE 17

FIGURE 18

MICROPHONE	CLASSIFICATION	FREQUENCY RESPONSE Hz	OUTPUT LEVEL dB	IMPEDANCE OHMS
A	CARDIOID DYNAMIC	30 TO 10,000	−48	50
B	CARDIOID CRYSTAL	50 TO 11,000	−60	HIGH
C	CARDIOID CERAMIC	60 TO 8000	−60	HIGH
D	CARDIOID VELOCITY	30 TO 15,000	−87	50
E	OMNIDIRECTIONAL CONDENSER	20 TO 20,000	−50	600
F	OMNIDIRECTIONAL CARBON	95 TO 6000	−30	50

FIGURE 19
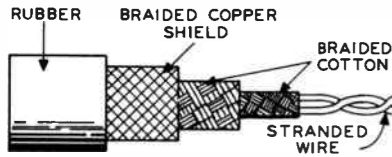
FIGURE 20
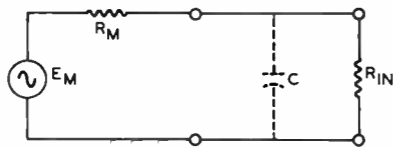
FIGURE 21

FIGURE 22

FIGURE 23

4712
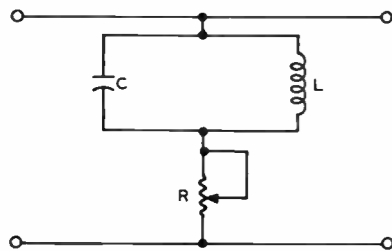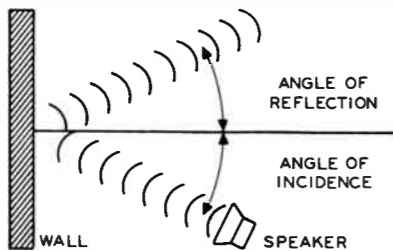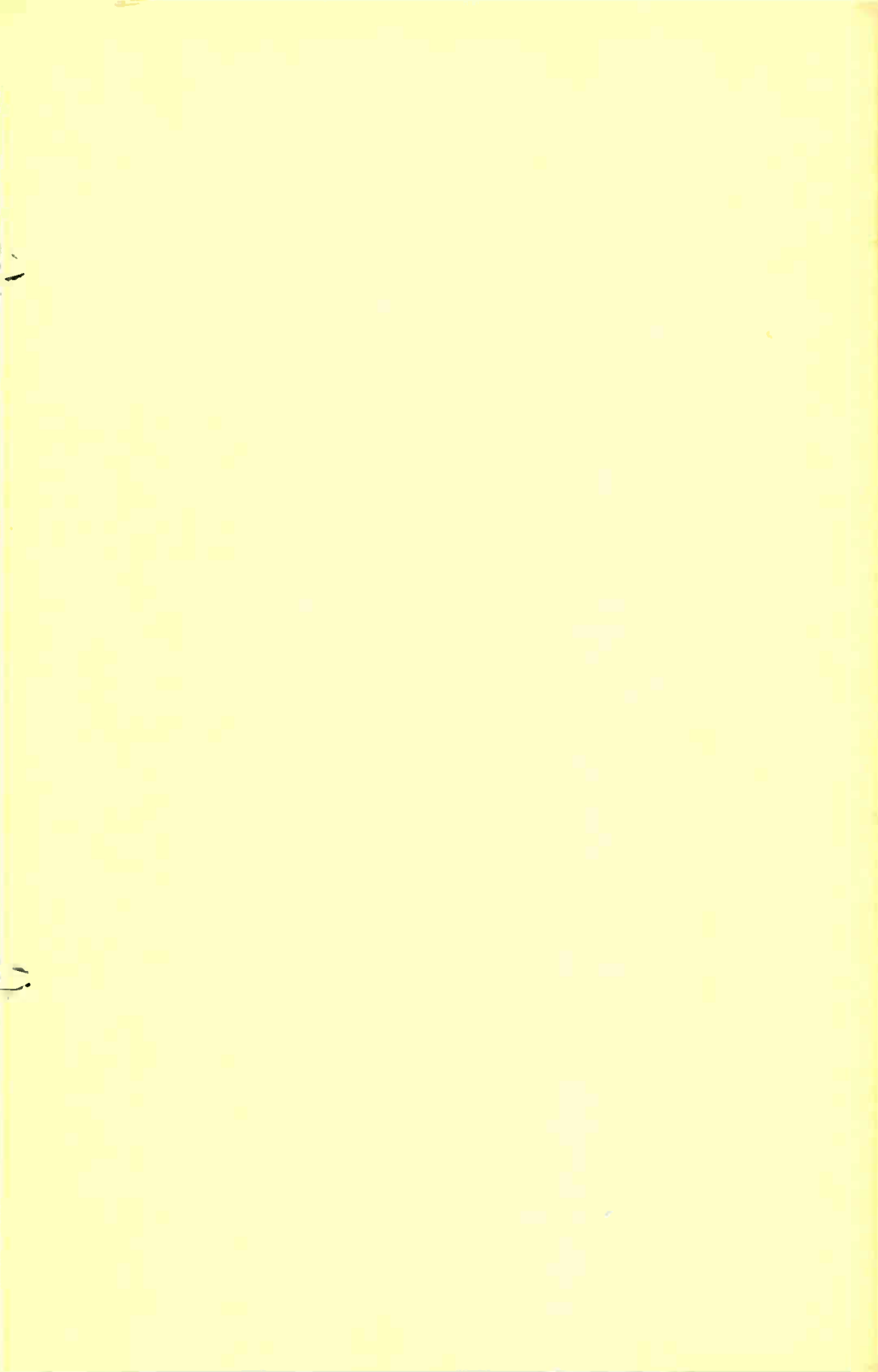
RECORDING
AND PLAYBACK
Lesson 4715

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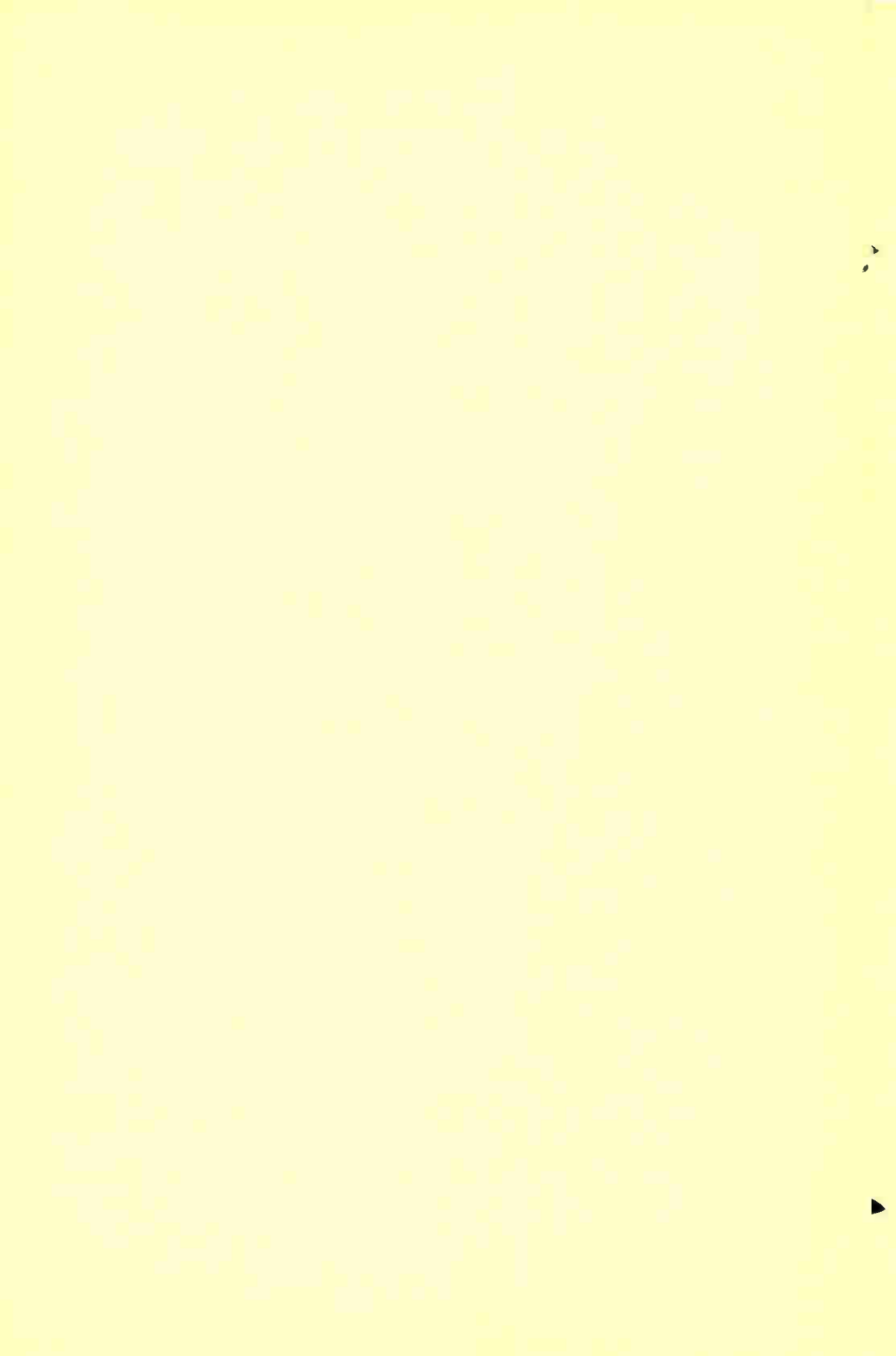
RECORDING AND PLAYBACK

Revised 1968

OPPORTUNITY

3

A view of a broadcast studio shows the professional type turntables used to play phonograph records. This is one of the studios of Station WXYZ, Detroit.

Courtesy Gates Radio Company

RECORDING AND PLAYBACK

CONTENTS

****

Education makes people easy to lead,
but difficult to drive; easy to govern,
but impossible to enslave.

--H.P. Brougham

RECORDING AND PLAYBACK

Recordings are an important part of modern communication. For example, disk recordings are commonly used in broadcasting music; magnetic tapes are often used to record commercials and complete programs before they are broadcast; and in many cases, live broadcasts are "taped" to provide a permanent record that may be checked at some later time. In this lesson we investigate some of the important characteristics of recording and playback equipment as used in modern broadcast work.

DISK RECORDING

Disk recordings have been used for many years to obtain permanent records of information. In disk recording, a signal from a microphone or other signal source is amplified and applied to a RECORDING HEAD or CUTTING HEAD which includes a CUTTING STYLUS. The chisel-like stylus cuts a varying groove into the record according to the amplitude and frequency of the signal.

*　　　　　*　　　　　*

1.　The instrument that does the actual cutting in disk recording is called a＿＿＿＿＿＿＿＿＿.

*　　　　　*　　　　　*

The original record has a soft, plastic surface, and is not normally released to the general public. It is used to make a metal MASTER copy. The master is a negative copy, since it has ridges where the original had grooves. A metal MOTHER copy is produced from the master. The mother is a positive copy; that is, its grooves correspond to the grooves on the original. Negative STAMPERS are made from this mother. These stampers are used to make pressings (records) that are sold to the general public and used by broadcasting studios.

*   *   *

2.   Disk recordings used by broadcast studios are called masters.
      True or False?

*   *   *

The information on a record disk is recovered by means of
a PLAYBACK CARTRIDGE or PICKUP CARTRIDGE and
PLAYBACK STYLUS which functions in the reverse order
of the recording head and cutting stylus. As the playback
stylus follows the groove variations, the pickup cartridge
develops a signal proportional to the variations in the
groove.

*   *   *

3.   Compare the basic functions of a recording head and a pickup
      cartridge as used in modern disk recording.

*   *   *

The signal produced by a playback cartridge is usually very
small, and must be fed into a PREAMPLIFIER designed to
handle small signals. The output of the preamplifier is fed
to the basic amplifier or POWER AMPLIFIER, which in-
creases the power of the signal to the level required to
drive the monitoring speaker systems and to serve as a
modulating signal for the transmitter. The r-f signal out-
put of the station, whether it is music or voice, contains
essentially the same information as that recorded in the
first step of the operation.

*   *   *

4.   Why is a preamplifier required in a broadcast studio playback
      system?

*   *   *

Information is recorded on a phonograph disk when the cut-
ting stylus modulates the groove. In a professional re-

corder, the recording head is usually mounted on a lathe arrangement which drives the head across the surface of a record "blank" rotating on a turntable. The groove forms a spiral from the outside toward the center of the record disk. Signals applied to the head produce the stylus motion which modulates the groove.

In monaural recording, groove variations can be cut by either of two methods: the lateral cut or the vertical cut. Current monaural recordings are made using lateral cutting of the groove. Stereophonic disks use a combination of vertical and lateral cutting to produce two channels of information.

*   *   *

5.   What two types of cutting may be used to produce monaural disk recordings?

6.   What cutting method is generally used for monaural recording? For stereo recording?

*   *   *

Figure 1A is a greatly magnified view of a vertically cut groove. The stronger the signal applied to the recording head, the deeper the stylus cuts into the record, and the wider the groove will be. This is shown by the variations in the width of the groove. Notice that the center of each groove does not swing left or right. This system was used in some early recorders, but is rarely used in modern recording systems.

Figure 1B shows the result of lateral cutting. The depth of the groove remains constant as the cutting stylus moves from side to side. Depending upon the amplitude and frequency of the applied signal, the lateral motion varies. For example, large signals cause the stylus to swing farther from the center than small signals, and high frequency signals cause more rapid swings of the stylus than low frequency signals. The lateral cutting method is used in practically all monaural systems.

*   *   *

7. Describe the main difference between the vertically cut
    grooves of Figure 1A and the laterally cut grooves of Fig-
    ure 1B.

*   *   *

Stereo recording produces a groove which combines the
vertical modulation of Figure 1A and the lateral modulation
of Figure 1B. The result is shown in Figure 1C. The out-
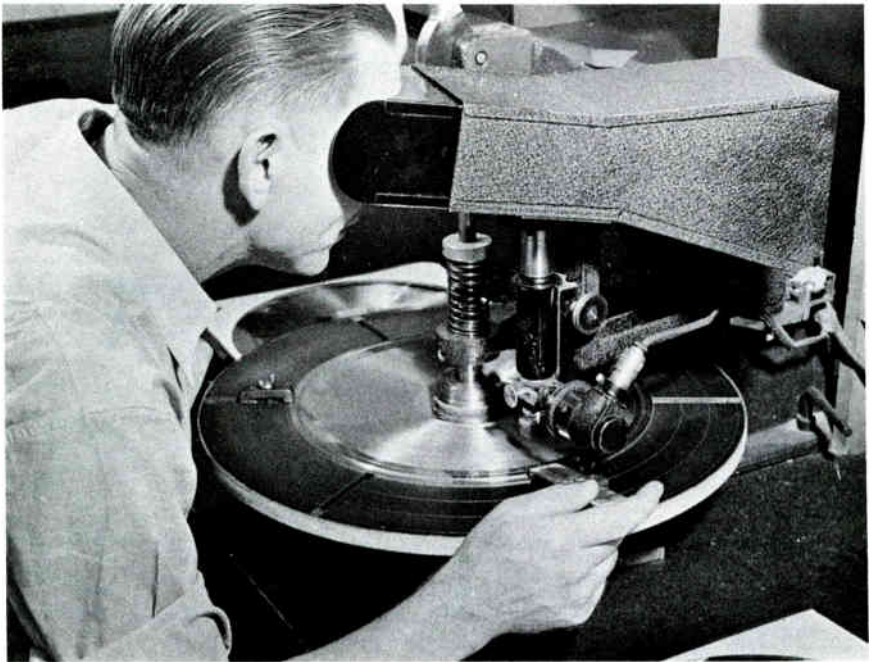
Inspecting the grooves in a metal copy of a phonograph record. In commercial record manufac-
turing, microscopic inspections such as this are important to insure noise-free reproduction.
Courtesy Radio Corporation of America

side groove (right) in this figure contains no modulation.
The combination of vertical and horizontal motion of the
cutting stylus in one plane (between upper left and lower
right, at a 45° angle with respect to the surface of the

record) causes modulation of the right groove wall. This is illustrated by the second groove in Figure 1C. A similar motion between lower left and upper right (again at 45° with respect to the record surface) causes modulation of the left groove wall, as shown by the third groove.

With this cutting method, one groove wall carries one "channel" of information, and the other wall carries a second "channel" of information. The last three grooves show modulation of both groove walls to produce the two channels simultaneously.

*   *   *

8. In stereo disk recording, the same information is carried in both walls of the groove. True or False?

*   *   *

PHONOGRAPH DISKS

Over the years, many types of materials have been used to make phonograph disks. The main problem is always the amount of wear on the disk due to friction between the playback stylus and groove wall. Today vinylite is used to make almost all commercial phonograph disks. This material is easy to press, and yet is strong enough to endure the friction of the playback stylus without excessive wear.

When only a few records are required, they may be cut into acetate disks. This type of disk generally has a metal base. These masters are then played directly. No pressings are made.

*   *   *

9. The material used to make almost all commercial phonograph records is _____.

*   *   *

The groove spacing determines the PITCH of the recording

spiral, which refers to the number of grooves per inch of recording radius. The pitch ranges from about 20 to 500 grooves per inch in records produced today. The pitch of most commercial records is between 100 and 250 grooves per inch.

As the separation between the adjacent grooves is decreased (the pitch is made higher), the allowable signal amplitude is smaller. This is because the stylus would overlap into the adjacent groove on high amplitude signals. To prevent overlap, some record cutting lathes are used with a variable pitch device. This increases the distance between adjacent grooves when the stylus is making large swings, and decreases the distance between adjacent grooves when the material being recorded has very low amplitude.

*   *   *

10. Why is it necessary to restrict the maximum amplitude of the recorded signal when the groove pitch is high?

*   *   *

The shape of the groove cut by the cutting stylus is shown in Figure 2, which illustrates an "end" view of several un-modulated record grooves. The groove depth, the width of the groove at the disk surface, and the spacing between the grooves (called the land) varies with the type of cutting and the number of grooves per inch. A typical groove depth is .0025 inch or 2.5 mils (1 mil = .001 inch). For standard grooves, as commonly used in 78 rpm records, the groove width is typically 6 mils and the width of the land is typically 4 mils. In comparison, a typical groove width in $33\frac{1}{3}$ rpm and 45 rpm microgroove records is 2 mils, with a 1.3 mil land between grooves. The angle of cut, as shown, is normally between 80° and 100°.

*   *   *

11. The grooves in a microgroove record are usually (a) wider, (b) narrower than those in a standard 78 rpm recording.

*   *   *

RECORDING SPEED

Three basic turntable speeds are used in modern disk re-
cording systems.   They are: $33\frac{1}{3}$, 45 and 78 revolutions
per minute (rpm).   By using the slower speeds, longer re-
cordings can be made on a disk of given diameter.   Most
long playing (LP) albums are recorded at $33\frac{1}{3}$ rpm.   Be-
cause of the increased popularity of 45 rpm and $33\frac{1}{3}$ rpm

A 16" phonograph turntable of studio quality. The speed selector lever at the left permits selection
of either 78, 45 or 33-1/3 rpm.   A built-in straboscopic disk in the center of the turntable permits
checking the actual turntable speed.

Courtesy Gates Radio Company

recordings, many broadcast turntables have only these two
speeds.

For best reproduction, the speeds of the recording and play-
back turntables should be identical. Professional turntables
such as those used in most broadcast studios usually have
provisions for adjusting the speed of rotation.   These ad-

justments are checked periodically to make sure there is no change in operating speed.

One way of checking the speed of a turntable is by using a STROBOSCOPIC DISK, such as that shown in Figure 3. This disk is placed directly upon the turntable, and rotated as a record. Note that this disk has a band of marks for each speed. The marks around the circumference of the disk are viewed under a fluorescent light (which fires and extinguishes at a rate of 120 times a second on the regular 60 Hz line). If the turntable is rotating at the proper speed, the marks appear to stand still. If the dots or marks appear to rotate clockwise, the turntable speed is too fast; when they appear to rotate counterclockwise, it is too slow.

Strobe disks are available for all standard speeds. Some turntables have a strobe disk built into the center of the table for convenience.

*   *   *

12. When a turntable is rotating at the correct speed, the marks corresponding to that speed on a stroboscopic disk appear to (a) stand still, (b) rotate clockwise, (c) rotate counterclockwise.

*   *   *

RECORDING HEADS

The recording head converts electric signals to mechanical motion of the cutting stylus. Examples of recording heads are shown in Figures 4 and 5. Figure 4 shows a crystal head, while Figure 5 shows a magnetic head. The magnetic head is more common in professional disk recording systems.

The crystal head operates on the piezoelectric principle: signal voltages applied between the opposite faces of a crystal cause the crystal to bend. A stylus is mechanically coupled to the crystal element, so that the crystal motion

causes the stylus to move from side to side. The resulting stylus swing corresponds to the amplitude and frequency of the signal applied to the crystal element.

In the magnetic recording head of Figure 5, the stylus moves as a result of interaction between the fixed magnetic field of a permanent magnet and the varying electromagnetic field produced by signal currents in an exciting coil. The stylus chuck is an extension of a pivoted armature, which passes through the center of the exciting coil. The coil assembly is mounted in the field of the permanent magnet.

With no signal current in the exciting coil, the armature is centered between the poles of the permanent magnet. Signal currents produce a varying field around the coil which aids or opposes the permanent magnet field, depending on the direction of signal current. The armature swings from side to side, thus causing lateral motion of the stylus. The amount of swing depends on the amplitude of the signal, and the rate of swing depends on the frequency of the signal.

*   *   *

13. A cutting head used for disk recording converts electric signals to mechanical motion. True or False?

*   *   *

The recording heads of Figures 4 and 5 have provisions for only one input signal. Thus, they are monaural recording heads. However, the basic principles of Figures 4 and 5 are also used in stereo cutting heads. Two driving elements are mounted physically at 90° with respect to each other, and at 45° with respect to the surface of the record. These two elements are coupled mechanically to a single cutting stylus. Signals applied to one element cause the stylus to move in one plane at an angle of 45° with respect to the record surface, and thus modulate one wall of the groove. Signals applied to the other element cause stylus motion in the other plane at 45° with respect to the record surface,

thus modulating the other groove wall. As a result, two channels of information are recorded in the two walls of a single groove as shown in Figure 1C.

THE CUTTING STYLUS

A diagram of a typical cutting stylus is shown in Figure 6. It consists of a chisel-like tip mounted in a shank. The tip or cutting edge of the cutting stylus is the portion that does the actual cutting. For this reason only the chisel tip has to be of a hardened material. The materials most commonly used are diamond and sapphire.

As the cutting edge of the stylus cuts the groove, the stylus provides the additional function of polishing the groove wall. This function is performed by the burnishing edge of the stylus. This burnishing action eliminates small imperfections in the groove and thus results in a "cleaner" recording.

The cutting stylus must be manufactured with extreme accuracy. Not only must the cutting edge be sharp, but the sides of the tip must be polished to a smooth finish. Otherwise, the groove material will be torn rather than cut from the record, resulting in a poor recording.

A great strain is placed upon the edge of the recording stylus as it cuts the record groove. The amount of noise obtained on playback depends on the ability of the stylus to maintain a sharp edge. The sharper the edge on the stylus, the quieter will be the recording.

The cutting life of the stylus varies with the hardness of the material to be cut and the speed of the recording being made. The softer the material being cut, the longer the stylus life. Increasing the recording speed increases the heat generated at the stylus. This reduces the stylus life.

*   *   *

14. Why do you think the cutting edge of a recording stylus is made of hard material such as sapphire or diamond?

*   *   *

The angle of the cutting stylus with respect to the record
has an important bearing on the quality of the recording.
This angle varies with the type of head used, the type of
material being cut, and the actual shape of the cutting edge
of the stylus. If the cutting angle is incorrect, there will
be an increase in surface noise.

*   *   *

15. List at least two factors that govern the angle of the cutting
stylus for best recording.

*   *   *

PICKUP CARTRIDGES

The pickup cartridge is that part of a playback system which
converts the variations in the walls of a record groove into
a corresponding electric signal. Four main types of car-
tridges are in common use: (1) magnetic, (2) variable re-
luctance, (3) moving coil and (4) ceramic or crystal. These
types of cartridges differ in the method of converting the
mechanical motion or vibration of the stylus into electric
signals.

*   *   *

16. Name at least two types of pickup cartridges used in modern
phonograph playback systems.

*   *   *

The Magnetic Pickup

The operating principle of the magnetic type of phonograph
pickup is illustrated by the simplified drawing of Figure 7A.
The magnetic field is produced by a U-shaped permanent
magnet, and to concentrate the lines of force, soft iron pole
pieces are placed between the magnet poles.

The armature is centered between these pole pieces and

mounted on a pivot, with the stylus attached to the lower extended end. At the upper end, the armature passes through a piece of rubber which holds it midway between the poles. Between the extensions of the poles a coil of wire is placed around the armature, but not connected to it.

When the armature is centered in the air gap, the magnetic flux divides equally, half of it passing through the upper pair of poles and half through the lower pair of poles. Except for those parts directly between the soft iron pole faces, there is no magnetic flux in the armature.

With the part of the armature in the center of the coil considered to be the core, under the above conditions there is no magnetic flux in the core of the coil. Since all of the flux passes through the pole pieces, practically no magnetic lines cut through the turns of wire which make up the coil, and the output voltage is zero.

*   *   *

17. In the cartridge of Figure 7A, when the armature is centered in the air gap, the output voltage of the cartridge is (a) maximum, (b) zero.

*   *   *

When the stylus is moved to the right by a variation in the record groove, the upper end of the armature moves toward the upper N pole piece. Iron has a much lower reluctance than air. Therefore, moving the stylus to the right reduces the upper left air gap, and reduces the reluctance of the magnetic circuit.

The reduced reluctance permits some of the magnetic lines to pass from the N pole of the permanent magnet, through the upper extension of the pole piece, across the shortened gap, down through the armature, to the lower S pole piece, and to the S pole of the magnet. The number of magnetic lines passing through the armature at a given instant depends on the distance the stylus is moved. The greater the

movement, the greater the number of lines.

In following the path from the upper left to the lower right pole piece extensions, all magnetic lines do not remain inside the armature, and part of the total flux cuts through
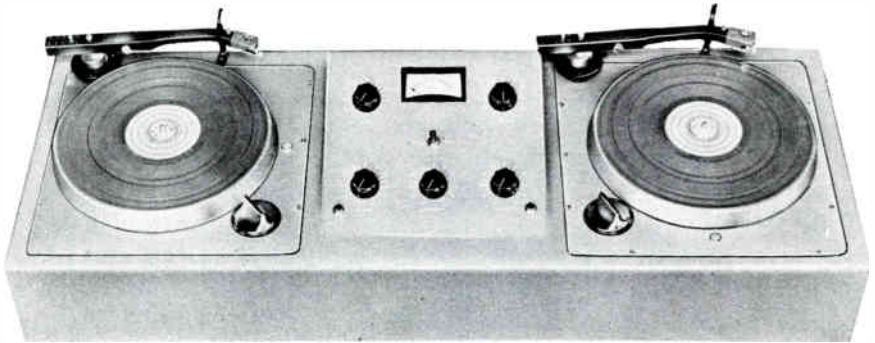
These two broadcast quality 3 speed, 12 inch turntables use transcription arms housing magnetic cartridges. Both the amplifiers and power supply are solid state.

Courtesy Gates Radio Company

the turns of the coil. When a wire cuts through, or is cut by magnetic lines, an emf is induced in the wire.

In the same way, when the stylus is moved in the opposite direction, the air gap between the armature and the upper end of the S pole piece is shortened and some of the magnetic lines, passing from the N to S pole of the magnet, travel up through the armature. The action is the same as that just described except that the induced emf is in the opposite direction in the coil.

*   *   *

18. In the magnetic pickup cartridge of Figure 7A, how does the voltage produced by a stylus swing in one direction compare with the voltage produced by a stylus swing in the opposite direction?

*   *   *

Thus, variations of a wave cut in the record groove cause

like variations of magnetic flux through the armature. Then, as that part of the armature between the arms of the poles is the core of the coil, the changing flux induces an alternating emf of like frequency in the coil. The alternating emf induced in the coil is coupled by means of an impedance matching transformer to the input of an audio amplifier, as shown in Figure 7B.

The Variable Reluctance Pickup

The basic construction of one type of variable reluctance pickup is shown in the simplified drawing of Figure 8A. A sapphire or diamond tipped stylus or needle is mounted on the free end of a small spring piece of magnetic material. This is magnetized by a tiny cylindrical alnico magnet, placed above one end of the spring material. The other end of the spring is free to move between two thin, flat pole pieces made of an alloy of iron and nickel, called "mumetal", which has a high magnetic permeability. The pole pieces extend upward through the cores of the coil and are joined at the upper ends by a yoke.

As the stylus moves laterally in the record groove, the attached spring decreases the length of the magnetic path to one pole piece while increasing the path to the other pole piece, thus changing the reluctance of their magnetic circuits. Since magnetic flux varies inversely as reluctance, the number of lines of magnetic force threading through one coil increases, while the number of lines through the other decreases. Therefore, as the flux increases in one coil it decreases in the other. The voltages generated in the coils by the expanding and contracting fields are directly proportional to the rate of change of flux in each coil.

*   *   *

19. What magnetic property is varied to produce the changing flux as the stylus moves from side to side in Figure 8A?

*   *   *

Due to the low mass of the moving element, the signal
waveform is a very close reproduction of the original sound.
The induced voltages in the two coils aid each other to pro-
duce a signal output greater than that available with one coil
alone. Also, due to the coil arrangement, hum or other
noise from external sources tends to induce equal and oppo-
site voltages in the coils, thus providing a cancellation of
hum or noise pickup. Since vertical motion of the stylus
between the pole pieces does not produce flux variations, no
voltage is generated by such movements, and considerable
frictional noise is eliminated.

*   *   *

20. The voltages induced in the two coils of Figure 8A as a result
    of the stylus motion (a) aid each other, (b) oppose each
    other.

*   *   *

The energy produced by this type of pickup is very small
and must be boosted by a preamplifier. However, this dis-
advantage is offset by the excellent frequency response and
low noise output.

Figure 8B shows the input circuit to a preamplifier. The
cartridge output is fed into R_1 and C_1, which form a tone
compensating network to improve the frequency response of
the pickup. R_2 offers a grid-to-cathode path for the grid
bias.

The Moving Coil Pickup

The moving coil pickup employs a stationary flux, and the
lines are cut by a coil which moves in accordance with the
variations in the record groove. In one arrangement of this
type of pickup, illustrated in Figure 9A, the coil is wound
on a thin split sleeve of steel, which is mounted around one
end of a short duralumin stylus. Two thin plastic vanes ex-
tend at right angles to the stylus, directly opposite each
other, and are anchored securely to the supporting bridge.

The thin edges of the vanes are placed in line with the record groove, and when the stylus follows the lateral excursions of the groove, the vanes flex on their center line and cause an oscillatory motion of the coil around its center. The poles of a small permanent magnet, not shown in Figure 9A, are placed close to each side of the coil so that, when it oscillates, it cuts the lines of flux and an alternating emf is induced. As explained for the pickup of Figure 7, here the coil is connected to the input of an audio amplifier with a transformer as shown in Figure 9B.

*   *   *

21. Although both operate on magnetic principles, explain briefly the main difference between the operation of the pickups of Figures 8A and 9A.

*   *   *

Crystal and Ceramic Pickups

Crystal and ceramic pickups are very popular because of their high output, simple connections to the audio amplifier input and, particularly in the case of the ceramic pickup, good fidelity. These types of pickup employ a crystal or ceramic element that generates a voltage when bent (piezo-electricity). The element is attached to the stylus assembly through a damping mechanism which controls the frequency response. Lateral movements of the needle due to the variations in the record groove cause the element to be twisted in accordance with the recorded sound wave. The resulting emf is applied to the input of an audio amplifier.

*   *   *

22. What principle is used in the operation of a ceramic pickup?

*   *   *

Stereo Pickups

Monaural recordings are generally laterally cut. Since

stereo material contains two channels of information there
must be two channels cut into each groove. There is 90°
between the channels in a groove. This is accomplished by
cutting each channel in a plane 45° from the surface of the
disk as shown in Figure 10A.

A simplified drawing of a stereo magnetic cartridge is shown
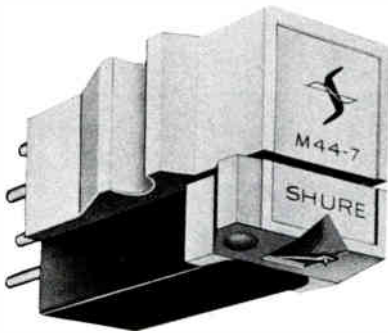
in Figure 10B. When the sty-
lus is resting in an unmodu-
lated groove, the armature is
equally spaced from each of
the pole pieces. As a result,
an equal amount of flux from
the permanent magnet is pres-
ent in each of the two pole
pieces. An equal steady flux
then cuts each coil and the
output from both Channel 1 and
Channel 2 is zero.

This stereo magnetic cartridge is typical of
those used in the broadcast industry. Its fre-
quency response is 20 Hz to 20 kHz at 11 mv
per channel and more than 25 dB separation
between channels. The cartridge uses a .0007
inch diamond stylus and tracks between 1-1/2
and 3 grams.

Courtesy Shure Bros.

When only one of the channels
is modulated, the stylus varies
about one of the pole pieces
while staying a fixed distance
away from the other pole piece.
Thus, a varying voltage is de-
veloped across one of the pickup coils while the voltage
across the other coil remains zero.

During the reproduction of a stereo signal, the stylus motion
in the groove is such that the armature motion causes the
flux field through both pole pieces to vary. The signals
developed in the coils correspond to the original signals
which were recorded.

Stereo cartridges are made in the magnetic, variable re-
luctance, moving coil and ceramic form for broadcast use.
Stereo cartridges can generally be used for either monaural
or stereophonic playback. Exact instructions for their use
are generally included with the pickup cartridges.

*   *   *

23. A stereo pickup is sensitive to stylus motion in two directions, thus responding to two channels of information. True or False?

*   *   *

THE PLAYBACK STYLUS

Many types of materials have been used for playback styli in the past. Some of these materials are: sapphire, osmium, steel, ruby and diamond. Of these the diamond is about the most popular for broadcast studio use. Due to the hardness of the diamond its life is much longer than that of other materials. The diamond is the hardest natural element known to man.

Although many people refer to a playback stylus as a "phonograph needle", it is important to note that the stylus actually has a rounded tip, and is polished to provide a smooth surface. A sharp stylus would be very undesirable, since it would ruin the record groove.

The approximate shape of a playback stylus in a recorded groove is shown in Figure 11, where the sides of the stylus touch the modulated grooves. The radius of curvature of the stylus tip should be about .003 inch or less. Styli for standard groove records have a typical width of 3 mils at the points where the stylus touches the groove walls. For comparison, typical styli for microgroove records have widths of about 1 mil. Stereo playback styli are typically .7 mil wide at the contact point.

Note how little of the playback stylus rests on the side walls of the groove. Only a small surface of the stylus is actually touching the walls. Though resting with a weight of only a few grams (1.5 to 4 grams is typical), the contact surface is so small that the weight per square inch is very high. With this in mind, you can easily see the reason for record and stylus wear. With any imperfections in either

the playback stylus or the record, both will suffer. For example, a chipped stylus may ruin a record in one playing.

*   *   *

24. For best reproduction, the playback stylus must match the shape of the groove perfectly, so that the tip rests on the bottom of the groove and the sides of the stylus make perfect contact all along the groove wall. True or False?

25. What is the likely result of a worn stylus?

*   *   *

EQUALIZATION IN DISK RECORDING

With the techniques used in modern recording systems, the higher frequencies tend to produce less stylus swing than lower frequencies of equal amplitude. If a record is cut in

The above stereophonic transistorized phono reproduction equalizer is self-contained, including its own power supply. It features three types of stereo equalizotion plus equalization to obtain a mono-phonic signal from a stereo disk.

Courtesy Gates Radio Compony

this way, the bass notes override the higher frequencies. In extreme cases, the stylus swing at low frequencies may be great enough to overlap into adjacent grooves. In commercial recording systems, this is prevented by boosting the higher frequencies and attenuating the lower frequencies at a predetermined rate before applying the signal to the recording head. This process is called EQUALIZATION.

The disk recording industry (Record Industry Association of America) has adopted the standard equalization illustrated by the solid line curve of Figure 12 for recording. This is known as the RIAA equalization curve. When a record is cut according to this curve, frequencies above 1 kHz are boosted at a rate that increases with frequency. Frequencies below 1 kHz are attenuated at a rate that increases as frequency decreases.

*   *   *

26. Why is equalization used in modern disk recording?

27. In using the RIAA equalization curve for recording, high frequencies are attenuated and low frequencies are boosted at the same rate. True or False?

*   *   *

When a record is played back, attenuated lows must be increased to their normal level, and the higher frequencies reduced to their normal level, to compensate for the equalization applied at the recording studio. The dashed line playback curve of Figure 12 is a mirror image of the solid line recording curve. The compensation network is normally found in the preamplifier of the broadcasting station playback system.

Notice that the frequency scale of Figure 12 ranges from 20-20,000 Hz, which is considered to be the audio range. The vertical scale is calibrated in decibels. If the recording curve and the playback curve were added together, point by point, you would theoretically have a flat frequency response from 20-20,000 Hz.

*   *   *

28. In playback, the higher frequencies must be attenuated, and the lower frequencies boosted, to compensate for the equalization applied in the recording system. True or False?

*   *   *

MAGNETIC TAPE RECORDING

Magnetic tape recording is used more now in broadcasting studios than ever before. Magnetic sound tracks are also used with some motion picture systems. Magnetic tape is used for recording commercials, for recording music which can be played on the air at any time, and for storing complete programs which may be used many times.

The magnetic tape recorder is a versatile device which can store much information in a small area. The basic reel-to-reel tape recording system is illustrated in Figure 13. In this unit, the recording amplifier receives the input signals, amplifies them, and applies them to the recording head. The recording head produces a varying magnetic field which records the information on the magnetic tape.

When a recorded tape is fed past the reproduce head, the magnetic patterns on the tape induce signal voltages in the reproduce head. The output of the reproduce head is applied to an amplifier which drives a speaker, or in the case of a broadcast system, is used to modulate the transmitter.

Magnetic tape consists of a plastic base coated with a layer of minute iron oxide particles. When an external magnetic field is applied to the tape, the oxide particles are magnetized according to the direction and strength of the field. A record of the information to be recorded is stored in the form of various states of magnetization along the length of the tape. The tape retains this state of magnetization until it is remagnetized by another external field.

*   *   *

29. What is the basic function of the recording head in a magnetic tape recording system?

*   *   *

THE RECORDING HEAD

The recording head is the device which changes the electri-

cal signals into magnetic signals and applies them to the
tape. For sound recording, the tape is moved past a sta-
tionary head. The recording head consists of a coil assem-

bly on a magnetic core in the
form of a closed ring. There
is a short nonmagnetic gap at
the point where the head con-
tacts the tape. Another gap
at the rear of the head balances
out the magnetic circuit. The
basic head arrangement is
shown in Figure 14.

The magnetic surface of the
tape contacts the magnetic
head at the gap, in effect com-
pleting the magnetic path in the
core. As the tape is moved
past this gap, magnetic lines
tend to take the lower reluc-
tance path through the oxide
coating of the tape, rather
than cross the gap. This mag-
netizes the segment of tape
within the gap according to the
signal applied to the head. As

A greatly enlarged photograph of magnetic
tape shows how the signal currents in the re-
cording head have created tiny magnetic
fields on the tape.
Courtesy Minnesota Mining and Mfg. Co.

the tape segment leaves the gap, it retains the magnetism
it received while it was in the gap.

*   *   *

30. In a magnetic tape recorder, at which point on the recording
    head does recording take place?

*   *   *

BIASING

If a curve is plotted of the flux density in the oxide material
of a magnetic tape for different values of magnetizing force,

a definite residual magnetization property of iron is noted. This **B-H CURVE**, as it is called, is shown in Figure 15. The horizontal axis represents the magnetizing force (H), and the vertical axis represents the resulting flux density (B) of the tape material.

Point O represents zero magnetization. Beginning at point O, if magnetic force of a given polarity (+H) is applied to the tape, the section of tape exposed to this force takes on magnetization of the +B polarity. Assuming the magnetizing force rises to $+H_{max}$, the magnetization increases to $+B_{max}$ as indicated by curve OA.

Removing the magnetizing force does not cause the magnetization of the tape material to drop to zero. Some residual magnetization remains, as represented by B_R in Figure 15. To reduce the magnetism to zero, a magnetizing force of opposite polarity (-H) is applied. Thus, the magnetism reduces to zero at point C.

As the negative magnetizing force is increased further, to $-H_{max}$, the magnetism is increased to negative saturation at point D. Again reducing the magnetic force to zero and then increasing it in a positive direction, the magnetism follows the curve from point D through $-B_R$ (at zero magnetizing force) to F, and from F to A. Therefore, with an alternating magnetizing force, the resulting magnetism follows the curve A-C-D-F-A.

*   *   *

31. If a segment of magnetic tape is magnetized by an external magnetizing force, the tape becomes completely demagnetized when the magnetizing force is removed. True or False?

*   *   *

When the magnetic material is placed in a gradually diminishing magnetic field that is periodically reversing polarity, the loops (A-C-D-F-A) become smaller as the magnetizing force decreases. If the path of the end points (A-D) of the

diminishing loops is plotted, a curve like Figure 16 is pro-
duced.   This curve is called the transfer curve or the re-
sidual magnetism curve for the magnetic material.

In the curve of Figure 16 there are only two sections that
are relatively linear. Since this is the magnetization curve
of the tape, a sine wave applied to the recording head alone
produces the distorted signal shown in Figure 17.   As you
can see, due to the nonlinearity of the transfer curve near
the origin, the recorded signal also is distorted.

In order to minimize this distortion, we first apply a high
frequency BIAS (Figure 18A) to the recording head.   Then
the signal (Figure 18B) is superimposed on the bias to form
the combination shown in Figure 18C. As shown in Fig-
ure 19, the net result is to shift the signal away from the
nonlinear portion of the magnetization curve. By using this
high frequency bias we can therefore operate on a fairly
linear portion of the curve.

The bias signal is usually a supersonic ac signal, well above
the high frequency limit of the audio range (30 kHz to 60 kHz
bias frequencies are common).   This signal is produced by
an oscillator circuit in the recorder.

*   *   *

32. What is the purpose of high frequency bias as used in magnetic
     tape recording systems?

*   *   *

PLAYBACK

During playback, the recorded tape passes a playback head
constructed much the same as the recording head. As each
small magnetized area on the tape passes across the head
gap, a voltage is induced in the coil at the frequency and
relative amplitude of the original recording signal.   Recall

that the voltage induced in a coil, which is cut by magnetic
flux lines, is proportional not only to the number of flux
lines, but to the speed with which they cut the coil.

A sine wave recorded on tape consists of two longitudinal
magnetic fields connected together by their like poles as
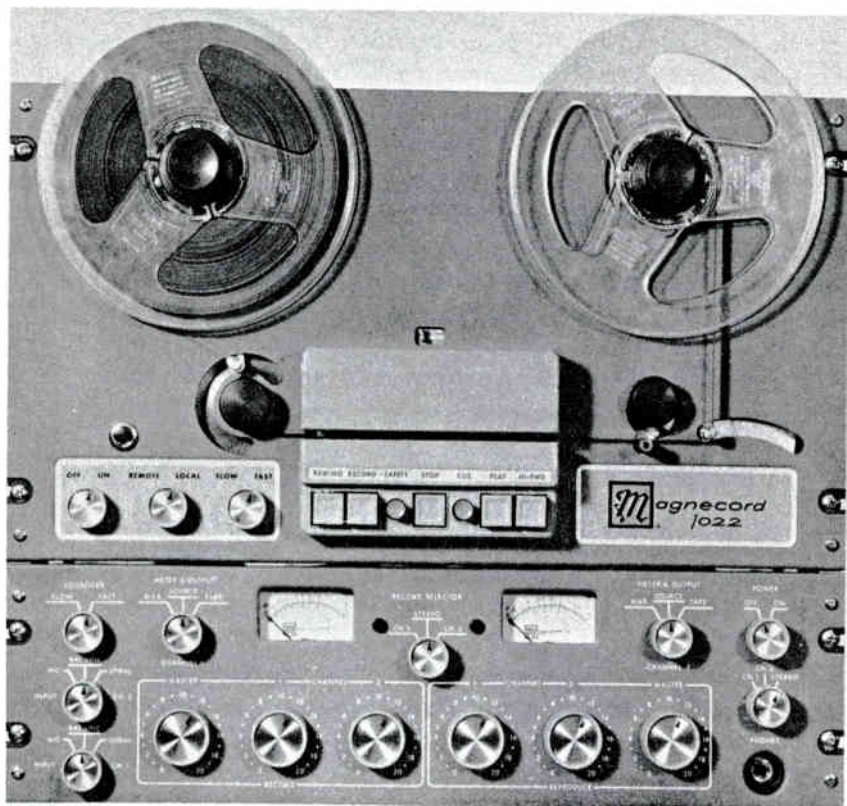
Reel-to-reel tape systems such as this ore used in broadcost studios. Eoch chonnel hos its own record
ond reproduce controls. Tope speeds are 7-1/2 ond 15 inches per second.

Courtesy Gotes Rodio Company

illustrated in Figure 20. The length of this magnet, or the
recorded wavelength, is determined by the applied signal
frequency, with all other factors remaining equal.   The
higher the frequency applied to the recording head, the
shorter the recorded wavelength.

*   *   *

33. The recorded wavelength in a magnetic tape system (a) in-
    creases, (b) decreases as the frequency of the applied sig-
    nal increases.

*   *   *

When two magnetic fields of given length and equal strength
are placed with like poles together, no flux lines flow from
end to end of the magnets because the ends have the same
magnetic polarity. When a playback head is used which has
a gap length equal to the wavelength of the recorded signal,
as shown in Figure 20, no voltage is induced in the coil be-
cause no flux lines pass through the core. On the other
hand, when the head gap is equal to one half the recorded
wavelength, maximum voltage is induced in the coil.

Since the recorded wavelength is a function of not only fre-
quency, but also tape speed, the head gap must be less than
the recorded wavelength at the highest frequency to be re-
corded. It is often designed to be no greater than one half
the wavelength of the highest frequency used.

*   *   *

34. For maximum induced voltage, the gap in the playback head
    must be equal to the wavelength of the recorded signal. True
    or False?

*   *   *

TAPE SPEED

The recorded wavelength (length of tape required for one
cycle of a recorded signal) is a function of tape speed and
signal frequency. This relation may be expressed as follows:

$$\text{Wavelength} = \frac{\text{Tape Speed}}{\text{Frequency}}$$

Transposing this relationship, we see that the frequency is

equal to the tape speed divided by the wavelength:

$$\text{Frequency} = \frac{\text{Tape Speed}}{\text{Wavelength}}$$

This relationship shows us that higher frequencies can be recorded at high tape speeds than at low tape speeds with a given playback head-gap.

*   *   *

35. Using a playback head with a given gap-width, higher frequencies can be recorded at high tape speeds than at low tape speeds. True or False?

*   *   *

Because of this relationship between tape speed and frequency, it is desirable to use the highest practical tape speed for good high-frequency response. Broadcast type recorders, which must have a response of 50 Hz to 15 kHz at an output of ±2 dB of reference level, often utilize tape speeds of 15 inches per second, and sometimes as high as 30 inches per second. In comparison, many tape recorders for home use have maximum speeds of 7.5 inches per second or even 3.75 inches per second. Increasing the tape speed reduces the length of program material that can be recorded on a given length of tape. However, for professional use this factor is secondary to good frequency response.

Figure 21 gives relationships between length of tape and the recording times for the four most popular speeds.   The times listed are for single track recording only.   When a double track recording is used the recording time can be doubled.

*   *   *

36. Suppose you plan to record a 30 minute program at a tape speed of 15 inches per second. Referring to Figure 21, at least how much tape would you need?

*   *   *

ERASURE

Tape can be erased and used over again an indefinite number of times. To erase a tape, a permanent or dc electromagnet can be used to magnetize the tape along its length to some constant magnetic condition, thereby removing any signal. However, this type of erasure introduces noise on the tape which is heard when the next recording is played back. The electronic erasing method, which is the most widely used, employs a supersonic signal applied to an erase head. Usually it is the same frequency as the biasing voltage (30 kHz to 60 kHz).

Referring back to Figure 15, the B-H curve shows the magnetic condition of a material which reaches saturation in both the positive and negative directions when subjected to an alternating flux.

Although most recorders include an erase system, bulk erasers such as the one shown here are also used for fast erasure. A bulk eraser provides a strong ac field that erases the entire reel of tape very quickly.

Courtesy Micratran

When the material is subjected to a gradually reducing magnetic flux, the loop ACDFA shrinks until it collapses to zero at approximately Point O. This represents complete demagnetization of the tape. This condition is shown graphically in Figure 22, illustrating the gradually reducing "hysteresis loop" formed by the B-H curves as the material or tape is removed slowly from a cyclic magnetic field.

*   *   *

37. What signal is commonly used to energize the erase head in a magnetic tape recorder?

*   *   *

TAPE EQUALIZATION

The impedance of the recording head in a magnetic tape re-

corder varies with frequency. This is due mainly to the inductive reactance of the coils, which tends to increase at high frequencies. As a result, the recording current at high frequencies is less than that at low frequencies for input signals of the same amplitude, and there is an inherent drop-off in high frequency response in the magnetic recording process.

To compensate for this loss in high frequency response, the high frequencies are boosted and the low frequencies are attenuated as illustrated by the solid line curve of Figure 23. This process is called **PRE-EQUALIZATION**. When the recording amplifier includes a pre-equalization circuit to compensate for the non-linear response of the recording head used in the recorder, the frequency response of the magnetization applied to the tape is relatively constant.

In playback, the relationship between recorded wavelength and playback head-gap size causes an inherent drop-off in low frequency response. To improve the frequency response, additional equalization is required in the playback amplifier. To distinguish it from the pre-equalization applied by the recording amplifier, the equalization in the playback amplifier is called **POST-EQUALIZATION**. A typical post-equalization curve is illustrated by the dashed line curve in Figure 23. Together, pre-equalization during recording and post-equalization during playback result in uniform frequency response throughout the audio range.

*   *   *

38. Pre-equalization is used to compensate for the inherent drop-off in low frequency response due to the relationship between recorded wavelength and playback head-gap size. True or False?

*   *   *

THE TAPE FEED SYSTEM

A typical tape feed system is shown in Figure 24, which il-

lustrates the means by which the tape is pulled past the
heads and wound up on the take-up reel. The tape deck, as
it is often called, includes three magnetic heads: a record-
ing head (R), playback head (P), and an erase head (E).
As the tape moves past the head assembly, it passes the
erase, recording and playback heads, in that order.

One of the main considerations in tape recording is the need
for absolutely constant tape speed past the head assembly.
The length of one cycle of the recorded signal is a function
of the tape speed and signal frequency applied. Therefore,
when the speed varies during recording, so does the wave-
length of the recorded signal. A very small variation, or
flutter as it is called, can be tolerated. However, this must
be a very small percentage of tape speed.

Consider what would happen if the tape were driven by sim-
ply driving the take-up reel. As the tape builds up on the
take-up reel, it increases the effective diameter of the reel.
If the reel is rotating at a constant speed, the tape speed
increases in proportion to the increase in diameter as the
tape builds up.

This increase in linear tape speed, using a standard reel,
may be from 2:1 to 5:1. Tape speed affects frequency re-
sponse to a great degree and, if this type of take-up is em-
ployed, the frequency response throughout the full length of
the tape does not remain the same.

*   *   *

39. What problem arises if the take-up reel in a tape transport is
    driven directly?

*   *   *

The solution to the problem of constant frequency response
is constant tape speed, as it passes the heads, throughout
the full recording time. Again, from Figure 24, if the
speed of the tape is to remain constant as it passes the head,
some means must be provided for allowing the take-up reel
to slow down as the tape builds up its effective diameter.

A clutch, used on the take-up reel, is one common method
of regulating the speed.   This clutch is adjusted to provide
just enough torque to wind up the tape, and just enough slip-
page to allow the speed of the reel to change according to
the tape tension.   The tape is pulled from the supply reel
by a CAPSTAN DRIVE.   The capstan, which is driven by a
constant speed motor, feeds the tape by pressure with a
capstan idler wheel at a constant speed past the heads.   The
mechanical units of a tape recorder are not dealt with in
great detail here. The primary interest is in the electronics
of the unit.

*   *   *

**40. How is the requirement of constant tape speed solved in mod-
ern recorders?**

*   *   *

The tape, when recording, is pulled past the three heads
shown in Figure 24 at a con-

This photograph shows the head assembly and
part of the drive assembly of a tape cartridge
playback system.

Courtesy RCA
Broadcast and Communication Product Div.

stant, linear speed. The erase
head, E, removes any trace
of previous recording from
the tape before it reaches the
record head. After the tape is
recorded by recording head R,
it passes playback head P.
This head can be connected to
an amplifier for monitoring of
the tape during recording.
The program from the moni-
tor is a fraction of a second
behind the actual program be-
cause of the distance between
the record and playback heads.
However, this delay is small
and provides the engineer with monitoring facilities for
checking the recording as it is being made.

On playback -- after the tape has been rewound -- the erase

head, E, the record head, R, and the bias circuits are de-
energized. Again the tape is pulled past playback head P
and, with associated amplifiers, the program recorded on
the tape can be reproduced any number of times. Most tape
recorders automatically disconnect the recording and erase
heads when switched to the playback position so there is no
possibility of accidentally erasing the tape during playback.

*   *   *

**41. Why is it important to disable the erase head during playback
of a recorded magnetic tape?**

*   *   *

Rewind is accomplished by simply reversing the direction
of tape travel. Thus, in Figure 24 the take-up reel becomes
the supply reel, and vice versa, during rewind. It is de-
sirable to rewind the tape much faster than it is to record
or play back. Most recorders provide a means of switching
from capstan drive to direct reel drive with a high speed
ratio, so that rewind speed is as high as 20 times the re-
cording speed. Most broadcast tape recorders also provide
facilities for fast forward operation so that the tape can be
advanced rapidly to a desired section of the recording for
each cueing.

During rewind or fast forward operation, the tape is usually
held away from the heads by mechanical "tape lifters". If
the tape contacts the heads during fast rewind it causes ex-
cessive wear, and the particles deposited due to the abra-
sive action necessitate frequent cleaning of the heads.

When it is desired to stop the tape, during rewind or fast
forward speeds, a braking system for the reels must be
provided. Otherwise the reels continue to spin due to mo-
mentum and, after the motor is stopped, there is the pos-
sibility of "spilling" tape. On most units, the reels are
braked by mechanical braking shoes as soon as the recorder
is switched to the stop position.

*   *   *

42. During rewind, the tape must be pressed firmly against the head assembly. True or False?

*   *   *

DUAL-TRACK RECORDING

The recording time available on a given length of tape may be increased without reducing the speed by employing dual-track recording. Figure 25A shows where the two tracks are recorded on a standard 1/4 inch tape. The recording is made on one track to the end of the tape, and then the reel is turned over and the second track is recorded.

The problem of limiting or restricting the recording flux to a track less than one half the width of the tape is easily accomplished by making less than one half of the core of laminated iron. The remainder is of copper which will not conduct magnetic lines of force readily. Therefore, as the tape passes over the head, as shown in Figure 25B, only that portion in contact with the laminated iron core is recorded. The other half is not magnetized until the reel is turned over and the tape is fed through again the same way.

The playback head on a dual-track recorder is constructed in the same way as Figure 25B in order to pick off only one of the recorded tracks for reproduction. The erase head for a dual-track machine is constructed so that the laminated iron part of the core is exactly one half the width of the tape, rather than less than one half as are the record and playback heads. This insures complete erasure of the entire half of the tape desired. The relative placement and width of the erase track, with respect to the record track, is illustrated in Figure 26.

*   *   *

43. Longer playing time for a given length of tape can be provided by (a) single-track recording, (b) dual-track recording.

44. It is sometimes desirable to "edit" a recorded tape by cutting out certain sections and splicing in replacement tapes. Can you think of a problem that might present itself if a dual-track recording is edited in this way?

*   *   *

STEREO TAPE RECORDING

Stereo tape recordings may be made using two-track or four-track tapes. During two-track stereo recording, one channel is recorded on one track while the other channel is being recorded on the other track. For stereo playback, a pickup head must remove the signals from both tracks at the same time. The total playing or recording time of a two-track stereo tape is the same as for a single-track tape of the same length.

Home tape systems and some broadcast studios use a four-track stereo system. Figure 27 shows the tracks on a section of tape. Tracks 1 and 3 contain one set of stereo information. One channel is recorded on track 1 and the other channel is recorded on track 3. After the tape has been completely recorded in one direction, the take-up and supply reels can be switched, the tape threaded through the machine again, and tracks 2 and 4 can be recorded. Twice as much stereo recording time can be obtained from a piece of tape in a four-track system than in a two-track system.

*   *   *

45. What is the advantage of four-track stereo recording as compared to dual-track stereo recording?

*   *   *

AUTOMATIC TAPE CARTRIDGES

The automatic tape cartridge is becoming a very important part of modern broadcasting studios. This cartridge does away with the loading of tapes and the rewinding of tapes after they have been played.

When the tape is threaded on an automatic tape cartridge it is no different from the standard tape reel except that the
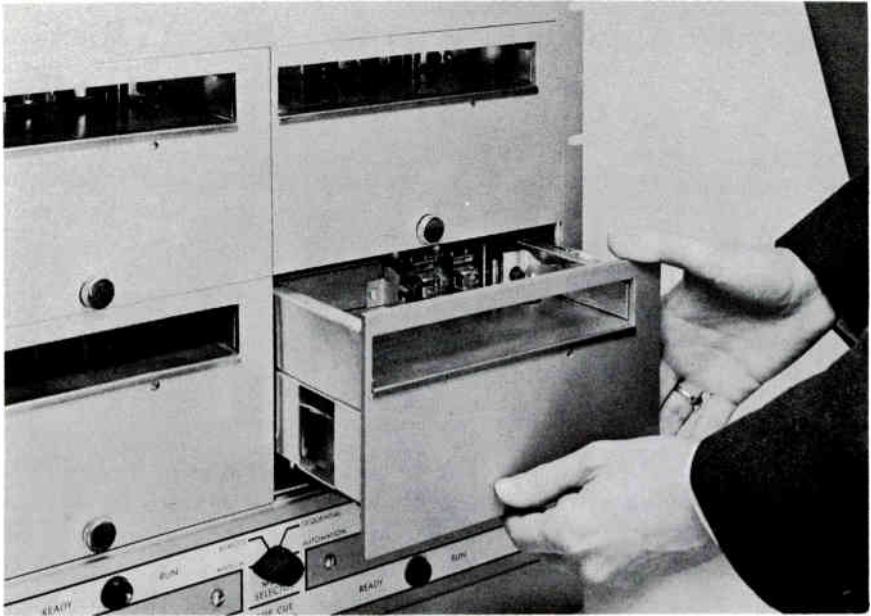
Roll-out tape transports provide accessibility for routine maintenance of the cartridge tape decks.
Courtesy RCA
Broadcast and Communication Product Div.

beginning of the tape is at the hub of the reel and the end is at the outside. This is shown in Figure 28A.

One common type of tape cartridge is called the continuous loop. This type of cartridge can be played continuously without rewinding. When splicing a tape for a continuous loop you splice together the beginning of the tape, which is at the hub, and the end of the tape as shown in Figure 28B. This gives you a continuous loop of tape which will play continuously. As the tape is taken out of the center of the reel it is rewound on the outside of the reel.

Monaural continuous loop tape cartridges are often recorded with two tracks. One track contains the desired program

PRACTICE EXERCISE SOLUTIONS (Continued)

25. high

26. True

27. True

28. 56.5

29. 60
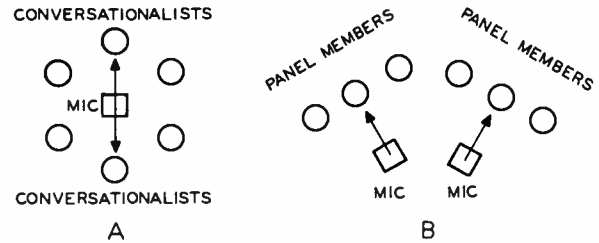
FIGURE 24
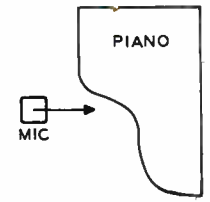
FIGURE 25
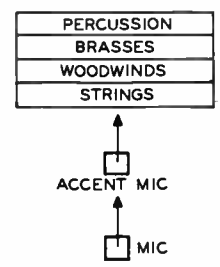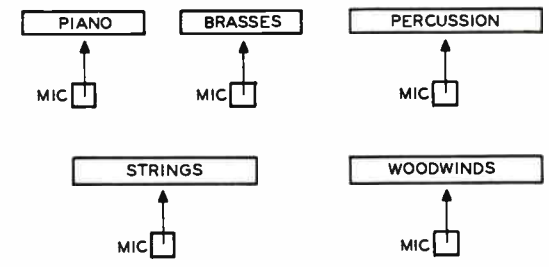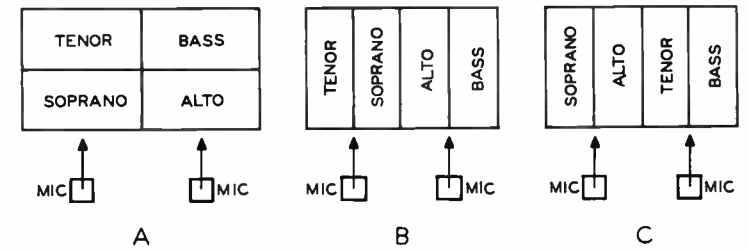
FIGURE 26

FIGURE 27

FIGURE 28

FIGURE 29

QUESTIONS

Example: An animal commonly found in a farmyard is the

(A) tiger. (B) chicken. (C) leopard. (D) cougar.

LESSON CODE

4712A

1. The two components of sound energy are

(A) pressure and velocity. (B) speed and frequency. (C) compression and expansion. (D) high and low pressure points.

2. The operating principle of the dynamic microphone is

(A) the piezoelectric effect. (B) reverberation time. (C) electromagnetic induction. (D) variable resistance.

3. Two types of piezoelectric microphones are the

(A) pressure and velocity types. (B) single-button and double-button types. (C) dynamic and static types. (D) crystal and ceramic types.

4. The distance between the diaphragm and the backplate of a condenser microphone

(A) depends on electromagnetic induction. (B) must not exceed 56.6 ft. if loss of intelligibility is to be minimized. (C) determines the voltage across the plates of the unit. (D) is not important to the operation.

5. If the carbon granules in a carbon cup are compressed, the resistance

(A) remains the same. (B) decreases. (C) increases. (D) drops to zero.

6. A microphone containing a narrow metallic ribbon that responds to the velocity component of a sound is called a

(A) velocity microphone. (B) dynamic microphone. (C) ceramic microphone. (D) carbon microphone.

7. Referring to the chart of Figure 19, the microphone with the lowest output is the

(A) omnidirectional condenser microphone. (B) velocity microphone. (C) omnidirectional carbon microphone. (D) dynamic microphone.

8. Long lengths of high impedance microphone cable sharply attenuate

(A) all audio frequencies. (B) low audio frequencies. (C) high and low audio frequencies. (D) high audio frequencies.

9. The unequal transmission of high and low audio frequencies in shielded cable is compensated for by the use of

(A) an equalizer. (B) a step-up transformer. (C) a step-down transformer. (D) high capacitance cable.

10. Reverberation time is

(A) the time for one cycle of vibration. (B) the time required for the intensity of a sound to drop to zero after the original sound has stopped. (C) the time required for the intensity of a sound to drop 60 dB after the original sound has stopped. (D) the time required for sound to travel 113 ft at room temperature.

material. The other track contains signals for stopping the tape at predetermined points. Stereo tapes generally are recorded with three tracks. Two tracks are for the stereo signal. The third track is for the controlling signals.

This cartridge can now be placed into a cartridge playback unit and used. Broadcasting studios use a cartridge such as this for many of their daily operations, such as commercials and broadcasting of music.

*   *   *

46. In a three-track continuous loop stereo tape cartridge, two of the tracks provide the two channels of stereo information. What is the purpose of the third track?

*   *   *

A TYPICAL TAPE RECORDER

Figure 29 shows a tape deck and control panel typical of professional recorders used in broadcast work. This recorder operates at either $7\frac{1}{2}$ ips or $3\frac{3}{4}$ ips. At $7\frac{1}{2}$ ips the frequency response is from 45 Hz to 18 kHz ±2 dB. At $3\frac{3}{4}$ ips the frequency response is from 35 Hz to 8 kHz ±2 dB. The reel sizes are 5, 7 and 8 inch.

This recorder will rewind a full 1200 feet of tape in 80 seconds. Playback time in broadcasting is extremely important due to the close timing followed in broadcast production. The playback time of this recorder is within .2% of the recording time. In other words, if a 29 minute and 30 second show is recorded, the playback time will be within 3.6 seconds of 29:30.

In setting up the recorder of Figure 29, the tape to be recorded is placed on the left, making sure that the oxide coated side of the tape is facing the heads. The oxide coating is the dull side, compared to the shiny plastic base. The tape is threaded as shown. The heads are in the shielded compartment above the tape drive control panel. The capstan drive is just to the right of the head assembly.

To set up the machine for recording, the input source, such as a microphone or the output of a phonograph playback unit, is connected to an input at the rear of the recorder. The recorder has provisions for three inputs: microphone, balanced line, or unbalanced line. The desired input is selected by the INPUT SELECTOR switch on the panel. The tape speed can be set to FAST ($7\frac{1}{2}$ ips) or SLOW ($3\frac{3}{4}$ ips) by means of the speed selector on the tape deck. The faster speed is usually preferred for music, whereas the lower speed can be used for voice recordings.

The EQUALIZER switch on the control panel is set to correspond with the tape transport speed.

The METER & OUTPUT selector switch is set to the SOURCE position. The recorder then monitors the signals being recorded, and the VU meter on the panel indicates the recording level. With both power switches ON, you can make a preliminary setting of the RECORD LEVEL gain controls. Everything is now ready for recording.

Depress first the SAFETY button and then the RECORD button. The RECORD button can only be depressed when the SAFETY button is depressed. This is a precaution which prevents the erase signal from being applied when the tape is being played back. With the RECORD button depressed and latched, the record indicator lamp should light, indicating the unit is recording. The RECORD LEVEL gain controls can be adjusted for the desired level of recording, as read on the VU meter. The recorded signal or the signal being recorded may now be monitored by headphones inserted in the PHONES jack, or by a built-in speaker if headphones are not used. The monitoring level is controlled by the REPRODUCE and MONITOR gain controls.

The playback procedure is as follows: First connect an amplifier to the desired connections at the rear of the unit. In a broadcast application, the output of the recorder would be connected to the audio control console. Set the SPEED SELECTOR switch and the EQUALIZER switch to the speed

at which the tape was recorded.   Now set the METER &
OUTPUT selector switch to TAPE, and the RECORD LEVEL
gain controls to 0. Turn both power switches ON. Wait ten
seconds for the circuits to stabilize, and depress the PLAY
button.   Adjust the REPRODUCE and MONITOR gain con-
trols for the desired output level.

If the output signal overloads the VU meter, the METER &
OUTPUT switch can be set to the BIAS position.   The bias
signal only is then applied to the meter, and relatively large
signals can be fed to the equipment connected to the output
of the recorder.

The recorder of Figure 29 includes a remote control fea-
ture which is set up by the REMOTE-LOCAL switch on the
tape transport unit.   For normal recording or playback,
this switch is set to the LOCAL position.   In the REMOTE
position, the recorder can be started and stopped in either
recording or playback by a remote switch connected to the
back of the unit.

MAGNETIC DISKS

Disks coated with a magnetic film are also used in the
broadcast industry.   The disks look somewhat like groove-
less phonograph disks with a magnetic coating.   Compared
to tape cartridges, the magnetic disk is generally less ex-
pensive to produce.   Because no stamper is required, du-
plicate magnetic disks cost less to reproduce in small lots
than phonograph records.

During recording, the magnetic disk or mat rotates below
a magnetic recording head. As the disk rotates, the head
moves from the outside of the disk to the center.   As the
disk travels below the recording head, a magnetic pattern
is set up in the magnetic coating of the disk.

For playback, the magnetic disk is placed on a special turn-
table.   The disk and reproduce head are brought together.
As the disk rotates below the head, the information stored

magnetically on the disk results in an electrical output from
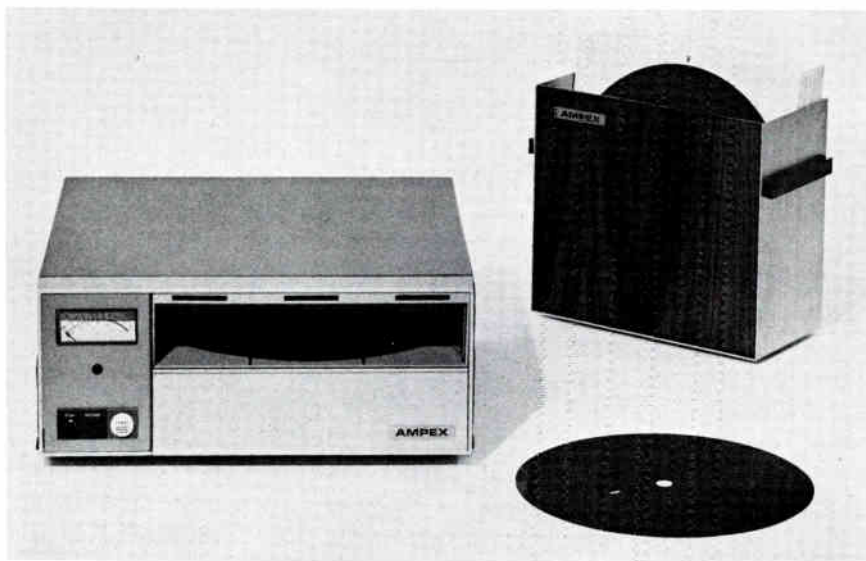
The CUE-MATIC recorder/reproducer at the left uses magnetic mats such as that shown at the right. A storage container is pictured above the mat.

Courtesy Ampex Corp.

the head.   During playback, the head travels from the out-
side of the disk toward the center.

After the disks have served their function they can be erased
and rerecorded. Because of their thinness, many magnetic
disks can be stored in a small area.

SUMMARY

Not all material broadcast is "live". Much of it is recorded
on phonograph records.   Commercials and other program
material are often recorded on magnetic tape and magnetic
disks.   The broadcast quality depends on the quality of both
recording and playback. The received signal will be no bet-
ter than the recorded signal or the signal from the playback
unit.

Much of the music and some of the commercials used in broadcasting are recorded on vinyl or acetate disks. Playback in the studio is generally done with magnetic or ceramic cartridges. Because of the many hours of stylus use, most broadcast cartridges use diamond tipped styli.

Magnetic recording and playback systems are becoming more popular. Reel-to-reel and automatic cartridges are used for music, commercials and whole or partial programs. In addition to these, magnetic disks are also being used.

IMPORTANT DEFINITIONS

B-H CURVE - A curve which represents the magnetic prop-
erties of a material. A plot of flux density (B) for
various values of magnetizing force (H).

BIAS - In magnetic tape recording, a voltage applied in
combination with the signal to be recorded in order to
shift the signal to the most linear region of the trans-
fer curve.

CAPSTAN DRIVE - In a reel-to-reel magnetic tape trans-
port, a rotating spindle used to drive the tape at a
uniform speed past the tape heads.

CUTTING HEAD - A unit that converts electrical signals to
mechanical motion, used to drive the stylus that cuts
the groove in a phonograph record. Also called a RE-
CORDING HEAD.

CUTTING STYLUS - A chisel-like stylus used to cut the
groove in a phonograph disk.

EQUALIZATION - [EE kwahl i ZAY shun] - The process of
boosting or attenuating certain frequencies in record-
ing and playback units to compensate for losses in
frequency response inherent to the system.

PICKUP CARTRIDGE - The unit that converts the motion of
a playback stylus in a record groove to an electrical
signal. Also called a PLAYBACK CARTRIDGE.

PITCH - In disk recording, the number of grooves per inch
of recording radius.

PLAYBACK CARTRIDGE - See PICKUP CARTRIDGE.

IMPORTANT DEFINITIONS (Continued)

PLAYBACK STYLUS - The stylus that rides in the groove of a phonograph record, and couples the groove variations to the playback cartridge, where they are converted to electrical signals.

POST-EQUALIZATION - In magnetic tape playback, the process of boosting the low frequencies and attenuating the high frequencies to compensate for the inherent nonlinearity of the playback process.

POWER AMPLIFIER - An amplifier which increases the power of an input signal to a level that will efficiently drive a loudspeaker or serve as the modulating signal for a transmitter.

PREAMPLIFIER - An amplifier designed to handle small signals and amplify them to a level that will efficiently drive a power amplifier.

PRE-EQUALIZATION - In magnetic tape recording, the process of boosting the high frequencies and attenuating the low frequencies in the recording amplifier to compensate for the inherent nonlinearity of the recording process.

RECORDING HEAD - In disk recording systems, the unit that converts electrical signals to mechanical motion which drives the cutting stylus. In magnetic tape recorders, the unit that converts electrical signals to a varying magnetic field which magnetizes the tape.

STROBOSCOPIC DISK - [STROH boh SKAHP ik] - A disk used to check the speed of a phonograph turntable. Marks on the rotating disk, when viewed under a fluorescent light, appear to stand still when the turntable is rotating at the correct speed.

STUDENT NOTES

STUDENT NOTES

STUDENT NOTES

PRACTICE EXERCISE SOLUTIONS

1. stylus

2. False -- The master is a metal negative of the original recording and cannot be used for playback.

3. In response to electrical signals, a recording head drives a cutting stylus which cuts a varying groove in the record. The pickup cartridge works in the opposite manner -- the groove variations in the record cause mechanical motion of the pickup stylus, and the pickup cartridge produces an electrical output signal.

4. The output of a playback cartridge is usually too small to drive a power amplifier, and thus must be "pre-amplified" to a suitable level.

5. lateral and vertical

6. Lateral cutting is usually used for monaural disk recording, and a combination of lateral and vertical cutting is used for stereophonic recording.

7. In Figure 1A the stylus moves up and down to produce widening and narrowing of the groove walls, but the center of the groove does not vary. In Figure 1B the lateral movement of the stylus causes the groove to "move" from side to side, but the width of the groove remains essentially constant.

8. False -- As a matter of fact, it is the ability of the system to produce two separate "channels" of information in the two walls that permits stereophonic reproduction.

9. vinylite

10. The maximum swing of the recording stylus must be limited to prevent overlapping into adjacent grooves.

11. (b) narrower

12. (a) stand still.

13. True
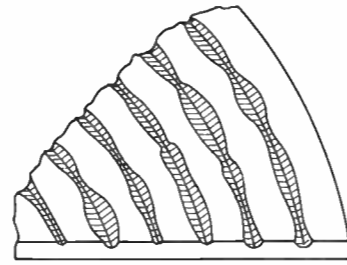
A

B

C
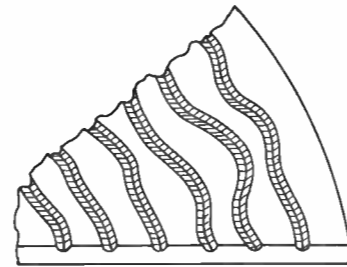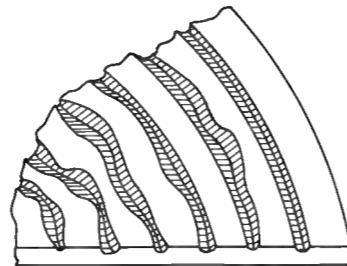
FIGURE 1
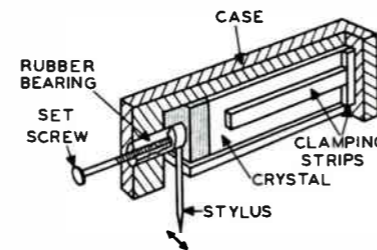
FIGURE 2
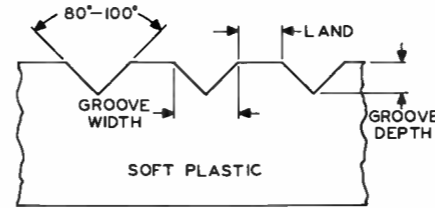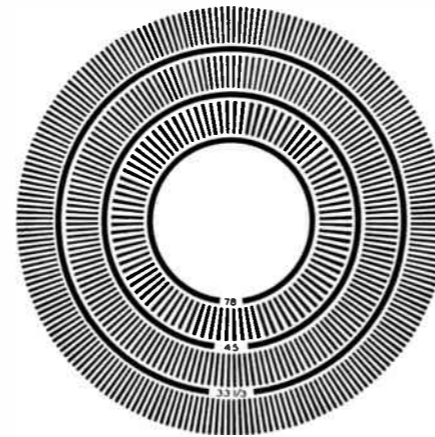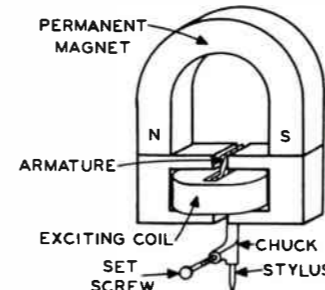
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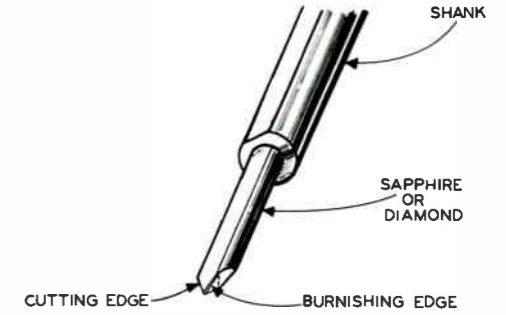
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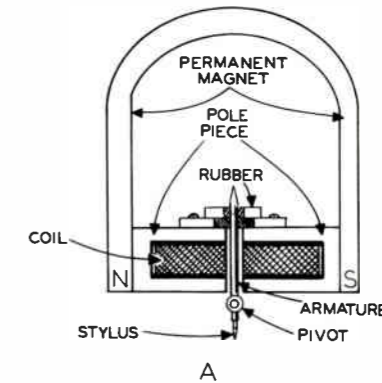
FIGURE 5

FIGURE 6

A
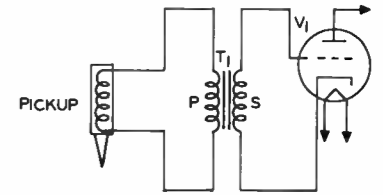
B

FIGURE 7
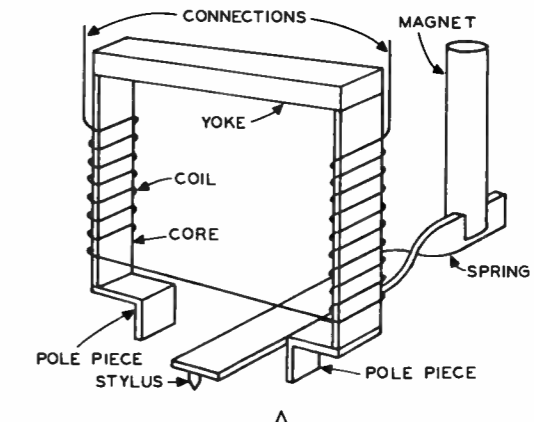
A
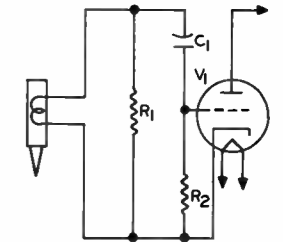
B

FIGURE 8

4715
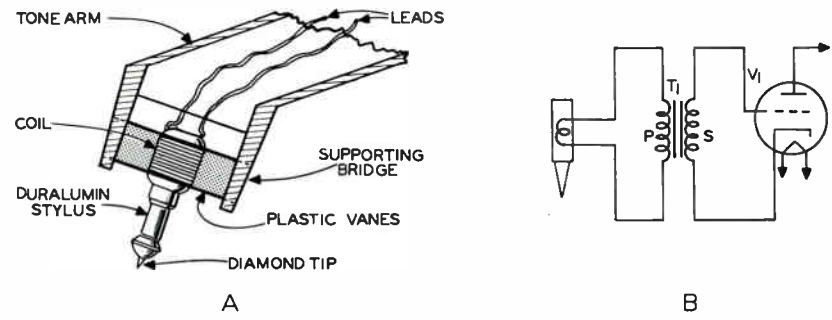
4715

TONE ARM
LEADS
COIL
SUPPORTING
BRIDGE
DURALUMIN
STYLUS
PLASTIC VANES
DIAMOND TIP

A

T₁
P S
V₁

B

FIGURE 9

STYLUS
DISK
SURFACE
CHANNEL 2
MODULATION
CHANNEL 1
MODULATION

A

MAGNETIC FLUX
CHANNEL 2
OUT
ALNICO 5
MAGNET
N
CHANNEL 1
OUT
S
FLOATING
ARMATURE
PICKUP
COILS
POLE PIECE
DIAMOND STYLUS

B

FIGURE 10

60°
RADIUS

FIGURE 11

20
15
10
+
5
dB   0
−
5
10
15
20
20 50 70 100   2   4 6 8 1   2   4 6 8 10 20
K   K K K K   K   K K K K   K
FREQUENCY IN Hz
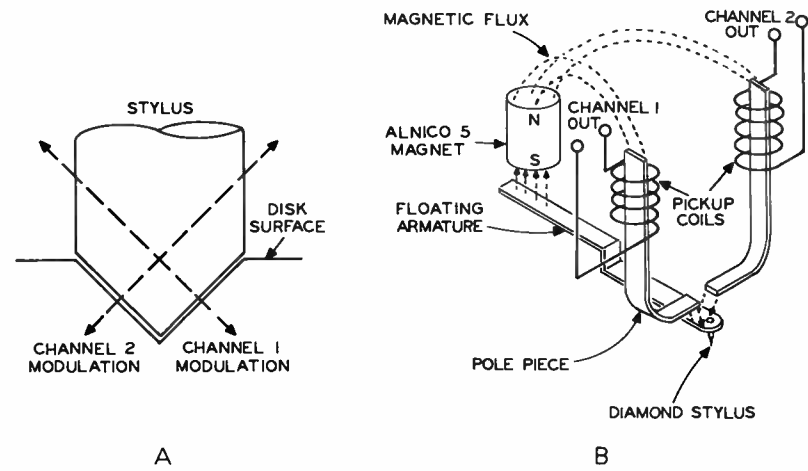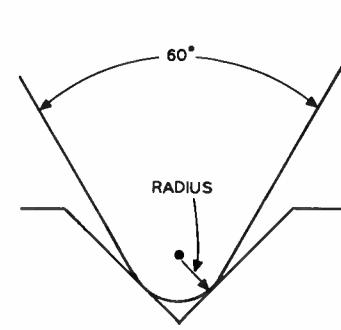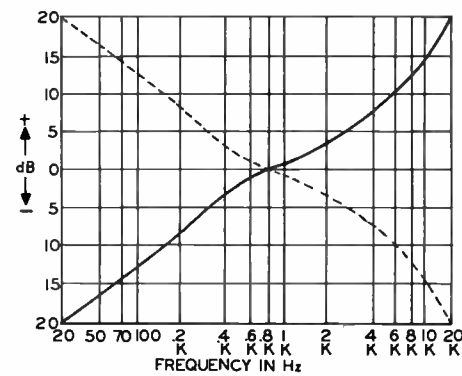
FIGURE 12

14. A hard material such as sapphire or diamond is used so that the cutting stylus will retain its sharp edge for a reasonable number of cuttings. Softer materials would tend to wear away rapidly, requiring frequent replacement.

15. The angle is governed by the type of cutting head, the type of material to be cut, and the shape of the cutting stylus.

16. magnetic, variable reluctance, moving coil, and ceramic or crystal

17. (b) zero.

18. The resulting voltages are of opposite polarity.

19. reluctance

20. (a) aid each other.

21. In the variable reluctance pickup (Figure 8A), the stylus motion varies the reluctance of the magnetic circuit, and thus causes an expanding or collapsing magnetic field to cut the stationary coils. In the moving coil pickup (Figure 9A), the field is fixed and the stylus motion causes the coil to move, thus cutting this stationary field.

22. piezoelectricity -- A ceramic element generates a voltage when subject to mechanical stress.

23. True

24. False -- The contact area between the playback stylus and groove wall is very small. The stylus rides on the walls, and the tip does not touch the bottom of the groove.

25. A worn stylus can damage the delicate grooves of a record. The stylus usually develops sharp edges as it wears, and can then cut into the groove walls to damage the record.

26. Equalization is used to prevent the lower frequencies from causing greater cutting stylus swings than those produced by high frequency signals of equal amplitude.

FIGURE 13

FIGURE 14

FIGURE 15

FIGURE 16

FIGURE 17

FIGURE 18

FIGURE 19

FIGURE 20

FIGURE 21

FIGURE 22

FIGURE 23

FIGURE 24

A

B

FIGURE 25

PRACTICE EXERCISE SOLUTIONS (Continued)

27. False -- It is the low frequencies that are attenuated, and the high frequencies that are boosted.

28. True

29. The recording head produces a magnetic field which varies according to the applied signal. The resulting field magnetizes the tape to produce a record of the input signal.

30. Recording takes place in the gap. More specifically, the recording takes place at the trailing edge of the gap, as the segment of tape is just leaving the gap.

31. False -- The tape retains a certain amount of magnetism even though the magnetizing force drops to zero. To demagnetize the tape, magnetic force of opposite polarity must be applied.

32. The bias is used to minimize distortion caused by the non-linear transfer characteristic curve of the tape.

33. (b) decreases

34. False -- A head gap equal to the wavelength of the recorded signal would result in zero induced voltage.

35. True

36. 2400 feet

37. The high frequency bias signal

38. False -- This is the purpose of post-equalization, which is provided in the playback amplifier.

39. The tape speed increases as the tape builds up on the take-up reel, and the frequency response varies from one end of the tape to the other.

40. The tape is driven by a capstan arrangement which feeds the tape past the heads at a constant speed. A clutch system on the take-up reel causes the reel to turn just fast enough to take up the tape fed to it by the capstan drive.

FIGURE 26

FIGURE 27

FIGURE 28

FIGURE 29

4715
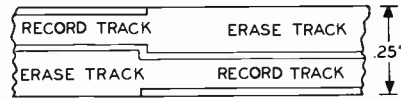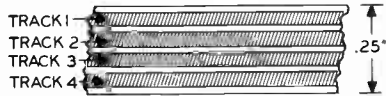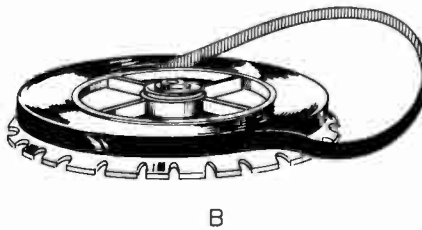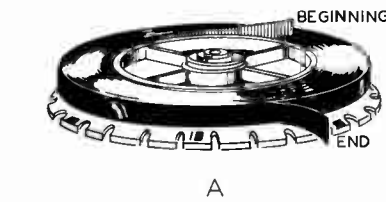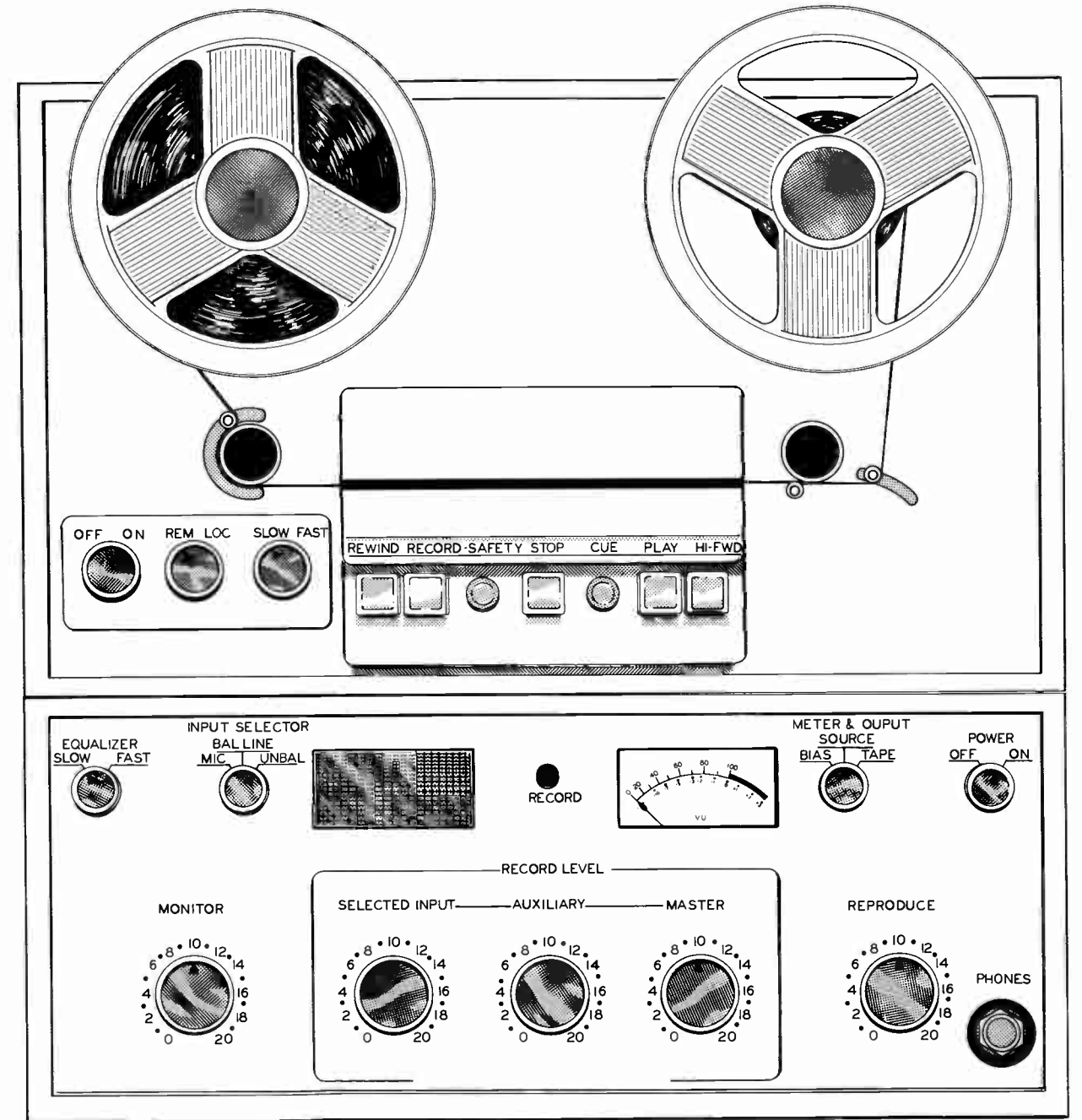
PRACTICE EXERCISE SOLUTIONS (Continued)

41. If the erase head were energized, it would erase the recorded material on the tape.

42. False -- The abrasive action of the tape moving past the heads at high speed would cause tape oxide particles to collect on the heads, causing excessive head wear and necessitating frequent cleaning of the heads.

43. (b) dual-track recording.

44. If a section of one track on a dual-track recording is to be cut out, the corresponding section on the second track is also cut out. Therefore, one track cannot be edited without destroying the material on the other track.

45. Four-track recording offers increased playing time compared to dual-track recording.

46. The third track carries control information used to automatically stop the tape at desired points.

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question, as illustrated in the example below.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

LESSON CODE

4715A

Example: A young cat is referred to as a
(A) colt. (B) kitten. (C) puppy. (D) calf.

1. Current monaural recordings for home and broadcast use are made using
(A) vertical cutting. (B) modulation of only one groove wall. (C) a combination of vertical and lateral cutting. (D) lateral cutting.

2. In disk recording terminology, the term pitch refers to
(A) the speed of the record. (B) the number of grooves per inch. (C) the angle of the groove walls. (D) the shape of the equalization curve.

3. A device used to check the speed of a turntable is the
(A) stroboscopic disk. (B) RIAA equalization curve. (C) cutting head. (D) variable pitch cutting lathe.

4. In the pickup cartridge of Figure 8A, the stylus motion causes changes in the
(A) piezoelectric properties of the coils. (B) position of the permanent magnet. (C) positions of the coils. (D) reluctance of the magnetic path.

5. Using the stereo magnetic cartridge of Figure 10B, if only one channel is modulated,
(A) the output of one pickup coil is zero. (B) the ouputs of both pickup coils are zero. (C) the pickup coils produce equal outputs. (D) the pickup coils produce equal and opposite outputs.

6. Distortion due to nonlinearity in the residual magnetism curve of magnetic tape material is minimized by using
(A) a large recording head-gap. (B) pre-equalization. (C) capstan drive. (D) high frequency bias.

7. All other factors equal, best high-frequency response in magnetic tape recording can be obtained by using
(A) the largest possible playback head-gap. (B) the lowest possible tape speed. (C) a very strong bias signal. (D) the highest practical tape speed.

8. In magnetic tape recorders, the erase head is usually driven by
(A) the playback amplifier. (B) a supersonic signal at the bias frequency. (C) the output of the microphone. (D) the recorded information in the tape.

9. To insure constant tape speed past the head assembly, tape recorders use
(A) mechanical tape lifters. (B) post-equalization. (C) capstan drive. (D) supersonic bias.

10. Dual-track recording is used to
(A) improve frequency response. (B) maintain uniform tape speed. (C) simplify tape editing. (D) increase the available recording time on a given length of tape.

4715A
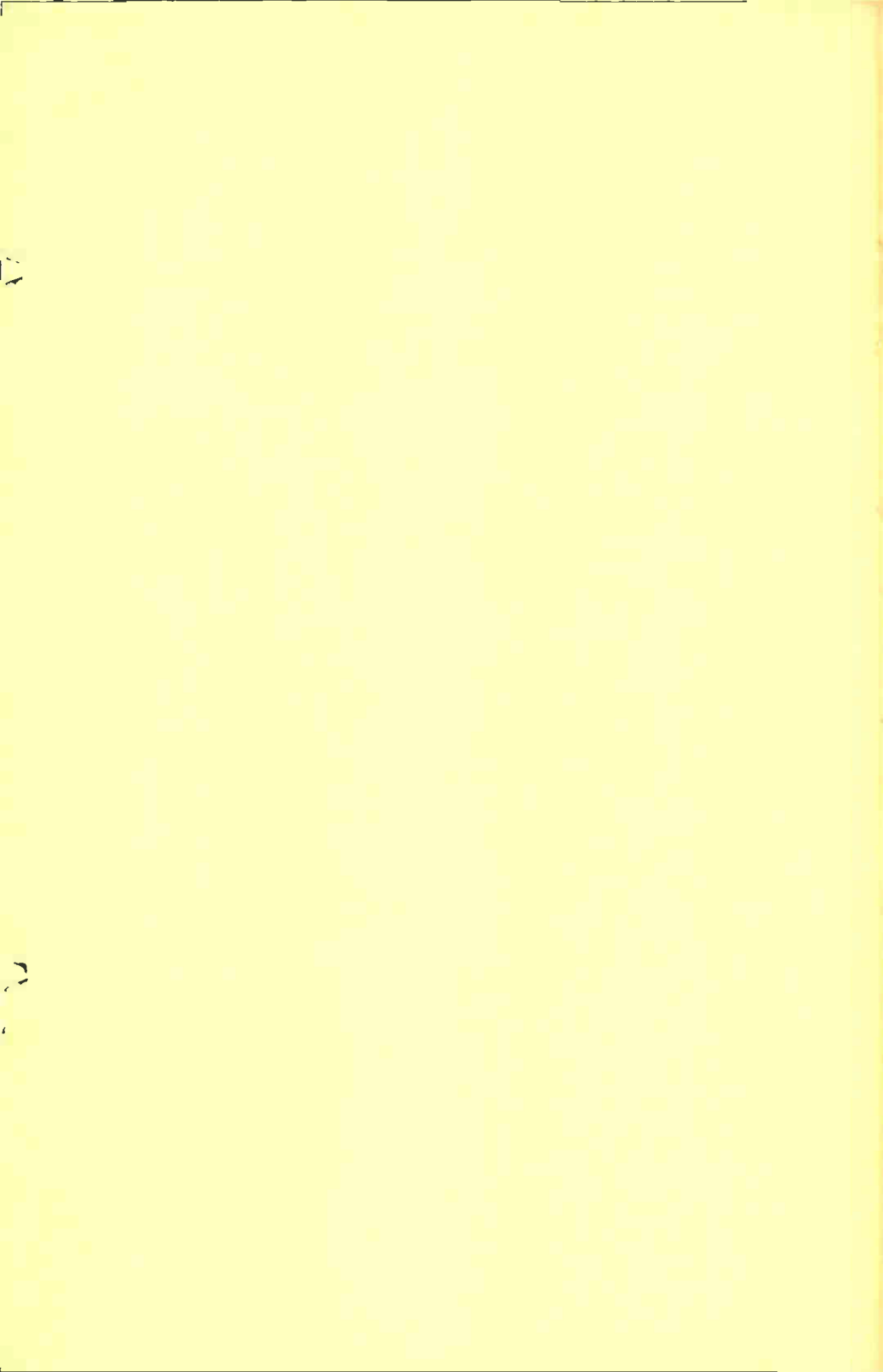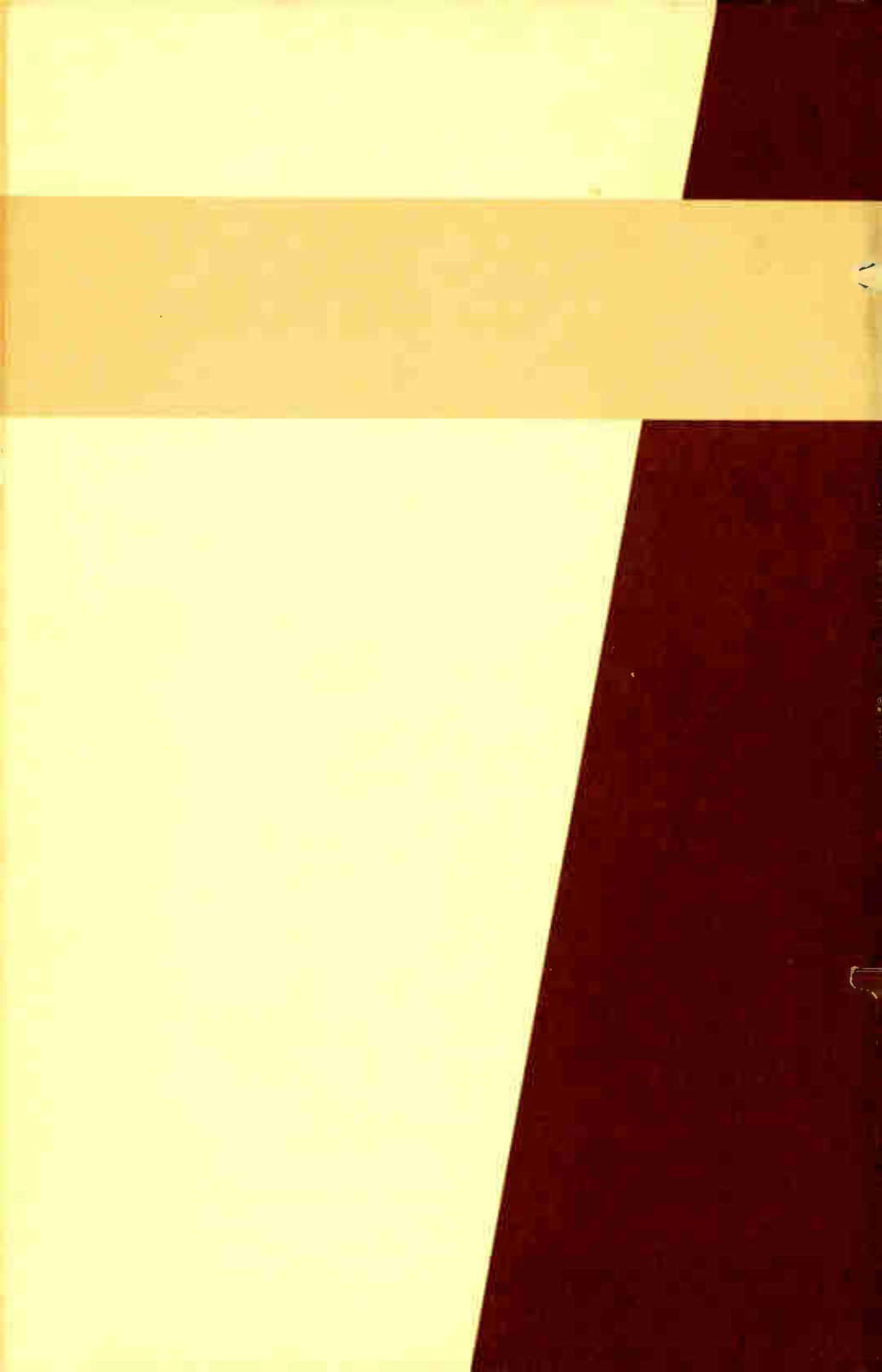
AUDIO CONSOLES

Lesson 4718

DeVRY INSTITUTE of TECHNOLOGY

CHICAGO   PHOENIX   TORONTO

AUDIO CONSOLES

Revised 1968

OPPORTUNITY

3
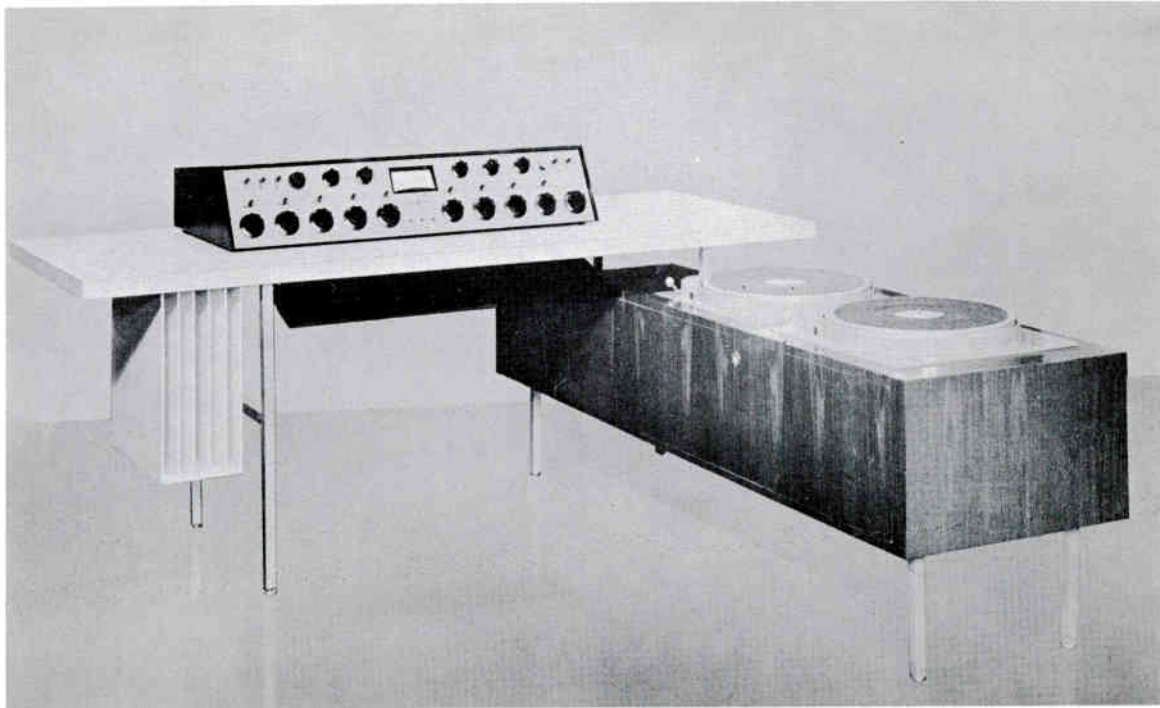
The audia cansole and dual turntable unit shawn here is typical of the equipment found in many braadcast statians.

Courtesy Collins Radio Co.

AUDIO CONSOLES

CONTENTS

****

Mind is the great lever of all things;
human thought is the process by
which human ends are answered.
--David Webster

AUDIO CONSOLES

Audio consoles, whether used in AM, FM or TV broadcast stations, have one basic purpose. They enable the operator to integrate the various sources of sound into a smooth flowing program that affords maximum pleasure to the listener. As simple as this seems, there are many problems that must be overcome.

The audio signal sources (microphones, magnetic tapes, phono pickups) have a wide range of output signal levels. The transmission lines that carry the signals from the sources to the console have different impedances and different frequency response characteristics. The amplification, attenuation, and mixing of these signals must be accomplished without any interaction between signals, while switching must occur at exactly the proper instant of time.

The audio console must be designed to handle as many audio input signals as are necessary for the successful operation of the station. This number might vary from four or five input signals in a small station to several dozen input signals in a large station. These input signals, regardless of their amplitude, must be brought up to approximately the same level at the output of the audio console. This is necessary because the output signal of the console is fed to the transmitter and eventually used as the modulating signal. To maintain a high modulation percentage without overmodulation, the output signal of the audio console must be fairly constant in amplitude.

BASIC BLOCK DIAGRAMS

Figure 1 is the block diagram of the simplest system we could have. The audio console consists of the blocks inside the dashed enclosure. Here, the microphone feeds the preamplifier, which builds up the level of the audio signal from the microphone. The output of the preamplifier is fed

through an attenuator to the program amplifier, which further amplifies the signal. The output of the program amplifier is monitored by a VU meter and fed through a pad to the transmitter line. Also, the output of the program amplifier is further amplified by a monitor amplifier and fed to the monitor speaker.

Now that we have given a brief general description of the audio signal flow through the audio console, let's go back and pick up some of the details.

In Figure 1, the microphone output is a low level (small amplitude) audio signal that must be amplified immediately in order to maintain a high signal-to-noise ratio. The PRE-AMPLIFIER is especially designed to handle a low level input signal and produce a medium level output signal with a high signal-to-noise ratio. The preamplifier output is then fed through the attenuator to the program amplifier.

                    *   *   *

1.   The purpose of a preamplifier is to amplify (a) low level signals, (b) high level signals.

                    *   *   *

The PROGRAM AMPLIFIER is designed to handle medium level input signals and produce an output signal of the proper level to feed the transmitter. The amplitude of the signal fed to the transmitter is usually +8 VU. The zero VU reference level is 1 milliwatt (.001 watt) of power dissipated in 600 ohms of resistance. Therefore, a signal that is rated as +8 VU is 8 dB above the zero reference level. You may also see this specified as +8 dBm. The letter "m" after dB means that 1 milliwatt across 600 ohms is the zero reference level. Thus, +8 VU and +8 dBm have the same meaning.

                    *   *   *

2.   A program amplifier is one which has (a) low level, (b) medum level signals applied to its input.

                    *   *   *

The pad between the program amplifier and the transmitter line is an isolation network that causes a loss of signal strength. In this case, the loss is 6 VU so that the program amplifier must produce an audio signal equal to +14 VU.

The VU meter, also connected to the output of the program amplifier, is the visual monitor that enables the console operator to adjust the attenuator to obtain the desired signal level. Although not indicated in Figure 1, this VU meter is preceded by a resistive network (pad) that causes a 14 dB signal loss. Thus, the +14 VU signal at the output of the program amplifier is reduced to the zero VU level when the signal is applied to the VU meter. Additional details are given later in the text.

*   *   *

3. The VU meter is connected to the input of the program amplifier. True or False?

*   *   *

A portion of the output from the program amplifier is fed to the **MONITOR AMPLIFIER.** This amplifier produces sufficient power (several watts) to drive the monitor speaker.

In Figure 1, the preamplifier has a gain of about 40 dB, and the program amplifier has a gain of about 60 dB, for an overall maximum gain of 100 dB. The output signal from the microphone is about -60 dBm, and a +14 dBm signal is required at the output of the program amplifier. Thus, the microphone signal must be amplified by 74 dB. The 100 dB gain of the two amplifiers provides an excess of 26 dB gain. This extra gain is necessary, however, to allow for a reduction in microphone output signal.

The attenuator provides a means of compensating for differences in signal output level from the microphone. The operator adjusts the attenuator so the signal has the desired amplitude at the input to the program amplifier.

*   *   *

4.   In a typical system, suppose a microphone provides an output
      signal of -55 dBm.   An attenuator causes an additional signal
      loss of 12 dB.   The output of the program amplifier must be
      + 8 dBm.   What is the minimum overall gain required from
      the preamplifier and the program amplifier?

*   *   *

Even though the arrangement of Figure 1 is so simplified
that it may never be encountered in actual practice, it serves
to illustrate the basic arrangement of all consoles. There-
fore, study it carefully and memorize the position of each
block and its function.

Figure 2 shows an arrangement that allows an additional
microphone to be used.   Here, we have added microphone
No. 2, preamplifier No. 2, attenuator No. 2, a selector switch

The attenuators on this console (the large, round, black knobs) allow the operator to adjust the in-
dividual channel gain and balance the signal levels.

Courtesy Gates Radio Co.

and a master gain control.   This arrangement provides se-
lection of either microphone signal and permits the console
operator to compensate for differences in the output level
of each microphone.

For example, assume that the output of microphone No. 1 is
-70 dBm and the output of microphone No. 2 is -60 dBm.
Using identical preamplifiers, each having a gain of 40 dB,

the output of preamplifier No.1 is -30 dBm and the output of preamplifier No.2 is -20 dBm. We can set attenuator No.1 for its minimum loss of 6 dB so its output is -36 dBm. Attenuator No.2 is then set for a loss of 16 dB so its output is also -36 dBm. With the two signals balanced, we use the selector switch to choose either of them. The master gain control is then adjusted for the proper signal level at the output of the program amplifier.

*   *   *

5.   In Figure 2, the output signal level of each microphone must be the same. True or False?

*   *   *

Figure 3 is a console block diagram showing how four microphones can be used with only two preamplifiers. Notice that this block diagram has a different appearance than the two previous diagrams. Here, the attenuator and the pads are indicated by resistive elements instead of blocks. Also, the switches are drawn more explicitly to show their exact function. This is the usual way of drawing console block diagrams, and we will use this method throughout the lesson.

In Figure 3, either microphone No.1 or microphone No.2 is selected by switch S_1 to feed preamplifier No.1. Attenuator No.1 (AT1) adjusts the preamplifier output signal to the desired level and feeds it to switch S_3. Since only one preamplifier is used for both microphones, the microphones should be closely matched as far as output signal level is concerned.

*   *   *

6.   In Figure 3, microphones No.1 and No.2 should be closely matched for output signal level. True or False?

*   *   *

Microphones No.3 and No.4 are handled similarly by switch

S_2, preamplifier No.2, attenuator ST2 and switch S_4. These two microphones should be closely matched for output signal level.

Switches S_3 and S_4 are three-position switches. The center position is OFF, the upper position is the PROGRAM (PGM) position, and the lower position is the AUDITION (AUD) position. In the PGM position, the S_3 audio signal is applied to the program amplifier and eventually fed to the transmitter line. Remember, the audio signal fed to the transmitter line is used to modulate the transmitter carrier. In the AUD position, the S_3 audio signal is fed through the monitor section of the console and produces sound from the monitor speaker.

The S_4 audio signal is handled the same way as the S_3 audio signal. This switching arrangement allows either signal or both signals to be fed to the program section of the console or to the monitor section.

*   *   *

7.   Briefly, what is the purpose of switches S_3 and S_4 in Figure 3?

*   *   *

Before analyzing consoles any further, let's investigate some of the circuits that are part of consoles or are used with consoles.

TRANSMISSION LINES

The transmission lines of concern to us are used to carry audio signals. They may vary in length from a microphone cable of several feet to the remote lines of many miles. The lines must be constructed so the following requirements are met:

1. Uniform response over required range of frequencies.
2. Signal-to-noise ratio is not decreased.
3. Signal level is not attenuated too much.

Transmission lines are leased from the telephone company to bring in signals from remote locations and from the network, and to feed signals to the network and to a distant transmitter.

Phono pickups, microphones, monitor speakers and other studio equipment are interconnected with the console by various types of transmission lines or cables.

There are two general types of transmission line connections -- balanced and unbalanced. The balanced type is shown in Figure 4 while the unbalanced type is shown in Figure 5. The basic difference between the two types is that the **UNBALANCED TRANSMISSION LINE** has one conductor grounded while the **BALANCED TRANSMISSION LINE** does not. When using a balanced transmission line, however, the center tap of the terminating transformers may be grounded.

                    *   *   *

**8.   A transmission line which has one conductor grounded is
       (a) an unbalanced line, (b) a balanced line.**

                    *   *   *

The primary advantage of the balanced line is its ability to cancel out noise voltages which may be picked up by the line. Since the two conductors are very close together, any noise signal is picked up equally by both conductors and causes two currents. As shown by the dashed arrows in Figure 4, these noise currents pass through the primary of the terminating transformer in opposite directions and cancel each other.

For the unbalanced line in which one conductor is grounded (Figure 5), noise signals picked up by the ungrounded conductor cause currents in the line which are added to the audio signal currents. This undesirable characteristic is minimized, however, by using a coaxial type cable in which the center conductor is ungrounded and an outer metal shield is the grounded conductor.

*   *   *

9.   In an unbalanced line, noise currents cancel each other. True or False?

*   *   *

LINE IMPEDANCE

In broadcasting, the lines are usually low impedance types that range from 50 to 600 ohms. Low impedance lines have some advantages over high impedance lines. These advantages are: (1) less noise voltage is developed across a low impedance line, (2) the capacitance between the conductors has less shunting effect on the higher frequency audio signals, and (3) broadcast microphones are usually low impedance units so impedance matching problems are minimized.

*   *   *

10. What is the usual range of transmission line impedances?

*   *   *

The output signals of broadcast microphones and phono pickups are very low in amplitude, usually less than a microwatt. With such low signal levels, it is necessary that noise pickup and signal attenuation be kept at a minimum. Low impedance lines are used for better signal-to-noise ratio, better frequency response and minimum losses in transferring the signal from one point to another.

*   *   *

11. The output signals of broadcast microphones and phono pickups are relatively (a) high, (b) low in amplitude.

*   *   *

TELEPHONE LINES

Telephone lines are used to feed program material from a

remote broadcast to the studios, from the studios to a dis-
tant transmitter, and to feed into or out of a network sys-
tem. These lines are installed and maintained by phone

Telephone lines are used to connect this remote amplifier to the studio console.
Courtesy Gates Radio Co.

company personnel. The broadcast operator is only re-
quired to connect the line termination to the station equip-
ment.

Almost all telephone lines used for program transmission
are 600 ohm lines connected as balanced systems. Each
end of the line normally terminates in a repeat coil which
is an isolation transformer having a 1 to 1 turns ratio and
an electrostatic shield between the windings to increase its
isolation effect.

*   *   *

12. What is the usual turns ratio of a repeat coil used to termi-
nate a telephone line?

*   *   *

For economic reasons, the telephone company must put

several transmission lines in the same cable in which each
conductor is insulated but not shielded from the other.   As
a result, signals in one pair of lines can be coupled to an-
other pair by inductive or capacitive coupling when signal
amplitude exceeds a certain level. This type of interference
is called CROSSTALK.

To minimize crosstalk, the telephone company limits the
signal level which may be impressed on its lines.   In most
cases the maximum allowable signal level is +12 VU.   That
is, 12 dB above 1 milliwatt.   There is no restriction as to
the minimum signal level, but it should always be high
enough to maintain a good signal-to-noise ratio.   Typically
the signal level is held between 0 VU and +12 VU.

*   *   *

13. Crosstalk in telephone lines is minimized by keeping the sig-
     nal amplitude (a) above, (b) below a certain level.

*   *   *

In cases where extremely long lines are used, and the at-
tenuation is severe, an amplifier may be inserted into the
line to increase the signal to the 0 to +12 VU level. An am-
plifier of this type is called a REPEATER.

LINE EQUALIZATION

Any two conductors which are fairly close together have a
capacitance between them which is directly proportional to
the length of the line. The reactance of this capacitance has
a shunting effect on the signals the line is carrying.   Since
capacitive reactance decreases with an increase of capaci-
tance and an increase of frequency, the shunting effect of
long lines on high audio frequencies may be very severe.

*   *   *

14. The capacitance of long lines has a severe shunting effect on
     (a) low, (b) high audio frequencies.

*   *   *

To compensate for these shunting effects, the line response
is equalized by connecting adjustable filters across the line
so the middle and low frequencies are attenuated to the same
degree as the highs.   Although this decreases the signal
level, the overall frequency response is greatly improved.
LINE EQUALIZATION consists of inserting various combi-
nations of inductance, capacitance and resistance across the
line to give attenuation characteristics opposite to those of
the line over the desired frequency range.

One type of equalizer is shown in Figure 6.   Here, the ca-
pacitor C and coil L are connected in parallel to resonate
at the desired audio frequency (8 kHz, for example). Con-
nected across the transmission line, the impedance of the
equalizer circuit is highest at the resonant frequency and
causes very little attenuation.   At other frequencies, the
impedance is reduced and losses are increased.

In series with the tuned circuit, variable resistor R con-
trols the effect of the circuit.   As the resistance is de-
creased, the low frequencies are attenuated more so more
equalization occurs.   As the resistance is increased, the
low frequencies are attenuated less so less equalization
occurs.

                    *   *   *

**15. In Figure 6, the equalizer offers the lowest impedance at its
resonant frequency.   True or False?**

                    *   *   *

ATTENUATION NETWORKS

Resistive networks of various types are used in audio signal
transfer circuits.   These networks are used for deliberate
attenuation of the signal level, for line balancing, for im-
pedance matching, and for isolation of one circuit from an-
other.   Since these networks attenuate the signal to some
degree, they are called **ATTENUATION NETWORKS** or
PADS.

Two types of pads are shown in Figure 7. These are the **T PAD** in Figure 7A and the **H PAD** in Figure 7B. The names are derived from the fact that the arrangements of the resistors resemble the letters T and H. The T pad places resistance in series with only one side of the line and is used when line balance is not an important consideration. The H pad places equal resistances in each line and is used in balanced lines.

*   *   *

16. Which type of pad is used in balanced lines?

*   *   *

T and H pads are used for any combination of impedances and, because of their similarity, the resistance values may be calculated by the same equations. Figure 7 shows the relative values of resistance in the two pads. The shunt resistance, R_3, is the same in both pads. The series resistances in the H pad are one-half the value of the series resistances in the T pad.

The impedance matching effect of the T pad is illustrated by the circuit of Figure 8A. Assume, for example, that the pad is placed in a line where the source has an internal impedance of 600 ohms and the load has an impedance of 600 ohms.

Starting with the load end, the 600 ohm load resistance is in series with the 200 ohms of R_2 for a total of 800 ohms. This 800 ohms is in parallel with the 800 ohms of R_3 for an equivalent of 400 ohms. This 400 ohms is in series with the 200 ohms of R_1 for a total of 600 ohms. Therefore, the load and the pad appear as 600 ohms to the source.

Since the circuit is symmetrical, the same conditions occur starting with the source end. Therefore, the source and the pad appear as 600 ohms to the load.

*   *   *

17. The T pad of Figure 8A is designed for use in a circuit where
    the load impedance and source impedance are_____ohms.

*   *   *

To show the attenuation effect of the T pad of Figure 8A, we
again start with the source. Assuming the source produces
6 volts of signal (any voltage may be assumed), there is 2
volts across the 200 ohms of R_1, and 4 volts across R_3.
(Remember, R_3, R_2 and R_L have an equivalent resistance
of 400 ohms.) The 4 volts across R_3 divides between R_2
and R_L, with 3 volts across R_L. Therefore, with 6 volts
produced by the source, there is 3 volts across the load.
With this pad, half of the source voltage always appears
across the load.

Converting this voltage loss to decibels we find that the dB
loss is

$$dB = 20 \log \frac{E_{IN}}{E_{OUT}}$$

$$= 20 \log \frac{6}{3}$$

$$= 20 \log 2$$

$$= 20 \times .3$$

$$= 6$$

Summing up, the T pad of Figure 8A causes a loss of 6 dB
so we call it a 6 dB pad.

*   *   *

18. The T pad of Figure 8A has no attenuation effects. True or
    False?

*   *   *

Referring now to the H pad of Figure 8B, it will produce exactly the same impedance matching and attenuation effects
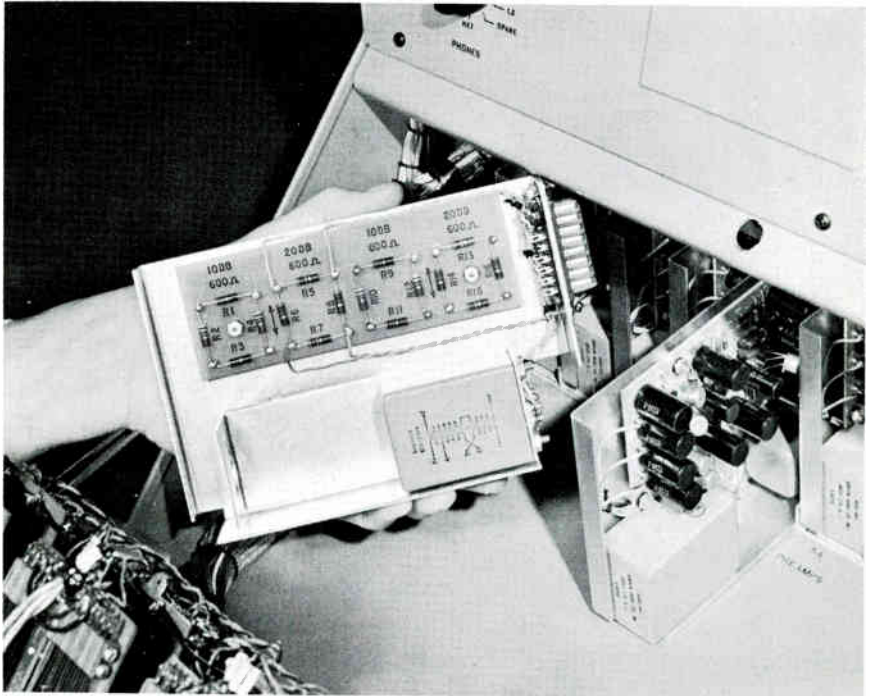
These attenuation networks, or pads, are part of a module in this console and are readily accessible for replacement.

Courtesy Radio Corporation of America

as its equivalent T pad of Figure 8A. Notice that the two series R_1 resistors of Figure 8B are one-half the value of the series R_1 resistor of Figure 8A. The two series R_2 resistors in Figure 8B are also half the value of that in Figure 8A. The shunt resistance, R_3, is the same in both circuits.

As a result, the effects of the H pad of Figure 8B are identical to the effects of the T pad of Figure 8A. The H pad is used with a balanced line while the T pad is used with an unbalanced line.

*   *   *

19. The series resistances of an H pad are (a) one-half, (b) twice
    the resistance of the T pad series resistances.

*   *   *

To further illustrate the effects of a pad, let's refer to the
T pad of Figure 9A. This T pad has also been designed for
use with a 600 ohm source and a 600 ohm load. Starting at
the load end, the 600 ohms of R_L is in series with the 492
ohms of R_2 for a total of 1092 ohms. The 120 ohms of R_3
is in parallel with this 1090 ohms, so the parallel equivalent
is

$$R_{EQ} = \frac{1092 \times 120}{1092 + 120} = \frac{131,040}{1212} = 108 \text{ ohms}$$

The equivalent resistance of 108 ohms is in series with the
492 ohms of R_1 for a total of 600 ohms. Since it is sym-
metrical, looking into the network from either end, a re-
sistance of 600 ohms is seen.

The isolation action of this pad is illustrated by opening or
shorting the load. For example, when the load circuit is
opened, resistors R_1 and R_3 remain connected across the
source with a total resistance of 492 + 120, or 612 ohms.
R_2 is effectively out of the circuit under open circuit con-
ditions.

When the load is short circuited, the 492 ohms of R_2 is
connected in parallel with the 120 ohms of R_3. This com-
bination has an equivalent resistance of

$$R_{EQ} = \frac{492 \times 120}{492 + 120} = \frac{59,040}{612} = 96 \text{ ohms}$$

This equivalent resistance of 96 ohms is in series with the
492 ohms of R_1 for a total resistance of 96 + 492, or 588
ohms. Under extreme conditions, the resistance of the
circuit changes only 12 ohms in either direction. For all

practical purposes, the pad of Figure 9A completely iso-
lates the load from the source.

The H pad of Figure 9B is the exact equivalent of the T pad
of Figure 9A. Once again the H pad is used with a balanced
line while the T pad is used with an unbalanced line.

*   *   *

20. In Figure 9A, if the load is shorted, how much impedance is
     presented to the source?

*   *   *

The pads of Figures 8 and 9 are designed to work in a cir-
cuit where the source impedance and the load impedance are
600 ohms. Why, then, are the resistance values so differ-
ent? The reason is the amount of attenuation desired or the
amount of isolation desired.   The pads of Figure 8 cause a
loss of only 6 dB while the pads of Figure 9 cause a loss of
20 dB.   On the other hand, the pads of Figure 9 provide al-
most complete isolation between source and load while the
pads of Figure 8 provide considerably less isolation.   As a
general rule, the amount of isolation provided by the pad is
directly proportional to the attenuation provided.

*   *   *

21. A 6 dB pad provides (a) more, (b) less isolation than a 20 dB
     pad.

*   *   *

Generally, the pads are designed to provide from 3 to 20
dB loss. However, there is a minimum attenuation that can
be obtained for every impedance combination.   The mini-
mum attenuation depends on the ratio between the input and
output (source and load) impedances and is calculated by
using a Z factor which is found by

$$Z = \sqrt{\frac{Z_1}{Z_2}} \qquad (1)$$

where Z_1 and Z_2 are the input and output impedances to be used in the pad design, and Z_1 is larger than Z_2.

By using the Z factor, the minimum loss may be obtained from

$$\text{Min dB loss} = 20 \log \left(Z + \sqrt{Z^2 - 1} \right) \qquad (2)$$

The smallest minimum attenuation is possible when the input and output impedances are equal, causing the Z factor to be 1. Theoretically, the minimum loss is zero dB, but this would require the series resistance to be zero ohms and the shunt resistance to be infinite.

In the actual calculations to determine the network components, a K factor is used to obtain the proper attenuation. K is the ratio of the input and output voltages of the pad and is determined by

$$K = \text{antilog} \left(\frac{dB \text{ loss}}{20} \right) \qquad (3)$$

*   *   *

22. What is the K factor?

*   *   *

Using the component notations of Figure 7A (R_1, R_2 and R_3), the resistances of the components are found by:

$$R_1 = Z_1 \left(\frac{K^2 + 1 - \dfrac{2K}{Z}}{K^2 - 1} \right) \qquad (4)$$

$$R_2 = Z_2 \left(\frac{K^2 + 1 - 2KZ}{K^2 - 1} \right) \qquad (5)$$

$$R_3 = \frac{2Z_1}{Z} \left(\frac{K}{K^2 - 1} \right) \qquad (6)$$

To see how we use all of these equations, let's design a T pad to match a 600 ohm source to a 600 ohm load with an attenuation of 6 dB. Referring to Equation 1 we calculate the Z factor by

$$Z = \sqrt{\frac{Z_1}{Z_2}} = \sqrt{\frac{600}{600}} = \sqrt{1} = 1$$

Next we use Equation 2 to find the minimum dB loss:

$$\text{Min dB loss} = 20 \log \left(Z + \sqrt{Z^2 - 1} \right)$$
$$= 20 \log \left(1 + \sqrt{1 - 1} \right)$$
$$= 20 \log \left(1 + 0 \right)$$
$$= 20 \log 1$$
$$= 0$$

This supports our previous statement that the dB loss can be as little as zero when the input and output impedances are equal. Therefore, it is possible to design a pad with a 6 dB loss and maintain impedance matching.

*   *   *

23. With equal input and output impedances, is it possible to obtain zero dB loss?

*   *   *

Continuing with our example, we find the K factor:

$$K = \text{antilog} \left(\frac{\text{dB loss}}{20} \right) = \text{antilog} \left(\frac{6}{20} \right) = \text{antilog} \,(.3) = 2$$

Next, we solve for the values of the three resistors:

$$R_1 = Z_1 \left(\frac{K^2 + 1 - \frac{2K}{Z}}{K^2 - 1} \right) = 600 \left(\frac{4 + 1 - 4}{4 - 1} \right) = 600 \left(\frac{1}{3} \right) = 200 \text{ ohms}$$

$$R_2 = Z_2\left(\frac{K^2 + 1 - 2KZ}{K^2 - 1}\right) = 600\left(\frac{4 + 1 - 4}{4 - 1}\right) = 600\left(\frac{1}{3}\right) = 200 \text{ ohms}$$

$$R_3 = \frac{2Z_1}{Z}\left(\frac{K}{K^2 - 1}\right) = \frac{2 \times 600}{1}\left(\frac{2}{4 - 1}\right) = 1200\left(\frac{2}{3}\right) = 800 \text{ ohms}$$

As shown in Figure 8A, these are exactly the values we chose for the T pad to cause a loss of 6 dB. The power lost in the pad is called the **INSERTION LOSS** and we would refer to the pad of Figure 8A as having an insertion loss of 6 dB.

*   *   *

24. The output signal from a pad is 12 dB lower than its input signal.   What is the insertion loss of the pad?

*   *   *

MIXERS AND FADERS

The purpose of **MIXERS** in sound work is to combine two or more signal inputs and blend them, at the proper levels,
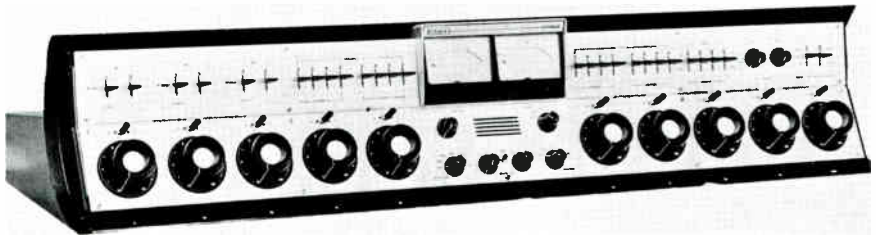
The ten faders on this console allow the operator to control the signal level in the separate channels.
Courtesy Gates Radio Co.

into a single program signal.   In general, a mixer consists of a variable attenuator, usually referred to as a **FADER,** for each audio signal input and a resistive network following each fader.   For example, a soloist may be singing into one microphone while the accompaniment is picked up by another.   With the faders, the console operator can adjust

the relative levels so the combined effect is pleasing.

*   *   *

25. What do we call the variable attenuators used to adjust the levels of audio signals?

*   *   *

A good mixing and fading system should satisfy certain general requirements so that optimum results are obtained. It should operate as noise-free as possible, and the frequency response should not change with variations in fader levels. Also, as the fader is varied, it should present a constant impedance to the entire mixing system so each fader affects only its own signal.

One classification of mixer types involves the signal level present in the mixing circuits. In LOW LEVEL MIXING, as the name implies, the mixing action occurs when the signals are low in amplitude. Good design and high quality components must be used to prevent excessive noise from being introduced into the desired audio signal.

*   *   *

26. Two audio signals are mixed when both are low in amplitude. This is called_____ _____mixing.

*   *   *

In HIGH LEVEL MIXING, the signals are mixed when they are relatively high in amplitude. Often, preamplifiers are used ahead of the mixing circuits to increase the signal amplitude of low level signals. Thus, noise produced by the mixing circuits has little effect on the signal-to-noise ratio because of the high level signals being mixed.

A common type of attenuator used in broadcasting is the variable-T attenuator shown in Figure 10. All three of the variable resistances are mechanically linked to one shaft, with clockwise rotation indicated by the arrows. Clockwise

rotation, which causes the resistance of R_1 and R_2 to decrease and the resistance of R_3 to increase, causes minimum attenuation. Counterclockwise rotation provides the opposite results and causes maximum attenuation.

In order to simplify drawings, the variable-T attenuator of Figure 10 may be drawn as shown in Figures 11A and 11B. The symbol of Figure 11B is frequently used in single block diagrams as previously indicated in Figure 3. The attenuators are then labeled AT1, AT2, and so forth.

*   *   *

27. The drawings of Figures 10, 11A and 11B all represent the same thing. True or False?

*   *   *

The circuitry of Figure 12 may be used when it is necessary to mix more than one input. Assuming that all source impedances, line impedances and load impedances are 600 ohms, the three attenuators are designed to present 600 ohms regardless of their setting. Also, the three R_1 resistors and the R_2 resistor (the mixing resistor) are 300 ohms each.

The values of the three R_1 resistors and the R_2 resistor are found from the general equation

$$R_1 = R_2 = \frac{R(n - 1)}{n + 1} \tag{7}$$

where n is the number of channels and R is the impedance of the attenuator. In this case

$$R_1 = R_2 = \frac{600(3 - 1)}{3 + 1} = \frac{1200}{4} = 300 \text{ ohms}$$

*   *   *

28. In Figure 12, if there were only two channels instead of three, what would be the resistance values of R_1 and R_2?

*   *   *

The mixing loss in dB is determined from the general equation

$$\text{Mixing loss} = 20 \log n \qquad (8)$$

where n is the number of channels.

In the circuit of Figure 12, the mixing loss is

$$\text{Mixing loss} = 20 \log 3$$

$$= 20 \times .477$$

$$= 9.54 \text{ dB}$$

This means that the mixing network of the R_1 and R_2 resistors causes an insertion loss of 9.54dB in addition to the insertion loss caused by the setting of the variable attenuators. The insertion loss is the price that must be paid for high fidelity mixing, but these signal losses can be compensated for by additional amplifying stages.

*   *   *

29. If there were two channels instead of three in Figure 12, what would be the mixing loss?

*   *   *

VU METER

With the introduction of Volume Units as a system of measurement, a special type of meter was also developed. It is called a "Volume Indicator" or VU METER. It is actually a voltmeter, with special response characteristics, calibrated to read volume units (VU's) when connected across a 600 ohm line. In addition to the VU markings, which range from -20 VU to +3 VU, the scale is also marked off in percentage of modulation from 0 to 100. The 100% modulation point coincides with the 0 VU point. The meter scale is shown in Figure 13.

*   *   *

30. On a VU meter, zero VU' s represents what percentage of
modulation?

*   *   *

When connected across a standard 600 ohm line, the entire
VU meter circuitry must have an impedance of 7500 ohms.
Figure 14 shows the arrangement of the circuitry.   A dc
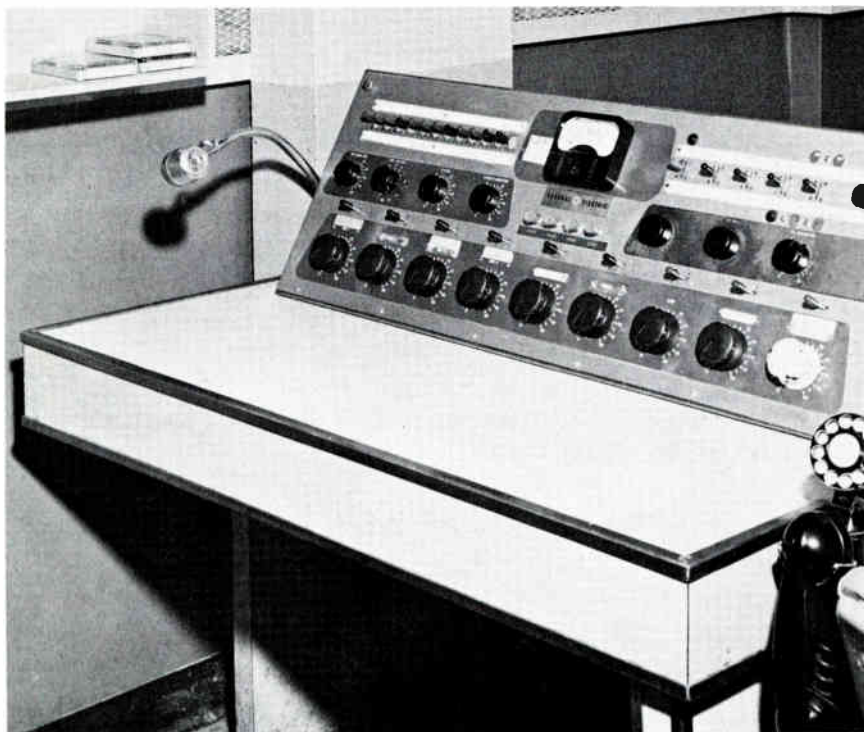
The VU meter, located in the top-center of this console, gives the operator a visual indication of
the signal level.

Courtesy WBKB, Channel 7, Chicago

meter movement and a full-wave copper-oxide rectifier are
used with a variable-T calibrating attenuator to provide a

constant impedance of 3900 ohms. This 3900 ohms is in series with an external resistance (R_S) of 3600 ohms to provide the required 7500 ohms.

The purpose of a VU meter is to let the console operator know the percentage of modulation that is being caused by the audio signal. The VU meter is usually connected at the output of the program amplifier because this signal is eventually fed to the transmitter, is amplified, and is used to modulate the carrier.

At the output of the program amplifier, the signal level must be about +14 VU to cause 100% modulation of the carrier. However, the required signal level will vary from station to station, depending upon the design of the transmitter. To compensate for these possible variations, the calibrating attenuator is adjusted so the VU meter indicates 0 VU when the signal is the proper level to cause 100% modulation.

For example, if the output of the program amplifier must be +14 VU to cause 100% modulation, the calibrating attenuator is set to cause a 14 dB loss and cause the VU meter to read 0 VU. If the output of the program amplifier must be +8 VU to cause 100% modulation, the calibrating attenuator is set to cause an 8 dB loss and cause the VU meter to read 0 VU.

The required level of the audio signal and the setting of the calibrating attenuator is pre-determined by the station engineer. Thus, the console operator merely has to adjust the master gain control so the audio signal causes the VU meter to read 0 VU or less.

PATCH PANELS

Although not part of the audio console, a patch panel is important to the successful operation of a broadcast studio. The console operator should understand the purpose of a patch panel.

The patch panel itself is composed of rows of jacks usually mounted in an equipment rack in the control room of the station. The input and output circuits of the studio console, the program amplifiers, booster amplifiers, tape and disk recorders, incoming remote lines and outgoing lines are all brought into the patch panel. The panel then provides a centrally located interconnection point where it is possible to reroute the signals merely by the insertion of a patch cord.

Figure 15 shows the manner in which the jacks are inter-connected. A signal applied to point A of J_1 is automatically applied to point A of J_2. The connection between point B of J_1 and point B of J_2 makes this automatic connection pos-sible and is called a **NORMALLED THROUGH** connection. If the normalled through connection is omitted, the two jacks are open. An external patch cord must then be used if it is desired to interconnect the two jacks.

*   *   *

31. A normalled through connection causes the signal applied to one jack to be automatically applied to another jack. True or False?

*   *   *

When two jacks are normalled through, it is still possible to break the connection between them. This is illustrated in Figure 16. Here, patch plug P_1 is inserted into jack J_1. The physical construction of the units is such that the prong of P_1 lifts the spring contact of J_1 so points A and B are dis-connected and the normalled through connection is broken. At the same time, the prong of P_1 is connected to point A of J_1. This causes the signal at point A to be fed through P_1 to wherever else the other end of P_1 is connected.

For example, Figure 17 shows the patch panel normalled through connections between the studio console, the limiter amplifier and the transmitter program line. During opera-tion, if the limiter amplifier becomes inoperative, the

engineer or operator can insert one end of a patch cord into
the studio console output jack.   The other end of the patch
cord is inserted into the jack connected to the transmitter
line.   This operation would break the normalled through
connections to the input and output of the limiter amplifier,
and the studio console output would be directly connected to
the transmitter line.   The station would be back on the air
and the limiter amplifier could be repaired.

                    *   *   *

32. When a plug is inserted into a jack, the normalled through
    connection is broken.   True or False?

                    *   *   *

AUDIO CONSOLES

The audio console is the focal point of all audio operations
in the broadcast station.   Its primary functions include the
selection of the signals to be broadcast, setting each signal
to the proper level, mixing the signals together, and rout-
ing the final signal to its required destination.

The console also provides other secondary services that
are necessary for efficient broadcasting.   Among these are
cueing, talkback and monitoring facilities.   To accomplish
all of these things, it is necessary that the console be op-
erated by a skilled operator.

                    *   *   *

33. List two secondary services provided by the audio console.

                    *   *   *

Signal Inputs

The number of signal inputs varies from a few inputs in
consoles designed for small station operation to many inputs
in units designed to handle several different studios in a

large station. A separate input is provided for each micro-
phone, turntable, and tape machine in use. Often, however,
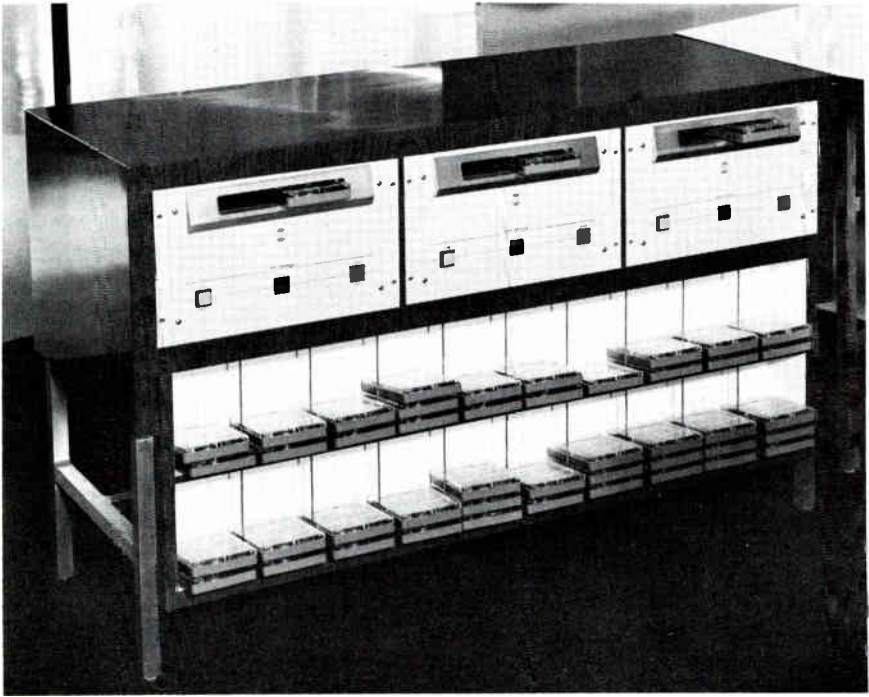
This automatic tape playback system feeds three audio signals to the console. The operator selects
the desired signal.

Courtesy Collins Radio Co.

two or more of these units must share the same channel in
the console.

Remote lines that are used frequently are wired directly to
the console.   Infrequently used remote lines are generally
wired through the patch panel to the console.

Each input may be applied either to the "program circuits"
for transmission or to "audition circuits" so that signals
may be heard without applying them to the transmitter or
network. It is possible to audition a signal entirely separate
from the signal being applied to the transmitter or network.

*   *   *

34. The (a) program circuits, (b) audition circuits apply the audio
signal to the transmitter or network.

*   *   *

Signal Outputs

The console provides a signal output of the program mate-
rial to feed the transmitter and the network when the station
is a network member. Monitor speakers and phones must
be provided with signals from the program circuits or the
audition circuits, whichever the operator chooses. Facili-
ties must also be provided to switch the monitor speakers
on or off.

A signal must also be furnished to the operator handling a
remote program before the remote program begins. This
is known as "remote cueing". With this signal the remote
operator can determine when to start the remote program
and can also be sure the telephone line is in operating con-
dition.

Meters

One or more standard VU meters are located on the console
to measure the signal level. A console used for monophonic
broadcasting need have only one VU meter which measures
the signal level on the program line. An optional VU meter
may be included to measure the signal level on the audition
line.

*   *   *

35. What is the minimum number of VU meters on a console?

*   *   *

A console used for stereophonic broadcasting must have two

VU meters, one each to measure the signal level on the left and right program lines. Again, optional VU meters may be included for the audition lines.

Monitor Controls

The program signal or the audition signal is fed to monitor speakers, or headphones, at several locations. One speaker is located in the control room. Other speakers may be in the transmitter room, the studios, or in the station lobby or offices. With these speakers, station personnel can hear the program material or they can audition material.

A monitor speaker is located in each studio, in the control room and on the console, and must be removed from operation when any microphone in that particular location is being used. This prevents acoustic feedback. Automatic cutoff of these speakers is accomplished by the console by means of a muting circuit for each monitor speaker.

*   *   *

36. Each monitor speaker is automatically cut off by a_____
    circuit at the proper time.

*   *   *

Talkback Facilities

During station operations that are not being fed to the program line, it is often necessary for studio personnel to converse with those in the control room. The TALKBACK facilities of the console make this possible. Sometimes the monitor speakers and the broadcast microphones are used for talkback. Other times, special talkback speakers are installed for this purpose. The talkback system also permits the console operator and the remote operators to talk back and forth while preparing to feed a remote program signal to the studio.

*   *   *

37. The talkback system only allows the remote operator to talk to the console operator. True or False?

*   *   *

A TRANSISTORIZED CONSOLE

Audio consoles are produced by a number of broadcast equipment manufacturers. Although each console may be different, they all embody the same basic functions. Most stations use standard consoles rather than custom-made units because the majority of the consoles have been designed to fit the needs of the average broadcast station.

One such console is the Gatesway II eight-channel monophonic audio console produced by the Gates Radio Company. Figure 18 is a front panel diagram of this console showing the location of each control. Figure 19 is a single-line block diagram. We will refer to both figures in our explanation of the console.

*   *   *

38. Most broadcast stations use custom-made audio consoles. True or False?

*   *   *

Mixing Channels

The console has a total of eight mixing channels, consisting of three microphone channels, two turntable channels, two tape channels and one net-remote channel. Starting at the upper-left of Figure 19, two microphones may be connected to channel 1. Input switch S_1 selects either of the "mike" inputs and feeds it to preamplifier A_1. The output signal of A_1 is fed through mixing attenuator AT1 to AUD-PGM switch

S25. The AUD-PGM switch, S25, allows the operator to apply the audio signal either to the program (PGM) bus or to the audition (AUD) bus, or to the "off" position load (center position).

Microphone channels 2 and 3 allow four additional mikes to be connected to the console. Input switches S2 and S3 select
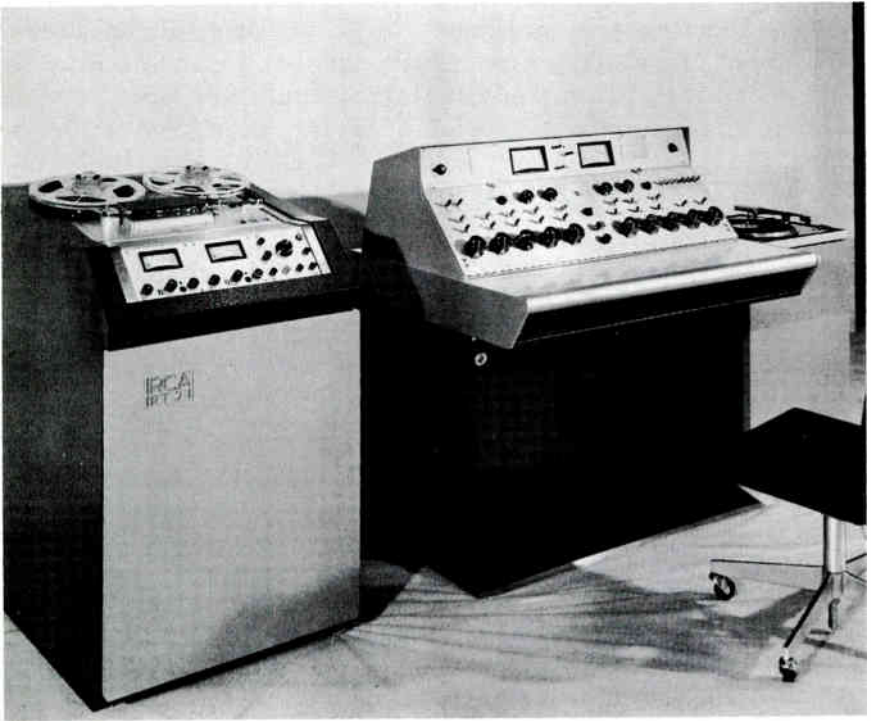
This photograph shows on audio tape recorder and audio console designed for broadcast and recording applications. The console is o dual-channel transistorized unit for AM ond FM stereo broadcasting. It feotures interchangeoble plug-in omplifiers for flexibility.

Courtesy Rodio Corporotion of America

one signal from each channel, and these two signals are handled the same as in mike channel 1. Finally, switches S26 and S27 allow the signals to be applied either to the PGM bus or to the AUD bus.

*   *   *

39. Switches S_1, S_2 and S_3 in Figure 19 are AUD-PGM switches. True or False?

40. Mixing channels 1, 2 and 3 in Figure 19 are for (a) turntable inputs, (b) microphone inputs.

*   *   *

Turntable channel 4 has provisions for four turntables to be connected to input connections A, B, C and D. No connections are made directly to turntable channel 5. However, the switching arrangement allows any of the channel 4 inputs to be applied to channel 5.

Let's assume, for example, that a turntable is connected to channel 4A. With all switches (S_4 - S_{11}) in the up position shown in Figure 19, the signal is applied to the movable contact of S_4, to the upper fixed contact of S_4, to the movable contact of S_8, to the upper fixed contact of S_8, to a 150 ohm pad. Thus, the signal is not applied to either channel 4 or 5, and these positions of S_4 and S_8 are the "off" positions.

Now, let's switch S_8 to the "on" position so the signal is fed to the lower fixed contact. This causes the signal to be applied through mixing attenuator AT5 to AUD-PGM switch S_{29}. Therefore, with S_4 turned off and S_8 turned on, the input to channel 4A is actually fed through channel 5.

Next, let's switch S_4 to the "on" position so the signal is fed to its lower fixed contact. This causes the signal to be applied through mixing attenuator AT4 to AUD-PGM switch S_{28}. Also, with the movable contact of S_4 in the down position (S_4 turned "on"), the signal is no longer applied to S_8 and it doesn't make any difference which position S_8 is in. This prevents the signal from being applied to both channels 4 and 5 simultaneously.

*   *   *

41. With S_4 and S_8 both switched "on", a signal applied to channel 4A input is fed through (a) mixing attenuator AT4, (b) mixing attenuator AT5, (c) mixing attenuators AT4 and AT5 simultaneously.

*   *   *

The net result of this switching arrangement is that with S_4 turned "on", the signal is applied to channel 4. With S_4 turned "off", the signal may be applied to channel 5 by turning S_8 "on". Channels 4B, 4C and 4D, in conjunction with switches S_5, S_6, S_7, S_9, S_{10} and S_{11}, are identical to channel 4A.

Tape channels 6 and 7 are identical to turntable channels 4 and 5. Thus, switches S_{12} - S_{15} are the channel 6 on-off switches, and switches S_{16} - S_{19} are the channel 7 on-off switches when the channel 6 switches are "off".

Net-remote channel 8 provides for one network input and three remote inputs. When switches S_{20} - S_{23} are switched to the MIX position (down in Fig. 19), any signals applied to the inputs are connected through T_1, and through AT8 to AUD-PGM switch S_{32}. (The other positions of switches S_{20} - S_{23} are discussed later.)

*   *   *

42. To apply a signal from Remote No. 3 through mixing channel 8, input switch S_{23} must be set to the (a) TB position, (b) cue position, (c) MIX position.

*   *   *

Although not shown on the block diagram, there are four utility switches on the console which are not connected to any of the circuits. The switches can be used for the selection of additional input signals or in any way the station engineer desires.

Let's summarize the console up to this point. The input connections provide for eighteen signals to be applied to the console. The input switches S_1 - S_{23} allow the operator to select the desired signals. The preamplifiers A_1, A_2 and A_3 amplify the signals in the three microphone channels. The mixing attenuators, AT1 - AT8, allow the operator to adjust the level of the signal in each channel. The AUD-PGM switches, S_{25} - S_{32}, allow the operator to switch any of the signals in the eight channels either to the audition bus, or to the program bus, or to the off position.

*   *   *

43. What is the function of mixing attenuators AT1 to AT8?

*   *   *

To determine the physical locations of the switches and mixing attenuators, refer to Figure 18. The channel mixers (AT1 - AT8) are the eight large knobs across the bottom of the console. Each mixer has a channel number just below the knob.

The AUD-PGM switches, S_{25} - S_{32}, are the lever switches which are located immediately above the channel mixers. The left position of each switch is "audition", the right position is "program" and the center position is "off".

The input switches, S_1 - S_{23}, and the four utility switches, S_{40} - S_{43}, are located across the top of the console. S_1 is above the channel 1 mixer, S_2 is above the channel 2 mixer, S_3 is above the channel 3 mixer, S_4 - S_7 are above the channel 4 mixer, S_8 - S_{11} are above the channel 5 mixer, S_{12} - S_{15} are above the channel 6 mixer, S_{16} - S_{19} are above the channel 7 mixer, S_{20} - S_{23} are above the channel 8 mixer, utility switches S_{40} and S_{41} are between S_1 and S_2, and finally, utility switches S_{42} and S_{43} are between S_2 and S_3.

Program and Audition Circuits

Although they are a very important part of the console, the

program and audition circuits are a relatively simple part
of the console. Referring to Figure 19, switches S_{25} - S_{32}
are the AUD-PGM switches. Notice that the upper fixed
contact of each switch connects to the program bus. (A bus
is merely a heavy line used as a convenient tie point for
several connections.) The program bus, in turn, is con-
nected to the input of the PGM-AMP (program amplifier).
Therefore, when switch S_{25} is thrown to the PGM position,
the signal applied to S_{25} is fed to the program amplifier.
The same situation is true for switches S_{26} - S_{32}. When
any of them are thrown to the PGM position, their input sig-
nals are fed to the program amplifier. Therefore, any or
all of the signals in the eight channels may be applied to the
program amplifier.

The master gain control, AT11, is adjusted so the output of
the program amplifier is at the proper level. In this con-
sole, the program amplifier output should be +14 VU. A
14 dB pad and a VU meter are connected to the output of the
program amplifier to allow the operator to keep the signal
at the proper level.

The output of the program amplifier is also fed through a
6 dB pad which reduces the signal to +8 VU at the program
output connection. This is the final output of the console
and is used to feed the transmitter and/or the network line.

*   *   *

**44. What is the signal level at the program output connection in
the console of Figure 19?**

*   *   *

When any of the switches, S_{25} - S_{32}, are thrown to the AUD
position, their input signals are connected to the audition
bus which, in turn, feeds the BST AMP (booster amplifier).
The output signal from the booster amplifier is fed to the
AUD position of monitor selector switch S_{35}. From S_{35},
the signal is fed through the monitor gain control, AT10,

to the input of the MON AMP (monitor amplifier). The out-
put signal from the monitor amplifier is then fed to the

This audio console is a modern, transistorized unit. It can handle as many as eighteen input signals
and has eight mixing channels.

Courtesy Gates Radio Co.

monitor speaker in the lobby, to the monitor headphones,
and through the solid state muting circuits to the monitor
speakers in the control room, in studio A, and in studio B.

*   *   *

45. When S_{27} is set to the AUD position, a signal being fed through
    channel 3 is applied to the (a) program circuits, (b) audition
    circuits.

*   *   *

By means of S_{35}, either of two additional signals may be
applied to the monitor amplifier. One of these is an ex-
ternal monitor input signal (EXT MON INPUT) which per-
mits monitoring an audio signal that is connected to this
point. The other is the program signal which is fed through
a 34 dB pad to the PGM contact on S_{35}. This allows the
operator, at his option, to aurally monitor the signal being
fed to the program line.

An additional feature of this console is the program equal-
izer (PGM EQUAL) that may be switched in or out of the
circuit as the operator desires. The program equalizer is
a filter circuit designed to improve the frequency response
of the signal fed to the program amplifier. It has two con-
trols which allow the operator to adjust the high frequency

response, the low frequency response, or both.

*   *   *

46. The program equalizer automatically controls the amplitude of the audio signal in the program line. True or False?

*   *   *

The physical location of the panel-mounted components in this portion of the console may be found by referring to Figure 18. The VU meter is in the center of the upper panel. The program equalizer switch and the equalizer controls are located below the VU meter. The master gain control, AT11, is immediately to the right of the VU meter. The monitor selector switch, S35, and the monitor gain control, AT10, are immediately to the left of the channel 5 fader.

Muting System

All consoles contain a MUTING SYSTEM that prevents a monitor speaker and a microphone in the same location from causing acoustic feedback. Although not shown in Figure 19, input selector switches S1, S2 and S3 have additional contacts which perform the muting functions.

*   *   *

47. The purpose of the muting circuits is to (a) maintain the volume at a constant level, (b) prevent acoustic feedback.

*   *   *

When any one of the microphone channel input selector switches (S1, S2 or S3) is set to the A position, the studio A speaker is cut off. When S2 or S3 is set to the B position, the studio B speaker is cut off. When S1 is set to the B position, the control room speaker and the console speaker are cut off.

In addition, the muting circuits turn on a warning light (usu-

ally red) when they cut off a speaker. This provides visual
indication that at least one microphone in that location is
alive.

Cue and Talkback

Besides the program, audition and muting circuits, the con-
sole contains CUE CIRCUITS and TALKBACK CIRCUITS.
Although these circuits do not feed the program line, they
are necessary for the successful operation of a broadcast
station. Suppose, for example, that we have a very simple
program in which a disk jockey plays recorded music and
makes comments. For the spoken comments, we need a
microphone channel. In this console, let's use channel 1
for this purpose.

Next, we need two turntables and two turntable channels.
So let's use turntable channels 4 and 5, and connect the
turntable output signals to points A and B of turntable chan-
nel 4. This applies one signal to input switch S_4 and the
other signal to input switch S_5. With S_4 set to the ON posi-
tion (down), the signal from turntable A is fed through mix-
ing attenuator AT4, to AUD-PGM switch S_{28}. With S_{28} set
to the PGM position, the signal is fed to the program cir-
cuits and is eventually fed to the transmitter.

While this recording is being aired (transmitted), the con-
sole operator must prepare the next recording so it can be
aired. To do this, he first makes sure that S_{29} is set to its
OFF position, then he turns mixing attenuator AT5 fully
counterclockwise to the CUE position and sets input switch
S_9 to the ON position. Turntable B is now connected through
S_5 to S_9; through S_9 to the CUE connection of AT5 and to
the CUE BUS; from the CUE BUS through a 28 dB pad to the
LISTEN-TALK switch K_1; through K_1 to the input of the cue
amplifier; from the output of the cue amplifier to another
contact on K_1; from K_1 to the muting circuit; and, finally,
from the muting circuit to the speaker mounted on the cen-
ter of the console panel.

*   *   *

48. When a mixing attenuator is set to the CUE position and a sig-
nal is applied, what amplifier is being used?

*   *   *

The console operator now starts turntable B, listens to the
sound from the console speaker, and stops turntable B so
the pickup is at the exact spot on the record that is the start
of the desired recording.   Next, he manually backs up the
record about a half turn because the turntable requires about
a half turn to reach normal speed.   This next recording is
now cued up.

To compensate for any differences in level at which the
transcriptions may have been recorded, the operator sets
AT5 to a somewhat lower setting than the AT4 setting. This
may cause the level of the next recording to be too low, but
this condition is better than risking the possibility of the
next recording starting too loud.

When the first recording is ended, the operator sets S_{28} to
the OFF position and waits for the disk jockey to signal the
start of the next recording.   When the signal is given, the
operator switches on turntable B, sets S_{29} to the PGM po-
sition, and adjusts AT5 to obtain the proper sound level.
The microphone channel is switched ON and OFF as neces-
sary.

There are variations of this procedure, and an experienced
operator can start the recordings exactly on cue with the
mixing attenuators preset to the proper level.

Tape channels 6 and 7 may be used in the same way when
the desired audio signals are obtained from magnetic tape
recordings.

Another cueing system is associated with NET-REMOTE
channel 8.   Notice, in Figure 19, that S_{21}, S_{22} and S_{23} all

have a CUE position that connects through impedance match-
ing transformer T_2 to the output of the monitor amplifier.

When preparing to feed a remote pickup from Remote No. 1
into the program section of the console, the remote operator
must know exactly when to start his program.   To do this,
the console operator sets the monitor selector switch, S_{35},
to the PGM position so the program signal being aired is fed

Several different types of remote amplifiers may be used at remote locations.   The unit chosen de-
pends upon the number of channels necessary to produce a smooth program.

Courtesy Gates Radio Co.

to the monitor amplifier.   The output of the monitor ampli-
fier is then fed through T_2 to the CUE position of S_{21}, and
through remote line No. 1 to the remote operator.

When the program in progress comes to an end, the an-
nouncer cues the remote operator by saying something like
"We now switch you to Mr. Jones".   At this time, the con-
sole operator switches S_{21} to the MIX position and S_{32} to
the PGM position.   The signal from the remote location is
now fed through S_{21}, through T_1, through AT8, through S_{32}

to the input of the program amplifier and the remote pro-
gram is on the air.

*   *   *

49. When using NET-REMOTE channel 8, the CUE position of S_{21}
    feeds the program signal out to the remote operator. True or
    False?

*   *   *

Another feature of the NET-REMOTE channel 8 is the talk-
back system which allows a remote operator and the con-
sole operator to talk back and forth just as though they were
using an intercom system.   Again using the remote line
No. 1 as an example, the console operator switches S_{21} to
the TB (talkback) position.   The remote operator's voice
signal is now applied through the TB position of S_{21}, through
a 600/45 ohms impedance matching pad, to the RMT 1 po-
sition of the cue selector switch S_{34}, through matching
transformer T_4, through the talkback switch K_1, to the in-
put of the CUE AMP, from the output of the CUE AMP,
through another section of K_1, through the muting circuit,
to the speaker located on the front of the audio console.

*   *   *

50. The talkback features of the console act the same as (a) a
    P.A. system, (b) an intercom system.

*   *   *

When the console operator wishes to speak to the remote
operator, he pushes the talk switch, S_{36}, (located to the
left of the console speaker in Figure 18) which causes K_1
to switch to the TALK position.   He now uses the console
speaker as a microphone and his voice signal travels the
reverse path back to the TB position of S_{21} and through re-
mote line No. 1 to the remote operator.

The NET input line feeding S_{20} cannot be used for talkback.
However, by switching S_{20} to the NET LISTEN position

(also called PRE-HEAR), and by switching S34 to the NET
position, the console operator can monitor the incoming
network signal. Then, at the proper time, he switches S20
to the MIX position and S32 to the PGM position. The in-
coming network signal is then fed to the program amplifier
and the network program is on the air.

SUMMARY

The major duties of a broadcast station console operator
are to select and control the signals that are put on the air.
Although the operator must be familiar with microphones,
turntables and tape recorders, the audio console is the piece
of equipment with which he must be most familiar.

The console explained in this text is only one of many dif-
ferent makes and models. However, all audio consoles
eventually perform the same basic functions. If you under-
stand the operation of this one, it will be relatively easy to
learn the operation of any other console.

IMPORTANT DEFINITIONS

ATTENUATION NETWORK - A group of resistive elements connected to deliberately reduce the amplitude of the audio signal. Also called a PAD.

BALANCED TRANSMISSION LINE - A line which has neither conductor grounded. Terminating transformers used with the transmission line may have the center tap grounded.

CROSSTALK - A type of interference caused by the unwanted coupling of the audio signal between pairs of phone lines.

CUE CIRCUITS - The console circuits that allow the console operator to prepare for the signal which is going on the air next.

FADER - A variable attenuator used to adjust the level of an audio signal.

H PAD - An attenuation network which has its elements arranged to resemble the letter H.

HIGH LEVEL MIXING - The mixing of audio signals when they are relatively high in amplitude.

INSERTION LOSS - The reduction in amplitude of an audio signal, expressed in dB, caused by an attenuation network.

LINE EQUALIZATION - The insertion of various L, C and R elements across a transmission line to improve the frequency response.

LOW LEVEL MIXING - The mixing of audio signals when they are relatively low in amplitude.

IMPORTANT DEFINITIONS (Continued)

MIXER - A resistive network designed to combine two or more audio signals into one signal.

MONITOR AMPLIFIER - An amplifier used to amplify a signal to a level that will operate the monitor speaker.

MUTING SYSTEM - A part of the console that automatically cuts off a monitor speaker when a microphone in that area is active. This prevents acoustic feedback.

NORMALLED THROUGH - The term used when two jacks on a patch panel are normally connected together. The connection is broken when a plug is inserted into either jack.

PAD - See ATTENUATION NETWORK.

PREAMPLIFIER - An amplifier designed to amplify a low level audio input signal and maintain a high signal-to-noise ratio.

PROGRAM AMPLIFIER - An amplifier designed to handle medium level input signals and produce an output signal of the proper level to feed the transmitter.

REPEATER - An amplifier used to increase the signal level of a telephone line when long lines are used, and attenuation is severe.

TALKBACK CIRCUITS - The portion of the console that permits the console operator and other members of the station staff to converse while a program is on the air.

T PAD - An attenuation network which has its elements arranged to resemble the letter T.

IMPORTANT DEFINITIONS (Continued)

UNBALANCED TRANSMISSION LINE - A line in which one
      conductor is grounded. This is practically always the
      outer conductor of a coaxial cable.

VU METER - A voltmeter calibrated to read Volume Units
      when connected across a 600 ohm line.

ESSENTIAL SYMBOLS AND EQUATIONS

$$
\begin{array}{rll}
K & - \text{ attenuation factor} & \\
n & - \text{ number of channels} & \\
R & - \text{ impedance of network} & (\text{ohms}) \\
R_1, R_2, R_3 & - \text{ resistance} & (\text{ohms}) \\
Z & - \text{ minimum attenuation factor} & \\
Z_1, Z_2 & - \text{ impedance} & (\text{ohms})
\end{array}
$$

$$
Z = \sqrt{\frac{Z_1}{Z_2}} \tag{1}
$$

$$
\text{Min dB loss} = 20 \log \left(Z + \sqrt{Z^2 - 1} \right) \tag{2}
$$

$$
K = \text{antilog} \left(\frac{dB \ loss}{20} \right) \tag{3}
$$

$$
R_1 = Z_1 \left(\frac{K^2 + 1 - \dfrac{2K}{Z}}{K^2 - 1} \right) \tag{4}
$$

$$
R_2 = Z_2 \left(\frac{K^2 + 1 - 2KZ}{K^2 - 1} \right) \tag{5}
$$

$$
R_3 = \frac{2Z_1}{Z} \left(\frac{K}{K^2 - 1} \right) \tag{6}
$$

$$
R_1 = R_2 = \frac{R(n - 1)}{n + 1} \tag{7}
$$

$$
\text{Mixing loss} = 20 \log n \tag{8}
$$

STUDENT NOTES

PRACTICE EXERCISE SOLUTIONS

1. (a) low level signals.

2. (b) medium level

3. False -- It is connected to the output of the program amplifier.

4. 75 dB -- Neglecting the attenuator loss, a gain of 63 dB is required to raise the -55 dBm signal to the +8 dBm level. An additional 12 dB gain is necessary to counteract the attenuator loss.

5. False -- The individual attenuators can be adjusted to compensate for differences in the output signal levels of the microphones.

6. True -- The two microphones are switched into the same attenuator circuit, and their signal levels cannot be individually adjusted.

7. They allow either signal or both signals to be fed to either section of the console.

8. (a) an unbalanced line.

9. False -- Noise picked up by the ungrounded conductor adds to the audio signal. Cancellation occurs in the balanced type line.

10. 50 to 600 ohms

11. (b) low -- usually less than a microwatt

12. 1 to 1

13. (b) below

14. (b) high

15. False -- As is typical of parallel LC circuits, the impedance is highest at the resonant frequency.
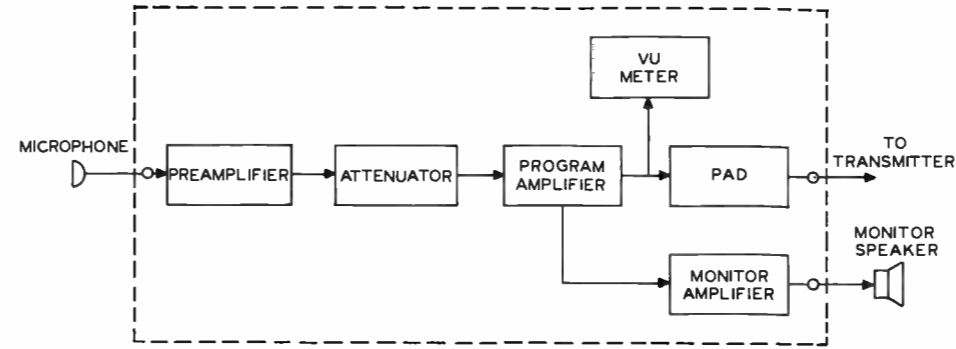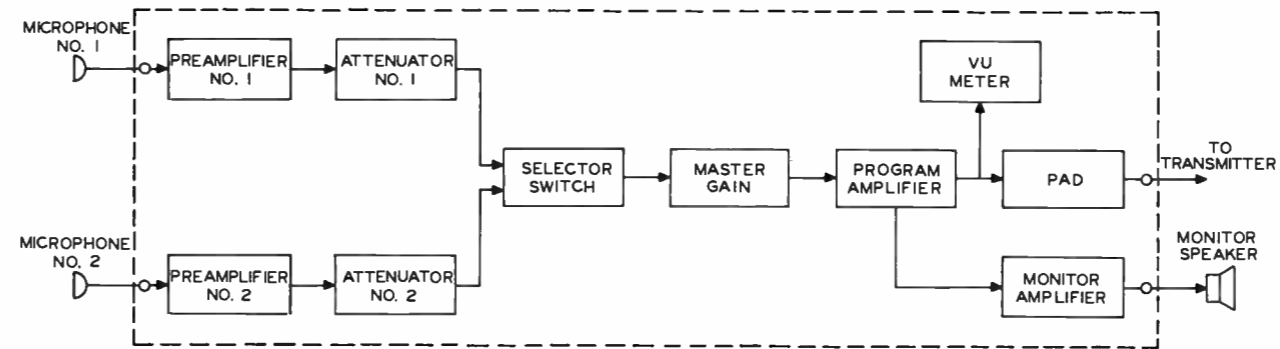
16. H pad

FIGURE 1

FIGURE 2
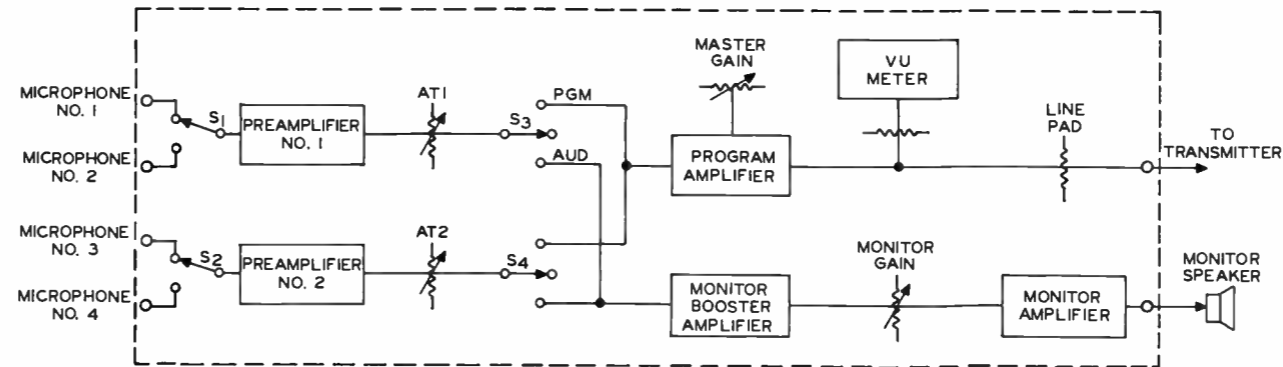
FIGURE 3

4718
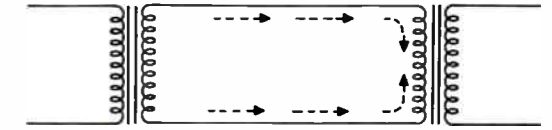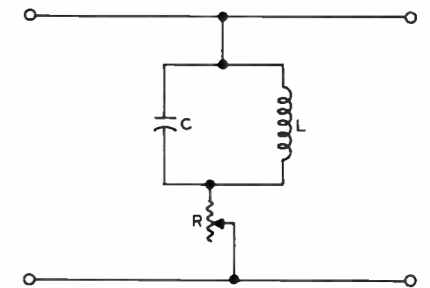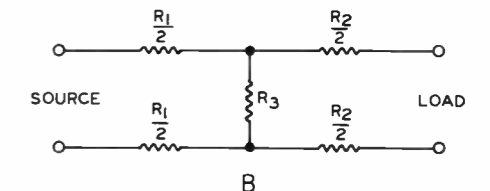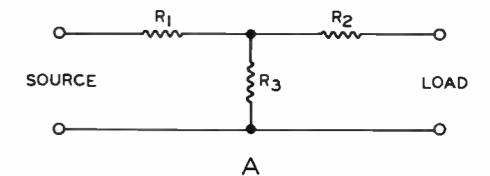
FIGURE 4
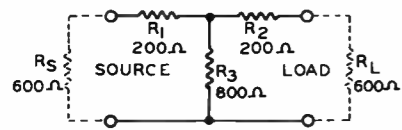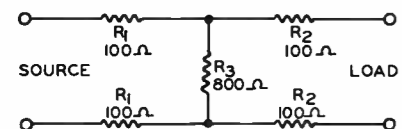
FIGURE 5

FIGURE 6
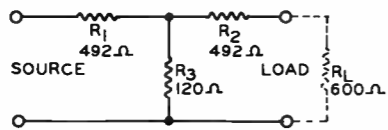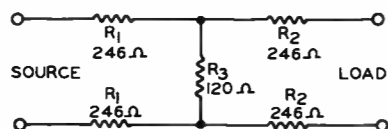
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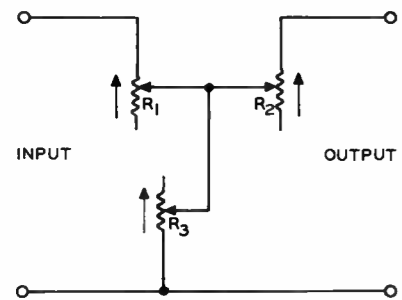
FIGURE 8
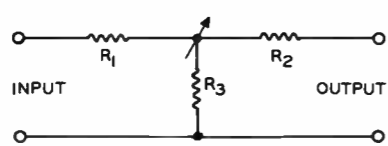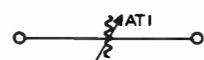
FIGURE 9
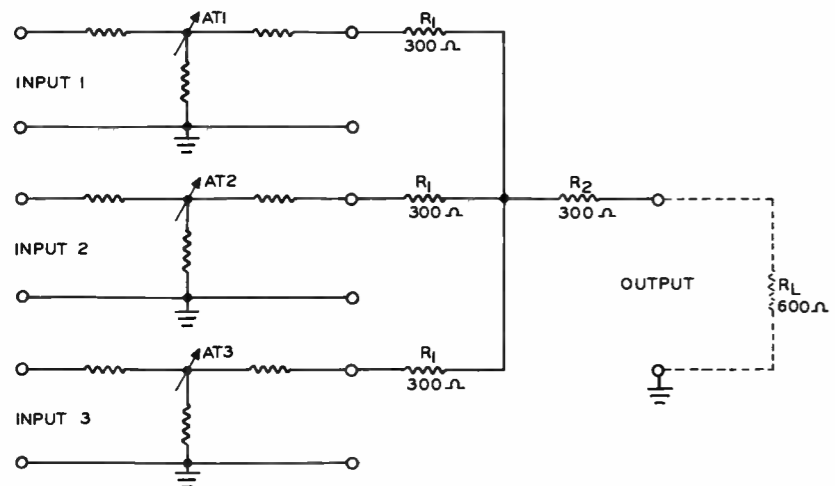
FIGURE 10

FIGURE 11

FIGURE 12

PRACTICE EXERCISE SOLUTIONS (Continued)

17. 600

18. False -- It causes a 6 dB loss.

19. (a) one-half

20. 588 ohms

21. (b) less -- The more attenuation a pad causes, the more isolation it provides.

22. It is the ratio of the input and output voltages of the pad.

23. Yes -- Any amount of dB loss can be obtained when the input and output impedances are equal.

24. 12 dB

25. faders

26. low level

27. True -- They are all symbols used to represent a variable-T attenuator.

28. 200 ohms

$$R_1 = R_2 = \frac{R(n-1)}{n+1} = \frac{600(2-1)}{2+1} = \frac{600}{3} = 200 \text{ ohms}$$

29. 6 dB

   mixing loss = 20 log n
        = 20 log 2
        = 20 × .3
        = 6 dB

30. 100% modulation

31. True

32. True
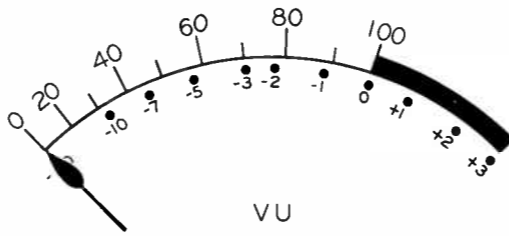
FIGURE 13

FIGURE 14

FIGURE 15

FIGURE 16

FIGURE 17

FIGURE 18

4718
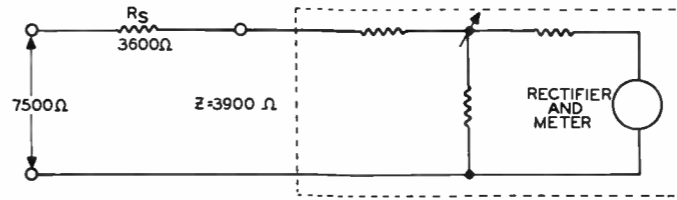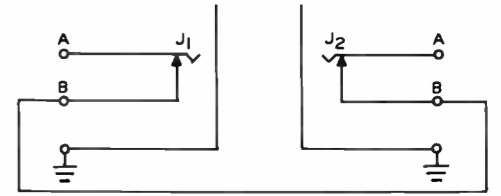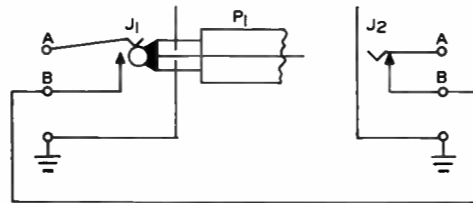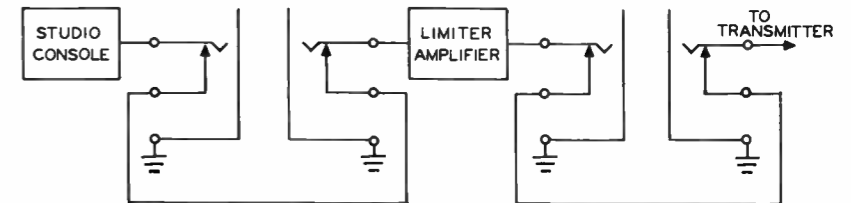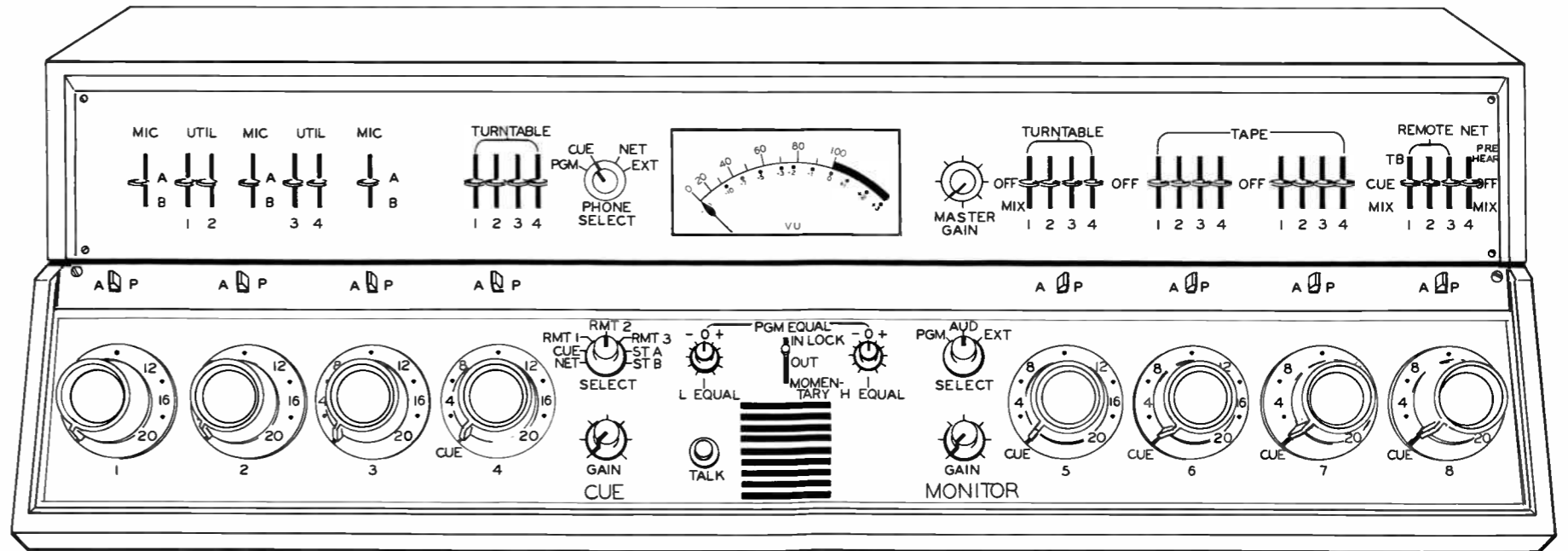
PRACTICE EXERCISE SOLUTIONS (Continued)

33. cueing, talkback, monitoring

34. (a) program circuits

35. one

36. muting

37. False -- Both operators can talk back and forth.

38. False -- It is common practice to use standard consoles, because they are designed for use in the typical studio.

39. False -- They are input switches.

40. (b) microphone inputs.

41. (a) mixing attenuator AT4. When S_4 is turned on, it removes the signal from S_8.

42. (c) MIX position.

43. They allow the console operator to adjust the level of the signal in each channel.

44. +8 VU

45. (b) audition circuits.

46. False -- The program equalizer affects the frequency response of the signal.

47. (b) prevent acoustic feedback.

48. the cue amplifier

49. True

50. (b) an intercom system.

4718

FIGURE 19

QUESTIONS

LESSON CODE

4718A

Example: A famous bridge in California is the

A
B
C
D

(A) Brooklyn Bridge.   (B) Wheatstone Bridge.   (C) London Bridge.
(D) Golden Gate Bridge.

1.
A
B
C
D

In the block diagram of Figure 3, the switching arrangement allows

(A) only the S_4 audio signal to be applied to the monitor booster amplifier.   (B) only the S_3 audio signal to be applied to the program amplifier.   (C) microphones No. 3 and No. 4 to feed preamplifier No. 2.   (D) either microphone No. 1 or microphone No. 2 to feed preamplifier No. 1.

2.
A
B
C
D

On telephone lines, crosstalk is minimized by

(A) using an equalizer at the end of each line.   (B) putting the pairs of lines as close together as possible.   (C) increasing the signal level to more than +12 VU.   (D) keeping the signal level at +12 VU or less.

3.
A
B
C
D

The primary advantage of the balanced line is

(A) its ability to cancel out noise voltages which may be picked up by the line.   (B) that the outer conductor is a grounded shield.   (C) that only one conductor is necessary.   (D) the reduction of shunting effect on high frequency audio signals.

4.
A
B
C
D

A VU meter is primarily used to measure the output of the

(A) program amplifier.   (B) cue amplifier.   (C) monitor amplifier.   (D) microphone preamplifiers.

5.
A
B
C
D

The amount of isolation provided by an H pad or a T pad

(A) has no bearing on the resistance values used.   (B) is directly proportional to the amount of attenuation provided.   (C) is always 10 dB.   (D) is decreased as the amount of attenuation is increased.

6.
A
B
C
D

In the block diagram of Fig. 19, adjustment of attenuators AT4 - AT8 to the maximum counterclockwise position causes signals in these channels to be applied to

(A) the monitor booster amplifier.   (B) the program amplifier.   (C) the cue amplifier.   (D) a microphone preamplifier.

7.
A
B
C
D

In Figure 19, switch S_{35}

(A) determines which of the speakers are muted.   (B) selects the signals applied to the program amplifier.   (C) selects a signal to be applied to the monitor amplifier.   (D) switches the program equalizer in or out.

8.
A
B
C
D

In Figure 19, when S_4 and S_8 are both switched to the ON position, a signal applied to channel 4A input is fed through

(A) both channels 4 and 5.   (B) channel 5.   (C) channel 4.   (D) neither channel 4 nor 5.

9.
A
B
C
D

In Figure 19, the function of the booster amplifier is to

(A) amplify all signals fed to the program bus.   (B) amplify all signals fed to the audition bus.   (C) amplify all signals fed to the cue bus.   (D) boost the program signal to the +14 VU level.

10.
A
B
C
D

In the muting system of Figure 19, the control room speaker is cut off when

(A) input selector switch S_1 is set to the A position.   (B) input selector switch S_2 is set to the A position.   (C) input selector switch S_1 is set to the B position.   (D) any of the microphone channels are in use.
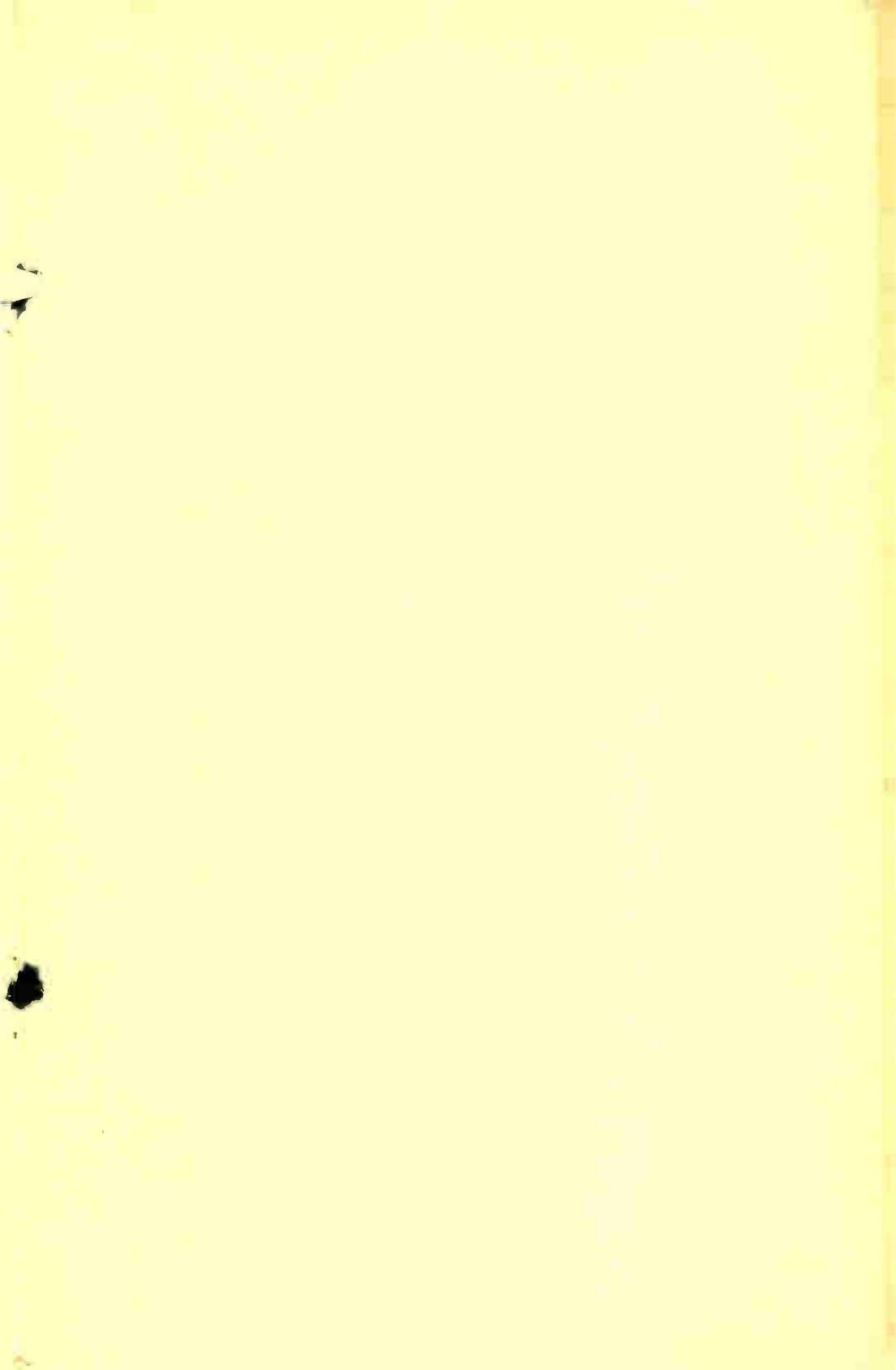
PHOTOLITHOGRAPHY
IN INTEGRATED CIRCUITS

Lesson 5506A

DeVRY Technical Institute

CHICAGO   TORONTO

PHOTOLITHOGRAPHY
IN INTEGRATED CIRCUITS

OPPORTUNITY
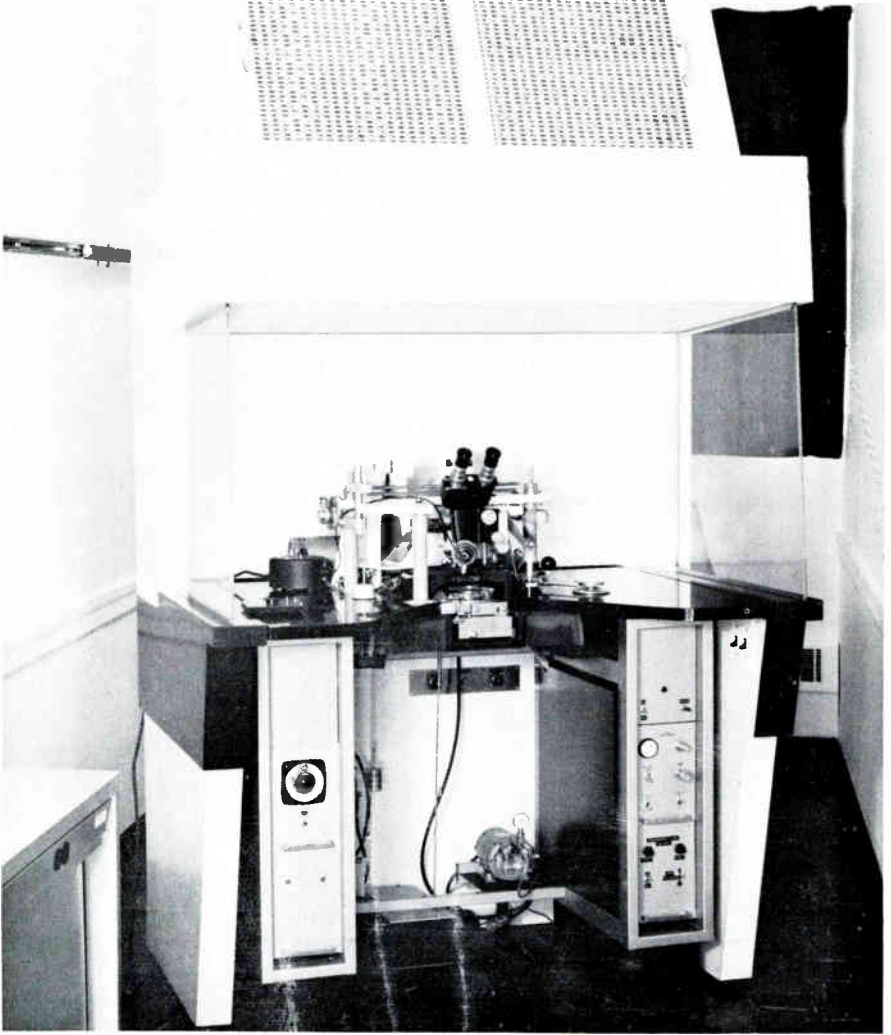
This mask alignment system offers magnification from $20\times$ to $400\times$ with alignment accuracies af .00002 inch. Other features are mechanical pre-alignment of the wafer and automatic alignment of each wafer parallel to the mask. The system is shown in a "clean bench" which keeps the machine free of contaminating dust.

Courtesy Kulicke and Soffa Mfg. Co.

PHOTOLITHOGRAPHY IN INTEGRATED CIRCUITS

Contents

Education is not for the young alone. It is a life-long process.

— Selected

PHOTOLITHOGRAPHY
IN INTEGRATED CIRCUITS

Photographic processes are used to achieve the fine detail needed to produce integrated circuits of microscopic size. To date, no equally convenient method of meeting the exacting requirements for the dimensions of the very small integrated components has been discovered. Photographic techniques are also relatively simple and inexpensive to apply.

Photography is used repeatedly during the integrated circuit fabrication process. A series of patterned **MASKS,** each produced photographically, are employed to control the processing steps. These masks are used to control the areas of diffusion, etching and metalization.

Almost every one of the individual processing steps requiring photographic techniques may be divided into three separate and distinct parts:

1. Preparing the master mask or pattern.
2. Transferring the master pattern to the wafer via a temporary or expendable mask.
3. Establishing the pattern permanently in the wafer or otherwise controlling the subsequent processing steps.

Photographic films serve the first two of these functions, as both reproducible master patterns and as the temporary (expendable) photographic patterns. These temporary patterns are developed directly on the silicon wafer. In this lesson we will consider the preparation of the master or original mask and the application of photoresist to form the intermediary or expendable mask.

<center>*　　　*　　　*</center>

1. **Photographic techniques are rarely used in integrated circuit fabrication. True or False?**

2. **For what purposes are the photographically produced masks used in the manufacture of integrated circuits?**

<center>*　　　*　　　*</center>

PHOTOLITHOGRAPHY

PHOTOLITHOGRAPHY is the process of reproducing exact images by the use of photosensitive (light-sensitive) materials. The photographic materials themselves are light-sensitive. They are used in master masks and they are applied to the wafer in the form of thin films of **PHOTORESIST (PR)**. During the photolithographic process, thin films of PR material are deposited uniformly on the wafer or substrate onto which the desired pattern is to be formed. Exposure to light rays causes **POLYMERIZATION** of the photoresist materials. That is, the materials in the exposed areas change their molecular structure. The difference between polymerized and undeveloped photoresist is most important. By careful exposure and development, polymerization can be closely controlled to produce intricate patterns with sharp **RESOLUTION,** or definition between the exposed and unexposed areas. These characteristics of photographic materials are used extensively in the fabrication of integrated circuits.

*   *   *

3. **What is photolithography?**

4. **When photoresist is exposed to light, the photoresist material becomes** (a) undeveloped, (b) polymerized.

*   *   *

The fabrication of an individual integrated circuit may require as few as five or as many as twenty different masking sequences. Figure 1 shows the series of masks used, one at a time, in the fabrication of a typical integrated circuit. With each mask, a new photoresist film and subsequent processing is required.

The performance capabilities of integrated circuits are largely determined by the quality of the photographic masks. The accuracy of the photographic materials and techniques and fabrication process control limit the characteristics of the finished integrated circuits. Among the photolithography limitations for these applications are:

1. The resolution limits of the photographic materials, both of the mask and the film.

2. Problems of aligning each mask in exactly the same position as the preceding masks.

3. The uniformity of the films, both in the master mask and in the expendable films.

4. The suitability of the film for the particular processing step, such as etching.

5. Limitations of the following processing steps, such as diffusion and etching (rounding of corners, spreading, etc.).

To a great extent, the maximum photographic capabilities determine the ultimate performance of the finished integrated circuit.

*   *   *

5. **Do photo masks in any way affect the performance capabilities of integrated circuits?**

*   *   *

PRINCIPLES OF MASKING

Masks used in integrated circuit fabrication are of two basic types—those which are intended to conceal or protect, and those which are transparent or open. For these purposes, there are two widely used types of masks:

1. shadow masks
2. photographic masks

The basic difference in operation between these two types is that the **SHADOW MASK** does not come into contact with the work or wafer, while the **PHOTOGRAPHIC MASK (PHOTO MASK)** is used in a contact process.

Shadow masks have limited application in the control of vacuum depositions of materials, particularly metals, on a substrate surface. Fig-

The central console shown at the right directs the passage of a razor-like blade through the masking material. This automatic process is completed in approximately 10 minutes.

Courtesy Bell Telephone Labs, Inc.

ure 2 shows a shadow mask being used for this purpose. In this application, slots or holes are cut in the mask. These holes permit the evaporant (evaporated material) to reach the surface in a direct path from the filament to the work surface. The filament is heated by passing current through it so that the evaporant melts. Other areas of the work surfaces are protected from the evaporant because they are in the shadow of the solid areas of the mask.

*   *   *

6. What is a shadow mask?

*   *   *

Shadow masking has several important limitations. The most impor-
tant of these is the limitation on the geometries possible. Slots, cir-
cles and some combinations of these can be employed. The mask
itself, however, must be self-supporting. Concentric circles cannot be
deposited by the use of one of these types of masks because there is
no convenient way to hold the center circle of the mask without break-
ing the circle itself.

Shadow mask material must be thick enough to be self-supporting.
Thin metal sheets, usually greater than 1 mil thick, composed of stain-
less steel, molybdenum, etc., are used. Large patterns can be formed
by machine methods, smaller ones by chemical etching. As geometries
become smaller, it becomes increasingly difficult both to cut the mask
pattern accurately and to maintain the tight tolerances with continued
use. Small holes tend to fill up, and square corners tend to become
rounded as the evaporant sticks to the mask. The evaporant is diffi-
cult to remove.

Alignment of two shadow masks with the work surface is also difficult
to hold to tight tolerance. The maximum alignment variations allowed
in the fabrication of many integrated circuits are $\pm.1$ mil or 100
microinches. Extreme care is required to align shadow masks to a
tolerance of better than ± 1 mil.

*   *   *

7. What limits the usefulness of shadow masks?

*   *   *

A major advantage of shadow masks is that they do not touch the
work surface but keep the evaporants from reaching those areas of

the surface where they are not desired. The use of single masks with several carefully spaced filaments permits the development of interesting patterns as shown in Figure 3. In this application, one heated filament will be used to deposit gold (Au), and the other aluminum (Al).

*   *   *

8. A shadow mask can permit deposition of only one type of material at a time. True or False?

*   *   *

A photographic mask, or photo mask, is a developed photographic film having clear or transparent areas and dark or opaque regions. The films are thin and relatively soft. They must be supported, either on the substrate they are used to control or on a transparent material such as a sheet of glass. A typical photo mask is illustrated in Figure 4.

*   *   *

9. What is a photo mask?

*   *   *

Photographic masking works by transferring a pattern from one very thin film of photographic material to another. The first of these, the **MASTER MASK**, is prepared before the actual processing, much like the shadow mask. The film is attached to a transparent substrate, usually a glass plate. It may be reused many times.

*   *   *

10. What is the basic principle of photographic masking?

11. What is the basic function of the master mask?

*   *   *

The second photographic film, the photoresist, is deposited undeveloped on the surface of the wafer. Photoresist is called a **CONTACT MASK.** It is not reusable. The second film is exposed to light through the first photographic mask. It is then developed in place on the wafer surface. The photoresist is selectively exposed where it is not shielded by the master mask, and is left unexposed in those areas where the light rays are interrupted by the master mask. The development process removes the unexposed areas of the photoresist while
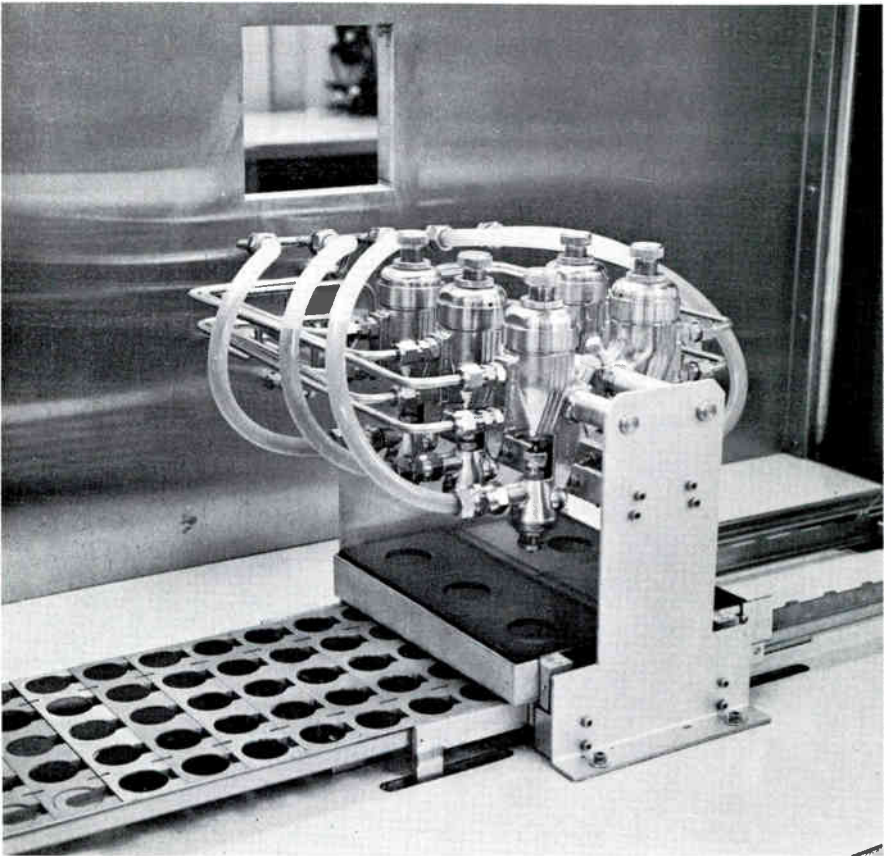
The device shown in this photograph sprays a controlled amount of photoresist on each wafer passing beneath it.

simultaneously hardening those areas which have been exposed. The developed photoresist protects the underlying material.

The areas from which the photoresist was removed remain exposed for the next processing step, which is frequently a chemical etching. After completion of the etching, the photoresist film must be removed completely. This is called a subtractive process. Since the photoresist is removed after etching and before the actual process step (diffusion, metalization, etc.), this film is called an **EXPENDABLE MASK.**

<p style="text-align: center">*   *   *</p>

12. In photolithography, the (a) master mask, (b) photoresist coating is an expendable mask.

<p style="text-align: center">*   *   *</p>

This basic subtractive process is used to cut windows in silicon dioxide for the control of the diffusion processes, as well as to establish the desired pattern of metalization for contacting and interconnecting the various components on the chip. Figure 5A shows how the photoresist process is used with a silicon substrate coated with a layer of silicon dioxide. The resulting layer of developed photoresist shown in Figure 5B is the negative or complement of the pattern in the glass mask. Photoresist layers are typically 5000Å (.5 mil) thick.

<p style="text-align: center">*   *   *</p>

13. What is the pattern relationship between the master mask and the developed PR coating?

<p style="text-align: center">*   *   *</p>

MAKING MASTER MASKS

The principles of photographic reduction are used to achieve the extremely small size and accurate geometry required for the final integrated circuit masks. One or more reduction steps may be used. Most

commonly employed processes use two such reduction steps in preparing the final masks for integrated circuits.

Practical mask making, as presently performed, involves the following six major procedures:

1. Circuit design—Designing the circuit and laying out the components.

2. Artwork—Preparing oversize master artwork for each of the individual masks required. An individual circuit may require five or more pieces of artwork to achieve a simple integrated circuit. Each separate piece of artwork must mate accurately with each of the other components in a set.

3. Size reduction—To reduce the large size of the master artwork to the final size and to hold the tight dimensional tolerance, it is desirable to make the original artwork as large as conveniently possible and then reduce it photographically.

4. Pattern repetition—Each integrated circuit covers a very small area of the wafer. Therefore, it is usually desirable to repeat and distribute each of the individual circuit patterns many hundreds of times over a wafer. This is usually accomplished by starting with master artwork for a single circuit. The repetition process can be accomplished separately, or as part of either the first or second reduction. It is more commonly done as part of the second reduction because the smaller image size makes handling easier.

5. Inspection—After producing the smaller multiple circuit mask, it is inspected to assure that the accuracy, uniformity and alignment requirements have been satisfied. This mask is called the **MASTER MASK**. A different master mask is usually required for each processing step. The group of masks is the **MASTER MASK SET**.

6. Copy making—For production purposes, a **COPY** of the master mask is usually used. The master itself is usually

reserved for the sole purpose of making additional copies as they are needed.

In the various steps of mask making, photographic films are used to accomplish many of the requirements. The master artwork is reproduced photographically, the reductions are produced in photographic films, etc. These films are very fragile and are easily damaged by carelessness or improper handling. They can also be easily contaminated. Scratches, dust and other contaminants can make them useless.

*　　　　　*　　　　　*

14. What are the basic steps in preparing a mask set?

*　　　　　*　　　　　*

MASK DESIGN LAYOUT

A circuit function that is to be integrated is reduced in the mask design process to a series of pattern layouts or masks. These masks are used to form active and passive components and isolation and interconnection regions. The result is to create the desired circuit in a relatively small area.

The specific requirements for each component and region must be satisfied. The layout must take into consideration the interrelationships resulting from integration and fabrication of the circuit without ideal or perfect components. In the layout used to produce the masks, each area must be clearly identified. Sufficient space to accommodate the requirements of each individual processing step must be provided.

The requirements for each individual mask can be determined from the mask design layout. Each area into which each diffusion is to be conducted must be identified separately. Special etching, metalization and test pattern requirements must also be determined. The effect of each of the basic process steps on the other steps must be taken into consideration. Usually, each major processing step in the production of integrated circuits requires its own separate mask.

ˈ   ARTWORK

Individual engineering sketches or scale drawings must be prepared
for each process requiring a mask. These drawings are usually made
between 200 and 1000 times larger than actual size on dimensionally
stable paper or film such as mylar. Greatly oversized artwork is used
so that inaccuracies in the drafting procedures are minimized by the
size reductions that follow. It is not difficult for a draftsman to hold
almost the same accuracy on a piece of artwork 20 inches across as
it is for one that is only 2 inches across. When they are both reduced,
however, the errors in the larger piece of artwork are reduced propor-
tionately. This results in a smaller percentage of error in the final
size work.

Figure 6 shows a piece of artwork being reduced to 1/10 its original
size. As a result, the error in width is also reduced to 1/10 its original
value.

*   *   *

**15. Why is the original master artwork for an integrated circuit normally
made several hundred times larger than the final circuit itself?**

*   *   *

Suppose a 50 mil accuracy is maintained in the original oversized art-
work. With a 200 times reduction, this results in a variation of only
50/200 mil, or one-quarter of a mil after reduction. The same 50 mil
variation, coupled with only a 10 times reduction, would result in a
50/10 mil or 5 mil variation in the final sized work. As a general rule,
the larger the magnification of the original work, the easier it is to
maintain dimensional accuracy in the final pattern.

*   *   *

**16. If the original artwork is 200X and the accuracy is 0.05 inch, what is the
dimensional accuracy in the final mask?**

*   *   *

This reduction camera has a $10\times$ to $20\times$ variable reduction capability. Turning the handle shown at the right moves the carriage. A dovetail slide system, mounted on top of the carriage, positions the observing microscope and film holder.
Courtesy David W. Mann Co.

A reasonably competent draftsman can usually produce artwork which will result in accurate final patterns if a reduction of 200 or more is used. Special equipment, such as **COORDINATOGRAPHS**, have been prepared for specially cutting the master artwork pattern to tighter tolerances. These devices are capable of maintaining tolerances of better than $\pm0.001''$ (1 mil). More accurate drafting and cutting techniques such as these must be used in preparing the original or master artwork, if it is impossible to reduce the artwork extensively by photographic means. However, where large physical reductions are possible, equipment with this tight tolerance is seldom necessary.

The design of the original artwork is produced with special mask-making material. For this purpose, a two-layer material is frequently

used. It is available under such trade names as Ruby Studnite and Cut-and-Strip. The top layer is a thin, deep red material which adheres to a clear, thicker transparent plastic base. The ruby red material is opaque to the light employed for developing the photographic plates. However, the clear film permits almost complete light transmission. In preparing the master artwork, areas of the ruby material are cut and removed where light is to pass through the film. The materials used in each of these processes are selected to have very good dimensional stability over the normal range of temperature and moisture conditions associated with the mask making procedure. This is necessary to minimize errors and tolerance problems.

If the final die size for an integrated circuit which we choose to make is to be 50 mils on a side, the original or master artwork can be made 20 inches square and a reduction of 400 times used. This could be accomplished in two steps of $20 \times$ reduction each.

In designing the artwork, it is extremely important that the proper density (opaque or clear) be established. Remember, with photographic processes each individual step of reproduction results in a reversal. That is, the opaque area becomes clear and the clear area becomes opaque. If an even number of steps is employed, the original art in the final pattern will be a positive copy of the original (clear areas on the original would be reproduced as clear areas, and opaque as opaque). However, if an odd number of processing steps is used, there will be a reversal between the original artwork and the final pattern (clear areas are reproduced as opaque areas, and opaque as clear).

*   *   *

17. What is a density reversal? Why do they occur?

*   *   *

PATTERN REPETITION

Economy dictates that optimum use be made of the space available on the silicon wafer within which the integrated circuits are to be produced. Each individual circuit must be assigned to an area, and as many circuits as possible must be produced on each mask. The mask making and processing is such that there is little or no cost associated with producing additional components on the wafer. It costs approximately the same to process a wafer with one circuit on it as a wafer with a thousand circuits.

The major problems involved in producing a large number of components within a given wafer substrate is associated with the matching or mating of the various masks required to process or construct the circuit components. To accomplish this, the single patterns or pieces of master art must be reproduced many times over the area of the production mask. There are three basic techniques currently being employed to achieve the repetition of images, or a multi-image array, across a wafer-sized mask. These are:

1. step-and-repeat
2. multiple-lens reproduction
3. multiple-aperture reproduction

＊   ＊   ＊

18. Why are a large number of identical patterns placed on a mask?

＊   ＊   ＊

Step-and-Repeat System

The **STEP-AND-REPEAT SYSTEM** uses a high quality, single-lens arrangement, which is moved from position to position. The master artwork pattern is repeatedly reproduced in separate areas of a photographic plate, while simultaneously being reduced in size. With this method, each individual image on the photographic plate requires a separate exposure. Figure 7 shows the master being reduced to 1/20th of its original size in step 1. In step 2 the artwork is reduced

again by a factor of 10. Here it is also repeated. The small image is produced again and again in a line, reindexed for each row, and stepped off again. The final master photo mask in Figure 7 includes the proper number and location of the images.

The pattern negative must be very carefully aligned before the pattern is photographically transferred to the photoresist on the wafer.

Courtesy Texas Instruments, Inc.
Semiconductor Components Div.

It is not uncommon to use over a thousand steps and repeats in producing the master photo mask. Each repetition in this process must be ACCURATELY positioned. The spacings, both horizontal and vertical, must match with their counterparts in ALL other masks so that, in the set, they will align properly with each other.

The most critical problem associated with the step-and-repeat technique is the mechanical control necessary to assure that each reproduction of the master art exactly corresponds from mask to mask. Satisfying this requirement contributes substantially to the system's relatively high cost. Since this method of making multiple images was developed first, it is currently in wide use.

*   *   *

19. **How does the step-and-repeat system work?**

20. **What makes this system so expensive?**

*   *   *

Multiple-Lens System

Rather than using a single lens to reproduce a single image, and repeating the process, it is possible to use a number of lenses simultaneously to produce the number of images desired from a single master mask. This **MULTIPLE-LENS SYSTEM** is frequently called the **FLY'S EYE SYSTEM,** because of its similarity to the eye of a common housefly. Its operation is illustrated in Figure 8.

Each lens in a fly's eye system must be in exactly the right position to form the multitude of images correctly. As may be expected, the cost of the lens system necessary for this operation is relatively high. Each individual lens is considerably smaller and of somewhat more limited quality than that used in the step-and-repeat system.

The multi-lens technique of mask making has several advantages. Only one exposure is necessary to produce the desired number of images. The problem of properly locating images from mask to mask

is automatically solved, since the same lens system is used for each mask exposure. This results in excellent registration.

In this camera system, the largest element of cost is the multi-lens plate. This contains the number of lenses required. It may be formed in one piece by precision molding. Plexiglas is often used for the lens and plate. A lens plate with its number of lenses fixed in position can only be used with one die size. The center-to-center distance between lenses in the camera system cannot be changed except by replacing the expensive lens plate with another equally expensive lens plate.

This system permits the use of lower quality lenses than in the step-and-repeat system. Any aberration, error or non-uniformity within any one of the lenses is repeated uniformly from mask to mask, minimizing damaging effects. Also, small distance variations in center-to-center spacings affect each mask identically. Hence, they do not cause the difficulty in the subsequent alignment procedures that a similar variation might in the step-and-repeat system.

*   *   *

21. What is the principle of operation of a multi-lens system?

22. Compare the advantages and disadvantages of a multi-lens system as compared to a step-and-repeat system.

*   *   *

Multiple-Aperture System

A **MULTIPLE-APERTURE SYSTEM** makes use of the pinhole camera principle. This technology was used to make the earliest photographic cameras. Recently, it has been developed into the most inexpensive camera system for producing multiple images from a single piece of artwork. The system works very much like the multi-lens system. In place of the plastic lens plate, however, a board with the equivalent number of small apertures or pinholes is used. Each pinhole, if small enough, acts as a lens.
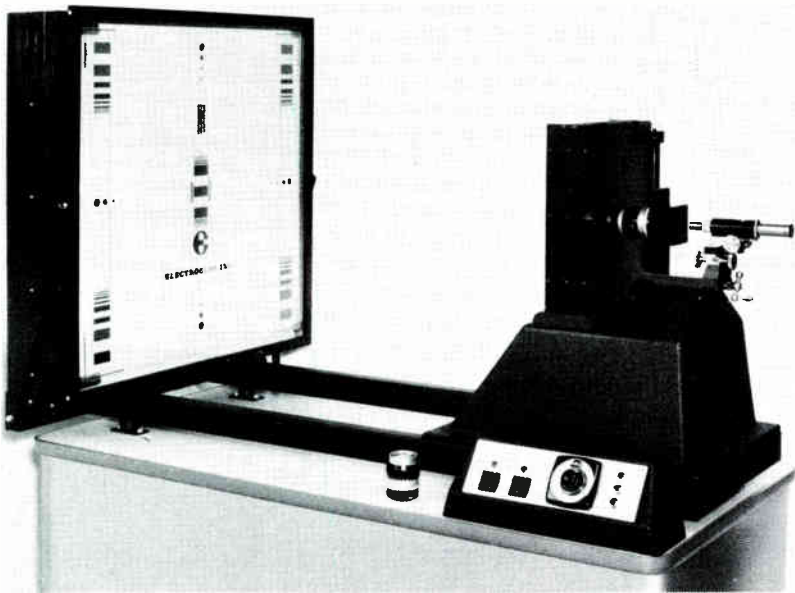
This camera system produces a 2" ✕ 2" final work mask from 400 ✕ or 200 ✕ artwork in two reduction steps. A 200 ✕ microscope is provided for fine focusing. Exposure timing is controlled electrically. The pinhole system used is free from linear distortion. Different combinations of multi-aperture plates are available for use with this system.

Courtesy Electroglas, Inc.

Pinholes are not capable of as good resolution as plastic lenses. In practice, this can be partially compensated by combining reduction and multiple-image production in the first rather than the second step as shown in Figure 9. This permits the use of a high quality single-lens system for the final reduction. The making of additional pinhole plates is more economical than new lens plates. Therefore, this system more readily permits the use of different center-to-center image arrays.

*   *   *

23.   What differences exist between a multi-lens and a multi-aperture system?

24.   How does a pinhole operate in a multi-aperture system?

*   *   *

CAMERA SYSTEMS FOR MASK MAKING

The proper selection of a camera and lens system to be used in making photo masks depends greatly upon the specific requirements. This decision is influenced by final size, resolution, and amount of reduction required, together with the technique used to obtain the multiple images required in the final mask.

To minimize the effects of tolerance errors in the original artwork, it is desirable to make the artwork as large as possible. The maximum artwork size is limited by the camera system. Increasing the size makes it more difficult to achieve uniform illumination, consistent lens operation, etc. Camera systems become much more expensive as they become larger.

The step-and-repeat system of mask making requires two cameras, each with high quality, single-lens arrangements and very precise mechanical controls to satisfy the multiple-image spacing requirements. The fly's eye system uses a single lens for the first reduction and a fly's eye lens for obtaining the second reduction and the multiple images. In the pinhole system, the multiple image is produced by the first reduction, and a single lens is used for the second reduction.

The step-and-repeat system produces the highest quality results, but is the most costly. The pinhole system is the cheapest but suffers slightly in quality compared to the others. However, several major suppliers of integrated circuits use the pinhole system exclusively without noticeable degradation of circuit performance.

*   *   *

25. In two-reduction camera systems, when are the multiple-image arrays normally made in the step-and-repeat system? The fly's eye system? The pinhole system?

26. Which is the most expensive mask making system?

27. Which is the least expensive mask making system?

*   *   *

MASK COPIES

A master **MASK SET,** produced by any of the methods outlined, is generally considered to be the most important part of integrated circuit tooling. It represents a major investment. Invariably, this master mask set is used solely for making **MASK COPIES** (photographic contact printed). The copies are then used during the fabrication process. This is necessary because photographic emulsions are easily damaged. Scratched and scarred masks are useless. Since the master set is used only to produce copies, a very large number of copies can be reproduced if care is exercised to avoid damaging the master.

*   *   *

28. Why must photo masks be handled with care?

*   *   *

Another important reason for preserving the master set is the necessity of making a complete set of masks at a time. The many critical factors involved with alignment, lighting, spacing, etc. make it difficult to produce one mask of a set separately from its mates. When a single master mask is damaged or changed, good practice normally dictates that a complete new master mask set be made.

*   *   *

29. If one mask in a six-mask set is damaged the usual practice is to replace (a) only the damaged mask, (b) the complete set of masks.

*   *   *

MIXING PATTERNS

The mixing of two or more patterns on an integrated circuit wafer is sometimes desirable. Test patterns for alignment, testing and control purposes are frequently used in this way. Figure 10 shows a typical arrangement of **ALIGNMENT PATTERNS** for control. A few of the useful chips are sacrificed to improve alignment.

TEST PATTERNS, such as squares or diamonds included within or surrounded by circles, are commonly used for alignment purposes. The squares, diamonds or circles are individually located on one mask, while their complement is included in the same position on other masks within the set. A pattern useful for a five-mask set is shown in Figure 11. It is much easier to align a pattern such as this than it is to align the patterns used for the formation of the integrated components. This is because the actual circuit patterns must fit within one another normally without touching the previous patterns produced on the chip.

Patterns may also be mixed when the two or more circuits are fabricated by an identical processing sequence. The different circuits may
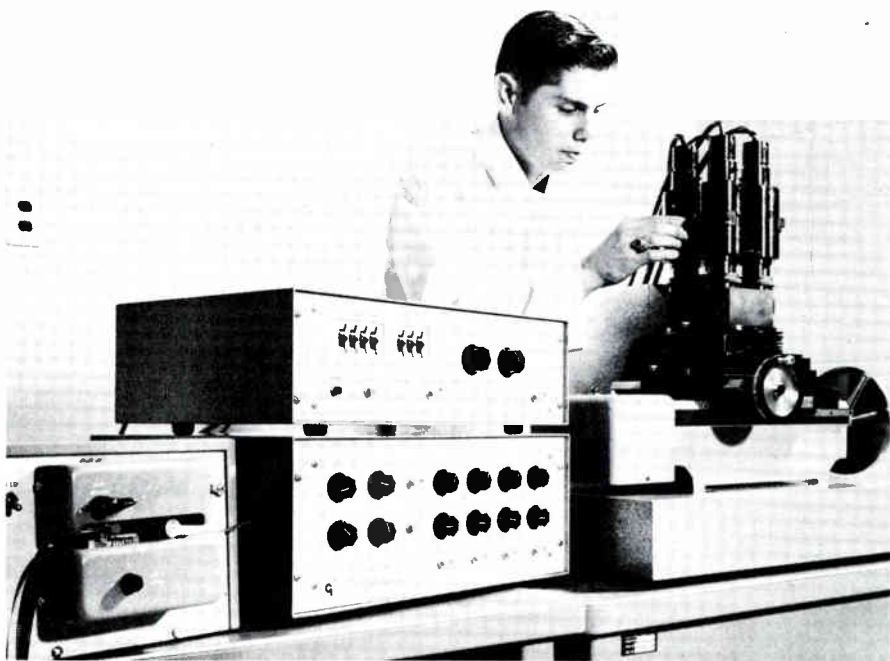
Four separate exposure systems (shown at the right) are controlled by the tape unit at the left. The spacing of the patterns and the operation of the flash systems is controlled electronically by the two units shown in the center.
Courtesy David W. Mann Co.

occupy alternate columns or rows. In preparing masks for such an arrangement, the preparation of a multiple-image array is more complicated than a single-pattern arrangement. In the step-and-repeat system, the steps must be correlated with the separate pieces of artwork. In the multi-lens or pinhole systems, the particular rows or columns not to be used must be blocked off. Sets of special baffle plates are inserted between the artwork and lens. Separate sets of master artwork and double or multiple exposures are required.

Mixing of circuits in these ways, while not extremely difficult, is not commonly done on a production basis. The technique might be used to advantage to satisfy limited or experimental quantity requirements. For convenience, the alignment patterns, test components, etc. are frequently included in corners or unused areas of the individual die as integral parts of the overall layout. When this is done, they appear on every die.

*   *   *

30. What are control patterns?

31. Several different circuit mask patterns can be incorporated within a single production mask. True or False?

*   *   *

PHOTOLITHOGRAPHY IN INTEGRATED CIRCUIT PRODUCTION

Photolithographic techniques are used to transfer the patterns of the photo mask to the silicon wafer. These are developed in place on the wafer. The developed photoresist is then used to control subsequent processes. Among these processes are:

1.   Etching SiO_2 to control diffusion.

2.   Etching SiO_2 to enable contact to be made to the terminals of the integrated circuit elements.

    3.   Establishing the pattern of wiring or component intercon-
        nections.

The latter requirement can be satisfied either by chemical etching or direct masking to permit the metal to contact the wafer surface only in the desired areas.

In each of these applications, the photographic processing steps are identical up until the last step. In all cases, the photoresist (PR) material acts as an expendable mask which is removed after having served its function. Where etching is required, the PR material, and chemical material removal, effectively transfer the mask patterns to the material permitted to remain. That is, the windows in the SiO_2 coating and the remaining coating have the same pattern as the mask. The opaque areas of the mask will be holes or windows, while the oxide will remain where the mask is clear.

<center>*   *   *</center>

32. The application of a photoresist film is necessary to reproduce the pattern of the photo mask on the wafer. True or False?

33. What is the purpose of etching?

<center>*   *   *</center>

The first step in the PR film process is to lay the wafer on a chuck or mandrel, where it is held in place by suction from a small vacuum pump. Two or three drops of photoresist material are placed on the wafer to be coated. The photoresist is treated to permit easy flow and uniform viscosity. A small motor rotates the mandrel. The wafer is then spun at a high rate of speed. The excess photoresist material is thrown off by centrifugal force, and a uniformly thin coating is left. The thickness of the photoresist coating can be closely controlled by controlling the combination of the viscosity, the amount of photoresist, and the speed of rotation.

*   *   *

34. How is a thin, uniform coat of PR placed on the wafer?

*   *   *

Next the coating is heated, permitting the solvents to evaporate. This hardens the photoresist. Sufficient drying takes a relatively short period of time (a few minutes) at relatively low temperatures (not exceeding 120°C). The resulting coat of PR is transparent.

The split-field microscope and exposure system shown above is used for split-field viewing and rapid aligning and exposure of sequential patterns. It provides magnifications from 19× to 1100×.

Courtesy Electroglas, Inc.

The wafer, coated with photoresist material, is now carefully aligned with the photo mask to assure proper mating between the mask pattern and patterns previously formed on the wafer. This is usually done under a high-powered microscope whose adjustments permit very accurate movements of the x, y and θ (rotational) planes. Frequently, a **BALLISTIC MICROSCOPE** is used for this purpose. A ballistic microscope employs a split image, making it possible to look at two different locations on the wafer, and having them appear side by side. Being able to see widely separated patterns in this way permits much more rapid alignment. This is shown in Figure 12.

The photoresist coating is exposed by a beam of light passing through the clear areas of the mask to the photoresist. That part of the photoresist which is exposed to light is polymerized. The areas protected by the opaque regions of the mask are unaffected by the exposure.

The PR materials commonly used for integrated circuit production are much more sensitive to the blue end of the spectrum. They are insensitive to yellow or red light. Rather than using a darkroom, in which it is difficult for most people to work, all the processing steps preceding exposure are conducted under yellow or red light. In commercial establishments, where this procedure is used extensively, special photoresist rooms have been constructed with this type of lighting.

*   *   *

35. What happens to the photoresist film during exposure?

*   *   *

After exposure, the PR coating is developed. The developer solution has a dual function: (1) It hardens, or leaves unaffected, the polymerized (exposed) areas, and (2) dissolves or washes away the rest of the coating (unexposed areas). The developed photoresist is hardened further by baking at a moderately elevated temperature (over

200°C). The hardening processes increase the film's resistance to the chemicals used in the etching process.

The wafer, with the hardened photoresist material remaining in specific areas, is then etched or further processed. When etched, the etching solution attacks the exposed wafer surfaces without affecting the photoresist or the underlying areas it protects. Alternatively, in a deposition process, the photoresist prevents deposition in the areas where it coats the surface.
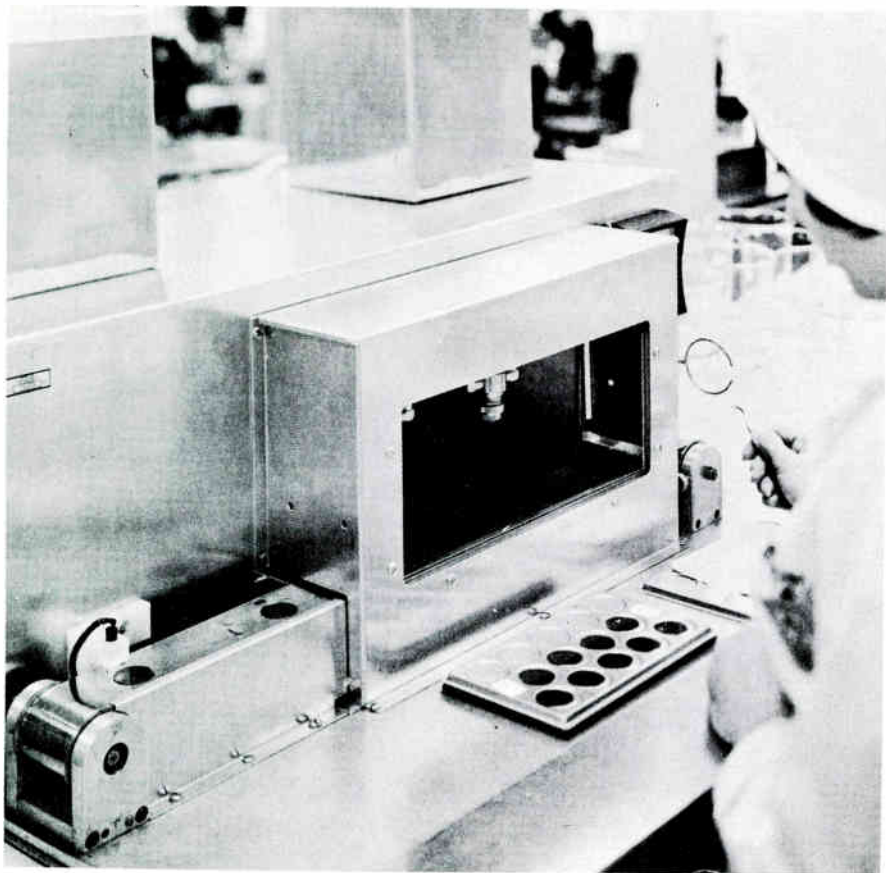
After the photoresist has been exposed, it is developed. Equipment like that shown in this photograph is used in the development process.

Courtesy Texas Instruments, Inc.
Semiconductor Components Div.

After etching or deposition, the balance of the photoresist material is removed. In most applications, it is very important that no trace of this PR material be permitted to remain. Scrubbing with heated solvents is often required. This must usually be followed by thorough cleaning to remove any troublesome solvents, etc.

The described method of applying photoresist is used many times during integrated circuit production. Its primary purpose is to establish the pattern of SiO_2 and metal films.

*   *   *

36. What is the effect of the developing process?

37. How is the photoresist hardened after exposure and development?

38. Why is the photoresist hardened?

*   *   *

Poor resolution can result in yield losses. High frequency performance of the resulting circuit can be severely limited. To assure good resolution, the wafer must be uniformly flat. Warped wafers prevent close contact between the PR coating and the photo mask. Refraction of light through gaps or separations causes fuzziness of the lines and loss of definition. Good resolution also requires that the PR coating be of uniform thickness and preferably very thin (also to prevent refraction of light).

*   *   *

39. Why is it desirable that the photoresist material deposited on the wafer be uniform and thin?

*   *   *

Misalignment is another major cause of yield losses. Shorted or improperly exposed junctions can result. This step in the procedure is subject to the widest range of variability. It is possible to have nearly

perfect alignment in one area of the wafer and gross misalignment in another. Figure 13 shows an example of gross misalignment. The metal does not fill the contact area. The junction, which is supposed to be protected by the SiO_2, is exposed.

*   *   *

40. What problems can result from misaligned masks?

*   *   *

Pinholes in the photoresist are another problem. Lumps in the photoresist, dust particles, and scratches or tears, either in the PR coating or photo mask emulsion, are the primary causes of pinholes. Incomplete PR coatings cause more serious problems of the same sort.

Etching an SiO_2 coating is used both to control diffusions and to make contact to the integrated components. Etching away portions of an aluminum metalization coating with a hydroxide etchant, thus leaving a metalization pattern, is a frequently used subtractive process for completing interconnection or "wiring". Vacuum deposition of aluminum on top of a developed PR film is another method of satisfying this last requirement.

SUMMARY

Masks are used in integrated circuit fabrication to define the areas which a process is to affect. These masks are the most important tooling costs for integrated circuits. Photolithography is the photographic process used to make masks. A series of masks is used to control the various processing steps.

Master masks are made of photographic film. Another light-sensitive film is that coating deposited on the wafer and called photoresist. Photoresist is an expendable mask because, after it is used, it is removed. Photoresist is not reusable. The performance characteristics of the photographic materials limit the characteristics of the finished circuits.

Shadow masks and photographic masks are the two types of masks used. Shadow masks do not come in contact with the wafer. They are used to control the vacuum deposition of metals.

Photographic masks are used in a contact process. The wafer is coated with a thin layer of photoresist. The photoresist is exposed to light through a copy of the master mask. Next, the photoresist is developed. This hardens the areas which were exposed to light and removes the photoresist in the other areas, exposing them for the next processing step. The exposed areas of silicon dioxide can then be etched away. After etching, the remaining photoresist is removed.

Mask making involves several steps. They are: (1) circuit design, (2) artwork, (3) size reduction, (4) pattern repetition, (5) inspection, and (6) copy making. The master mask set is generally reserved for making production copies of the masks.

The original artwork is generally made 200 to 1000 times larger than actual size. Many circuits are produced on a single wafer. To do this, the master artwork pattern is repeated many times over the area of the production mask. Step-and-repeat, multiple-lens and multiple-aperture systems are used for this repetition. Test patterns are often placed on the wafer for alignment, control and testing purposes.

IMPORTANT DEFINITIONS

ALIGNMENT PATTERN—A special pattern which facilitates aligning the various patterns in their proper positions. This is usually part of a test pattern. Geometric figures such as circles enclosing squares, etc. are easier to align than most integrated circuit patterns.

BALLISTIC MICROSCOPE—[buh LIS tik]—A microscope which uses a split or double image, making it possible to look at different locations on the wafer so that they appear to be side by side. It is used to permit rapid alignment without sacrificing accuracy.

CONTACT MASK—A mask whose principle of operation is based upon physical contact with the substrate. Photo masks are contact masks, while shadow masks are not.

COORDINATOGRAPH — Special equipment designed for cutting master artwork patterns to very tight tolerances.

EXPENDABLE MASK—A mask developed on the surface of a substrate to control a chemical process (such as etching), which is subsequently removed. None of the mask material is used in the actual processing operation.

FLY'S EYE SYSTEM—A mask making system which involves the use of a multi-lens camera. It gets its name from the fact that the optical senses of insects (i.e., the housefly) employ many small light-sensitive lenses in an array. Also called a MULTIPLE-LENS SYSTEM.

MASK—A protective covering used to permit a process to be conducted in localized areas, while being prevented from occurring in adjacent or masked areas.

MASK COPY—A copy made from a master mask. Mask copies are used for production because masks are easily damaged and deteriorated with use.

IMPORTANT DEFINITIONS—(Cont'd)

MASK SET—A series of different mask patterns which, when aligned with one another, are necessary to produce a completed integrated circuit.

MASTER MASK—The first completed mask set from which mask copies are made for production. The master mask set is usually used only to make mask copies.

MULTIPLE-APERTURE SYSTEM—A mask making system which involves the use of many small holes or openings, such as pinholes, for producing many images simultaneously.

MULTIPLE-LENS SYSTEM—See FLY'S EYE SYSTEM.

PHOTOGRAPHIC MASK (PHOTO MASK)—A mask made by photographic techniques, used in a contact process. Photo masks are a major part of the tooling for producing integrated circuits.

PHOTOLITHOGRAPHY—[foh toh li THAHG ruh fi]—The process of reproducing exact images by the use of photosensitive or light-sensitive materials.

PHOTORESIST (PR)—[FOH toh ri zisst]—Light-sensitive material usually applied in thin films deposited uniformly on the wafer or substrate. Photoresist coatings are used to transfer the pattern between the photo mask and substrate.

POLYMERIZATION—[pahl i mer i ZAY sh'n]—A chemical process which occurs in photosensitive materials when they are exposed to light. A certain type of change in chemical structure.

RESOLUTION—[rez uh LOO: sh'n]—The ability to separate between adjacent lines. The resolution limit is often specified. It is the smallest line separation that can be distinguished.

SHADOW MASK—A mask whose operation is dependent on shadowing or non-contact. To accomplish this a point source of light or coating material is required.

IMPORTANT DEFINITIONS—(Cont'd)

STEP-AND-REPEAT SYSTEM—A mask making procedure in which many individual exposures of an image are made sequentially in different areas of a photographic plate. The location of each image is determined by the steps.

TEST PATTERN—A special pattern arrangement used to determine the quality of the various processing steps. Test patterns frequently contain complete circuit elements as well as individual process step test regions and alignment patterns.

STUDENT NOTES

STUDENT NOTES

STUDENT NOTES

PRACTICE EXERCISE SOLUTIONS

1. False--Photographic techniques are used repeatedly in the production of integrated circuits.

2. Masks are used to control the areas where diffusion, etching or metalization are to take place. The masks control the places on the wafer where these processes are to occur, and the shapes and sizes of the areas to be affected by the process.

3. Photolithography is the process of reproducing exact images by the use of photosensitive or light-sensitive materials.

4. (b) polymerized.

5. Yes--The limits of photographic processing determine the best performance capabilities of integrated circuits.

6. A shadow mask is a mask which provides concealment by shadowing or blocking certain areas while its holes and slots permit formation of the desired deposited pattern.

7. The geometries possible with shadow masks are limited. They are not easy to make, and they are difficult to hold to tight tolerance with use. They are also difficult to align for small geometry work.

8. False--Materials from more than one type of filament can be deposited at the same time.

9. A photo mask is developed photographic film, composed of two parts or densities of materials, one which is transparent and permits the passage of light, and the other which is opaque or dense and conceals or blocks light rays to protect materials below it from subsequent processing.

10. Photographic masking operates on the principle of employing a master photo mask from which another film of photographic material is developed directly upon the substrate.

11. The function of a master mask is to provide the pattern in a flexible form that is mobile and reusable.

FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

FIGURE 5

FIGURE 6

FIGURE 7

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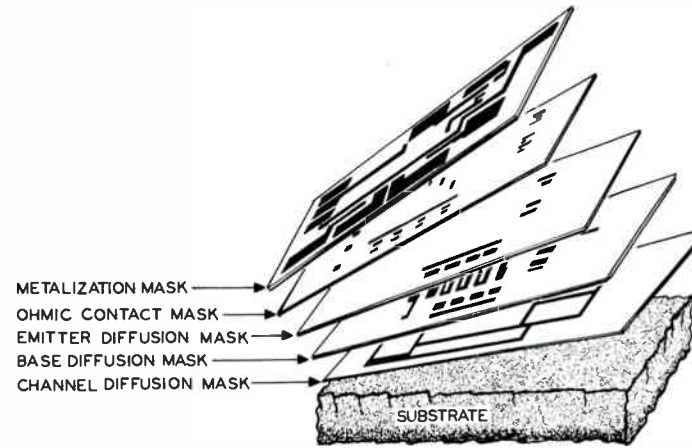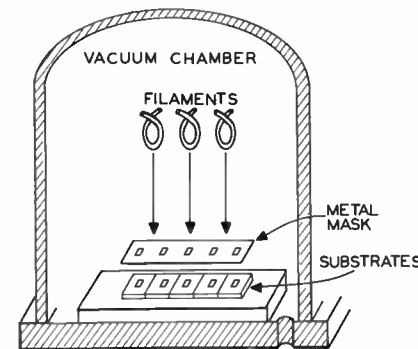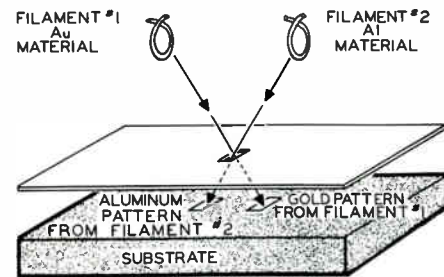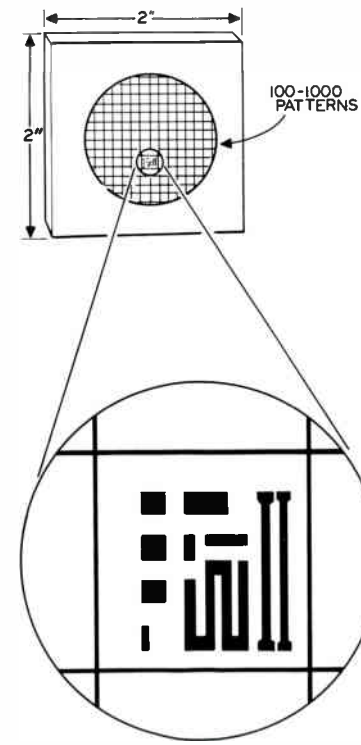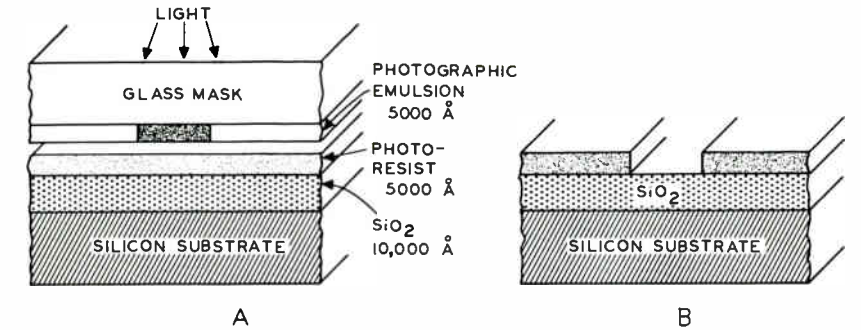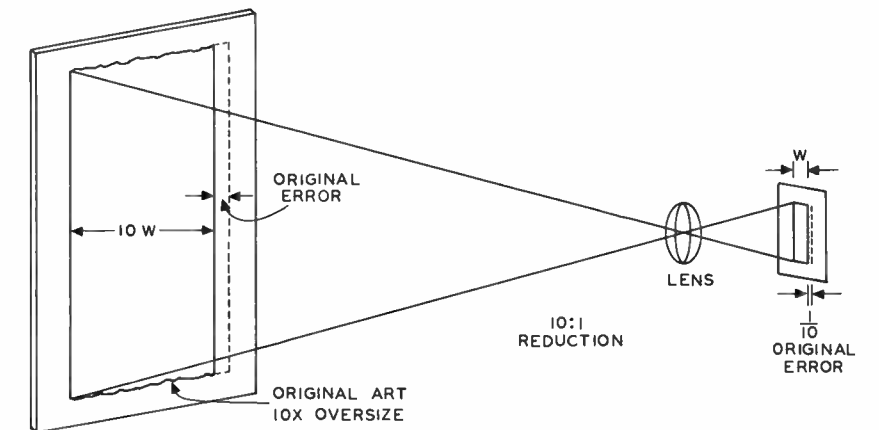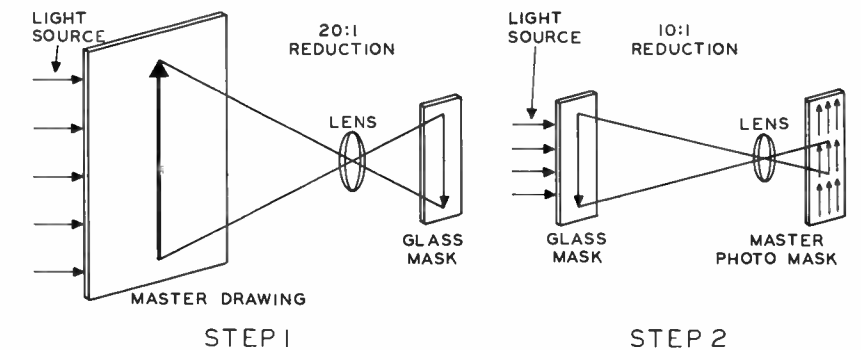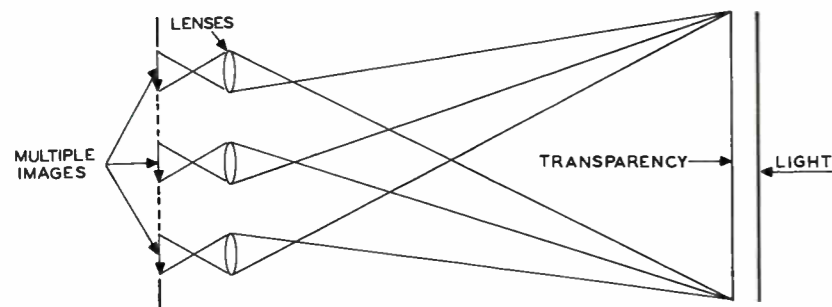
FIGURE 8

STEP 1

STEP 2

FIGURE 9

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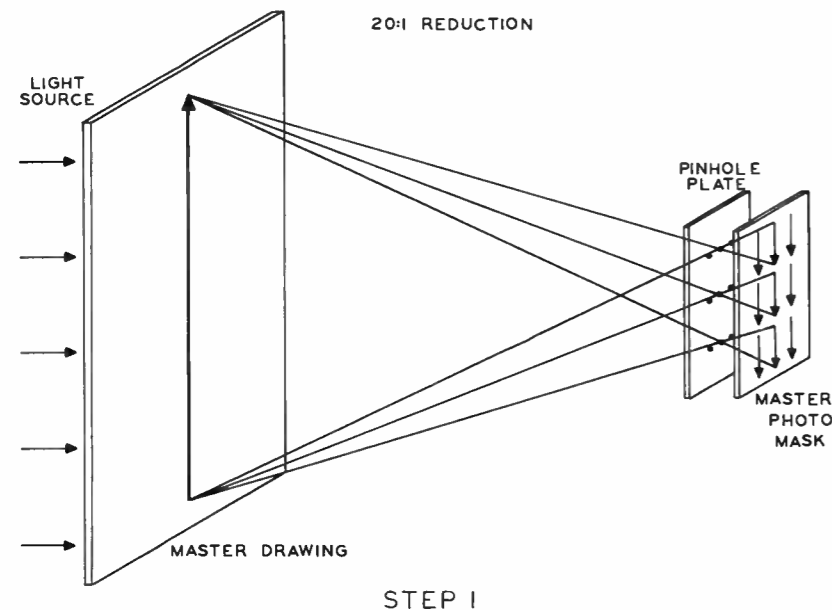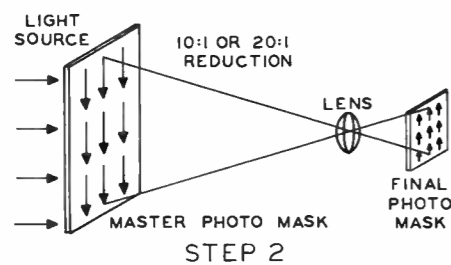
12. (b) photoresist coating

13. The relationship between the master mask and the PR material mask on the wafer is a positive-to-negative relationship, i.e. the clear areas of one appear as opaque areas of the other, and vice versa. The master mask is reusable, while the PR coating is destroyed after its use.

14. Basic steps in preparing a mask set are:

    (1) Circuit design

    (2) Artwork

    (3) Size reduction

    (4) Pattern repetition

    (5) Inspection

    (6) Copy making

15. The original master artwork for an integrated circuit is usually made several hundred times larger than it will appear in the final circuit itself to minimize the tolerance and artwork errors that normally occur in preparing the original artwork.

16. Final dimensional accuracy equals $.05/200 = 0.00025$ inch (1/4 mil).

17. A density reversal is from clear to opaque, or opaque to clear. This occurs in the use of photographic techniques, making it necessary that the master pattern be the negative of the desired pattern if an odd number of steps are used. A master with the same density pattern as desired on the final film is used if an even number of steps are employed.

18. A large number of identical patterns are usually placed on a mask for integrated circuit processing to obtain the maximum use of the silicon material and to obtain the large economical advantage of batch processing.

19. The step-and-repeat process works by the use of a single piece of artwork and a single lens which reduces the artwork to size and exposes the image on the final film many times in different locations.

20. The step-and-repeat system is very expensive because of the necessity of controlling the mechanical positioning so accurately.

21. The multi-lens system operates by using many lenses, each lens forming a single, distinct image in place on a photographic plate.

22. The multi-lens system has the advantage of maintaining spatial relationships very accurately. However, the lenses used in a multi-lens system are invariably inferior to those that are used in the step-and-repeat system.

23. The lenses of the multi-lens system are superior in resolution and other characteristics to the pinholes of the multi-aperture system. Usually a physical reduction of 10:1 to 20:1 is employed in the first step of the multi-lens system, whereas the multiple image, in addition to a reduction, is used in the first step of the multi-aperture system.

24. The pinhole principle is based on the fact that a suitable small hole through opaque material acts like a lens.

25. The multi-image array is made:

    (a) During the second reduction in the step-and-repeat system.

    (b) As part of the second reduction in the fly's eye system.

    (c) As part of the first reduction in the pinhole system.

26. The step-and-repeat system is the most expensive mask making system.

PRACTICE EXERCISE SOLUTIONS—(Cont'd)

27. The pinhole system is the least expensive mask making system.

28. Photo masks must be handled with care because the photographic emulsion films are easily damaged and, once damaged, they will reproduce the damaged section and distort or provide irregular or unwanted patterns.

29. (b) the complete set of masks. - - It is for this reason that a set of master masks is held for the sole purpose of making contact reproductions for use in processing.

30. Control patterns are separate areas where special circuit patterns or component patterns or alignment figures are produced in the mask and reproduced in the wafer for the purpose of control.

31. True

32. True - - The PR film is used to transfer the photo mask pattern to the wafer surface.

33. Etching transfers the photoresist pattern to the wafer and is used to open windows in SiO$_2$ films to permit diffusion and make metal contacts to the silicon wafer. It is also used with aluminum metalization to control the interconnection of components on the chips.

34. A thin, uniform film of photoresist is obtained by the use of centrifugal force or spinning. The film thickness is controlled by the speed of rotation and the viscosity of the photoresist material.

35. Exposure to the type of light to which it is sensitive causes the exposed portion of photoresist to polymerize or change its chemical structure.

36. Development removes the unexposed areas of the photoresist film while hardening or leaving the exposed areas unaffected.

STRATEGIC LOCATION OF RESOLUTION AND ALIGNMENT PATTERNS ON SILICON WAFER

FIGURE 10

COMPLETE ALIGNMENT PATTERN

ISOLATION

BASE

EMITTER

PRE-OHMIC

METALIZATION

FIGURE 11

VISUAL IMAGE

SPLIT IMAGE SCOPE

WAFER

FIGURE 12

FIGURE 13
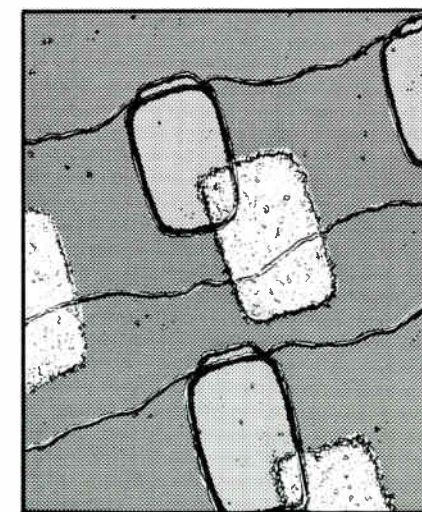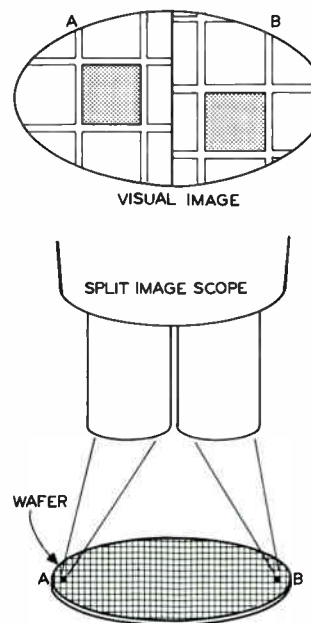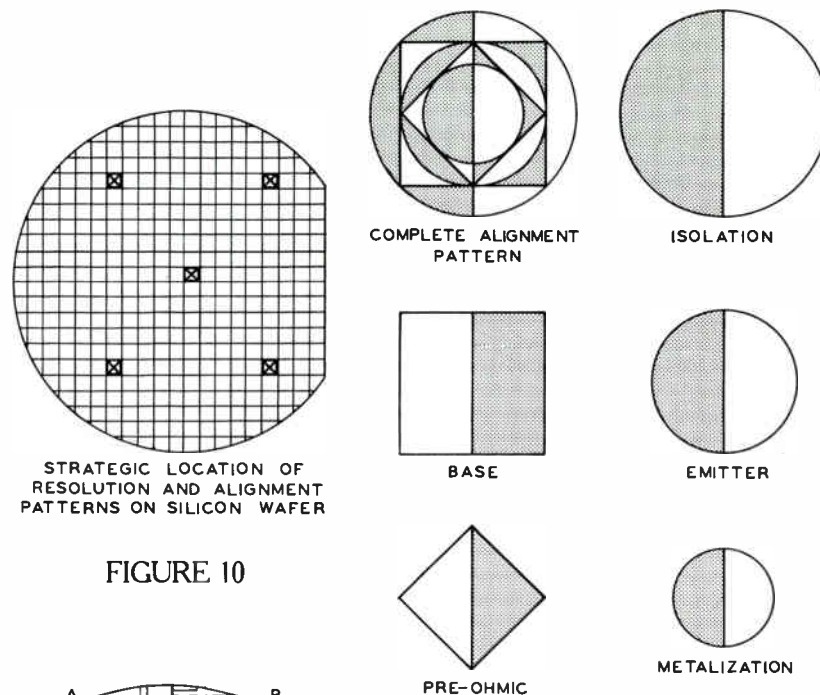
PRACTICE EXERCISE SOLUTIONS—(Cont'd)

37. The PR film is hardened after development by baking at temperatures of about 200°C.

38. Developed PR films are hardened to improve their resistance to the corrosive etchants used to remove SiO_2 or metal films.

39. Uniform, thin photoresist coatings are desirable to optimize the definition or resolution obtainable.

40. Misaligned masks can cause yield losses. It can cause diffusion, etching or metalization in the wrong places, resulting in short circuiting, deficient performance, and poor reliability.

PHOTOLITHOGRAPHY IN INTEGRATED CIRCUITS

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question, as illustrated in the example below.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

Example: **An animal that is a common house pet is the**

LESSON CODE

5506A

(A) elephant. (B) dog. (C) tiger. (D) gorilla.

1. Photolithography is used to
(A) produce diffusion. (B) manufacture master mask patterns but not to transfer these patterns to the wafer surface. (C) photographically reproduce images in the process of mask making. (D) obtain the high purity silicon materials utilized in integrated circuits.

2. Original artwork necessary for making master masks
(A) is several hundred times larger than final size. (B) is the same size as the master mask. (C) is many times smaller than the master mask. (D) is 5 to 10 times larger than the master mask.

3. Shadow masks
(A) are contact masks. (B) are used in the vacuum deposition of materials, such as metals. (C) are not reusable. (D) are washed off of the substrate after use.

4. A master mask set
(A) is made of photoresist. (B) is used to make production mask set copies. (C) is an expendable mask. (D) is placed over the photoresist on the substrate.

5. Multi-image arrays
(A) permit maximum use of the available space on the wafers used to produce integrated circuits. (B) are used because the mask making procedure is simpler than in a single image system. (C) require many pieces of original artwork, at least one for every image. (D) are used only when all of the integrated circuit components are arranged in a symmetrical pattern.

6. Step-and-repeat camera systems
(A) use many inexpensive lenses. (B) are also called fly's eye systems. (C) require a separate exposure for each image made on the mask. (D) use pinholes as lenses.

7. Alignment control patterns
(A) provide special patterns for alignment and for testing components. (B) control the depth of diffusion. (C) are simply regular circuits which are tested. (D) do not appear on the completely processed wafers.

8. Developed photoresist coatings
(A) are used to protect certain areas of the wafer from the chemical etching reactions. (B) are seldom able to resist the corrosive action of the etchants used for patterning. (C) should not be removed even after etching has been completed. (D) cover all areas of the silicon wafer immediately before etching.

9. Photoresist layers are typically
(A) 5 mils thick. (B) 5000 Å thick. (C) 50 Å thick. (D) 0.5 inch thick.

10. Photolithographic processes can be used to
(A) correct errors introduced in previous processing steps. (B) bring controlled amounts of diffusants into contact with the wafer surface. (C) form the pattern of metalization for component interconnection. (D) adjust the light sensitivity of the silicon wafers.
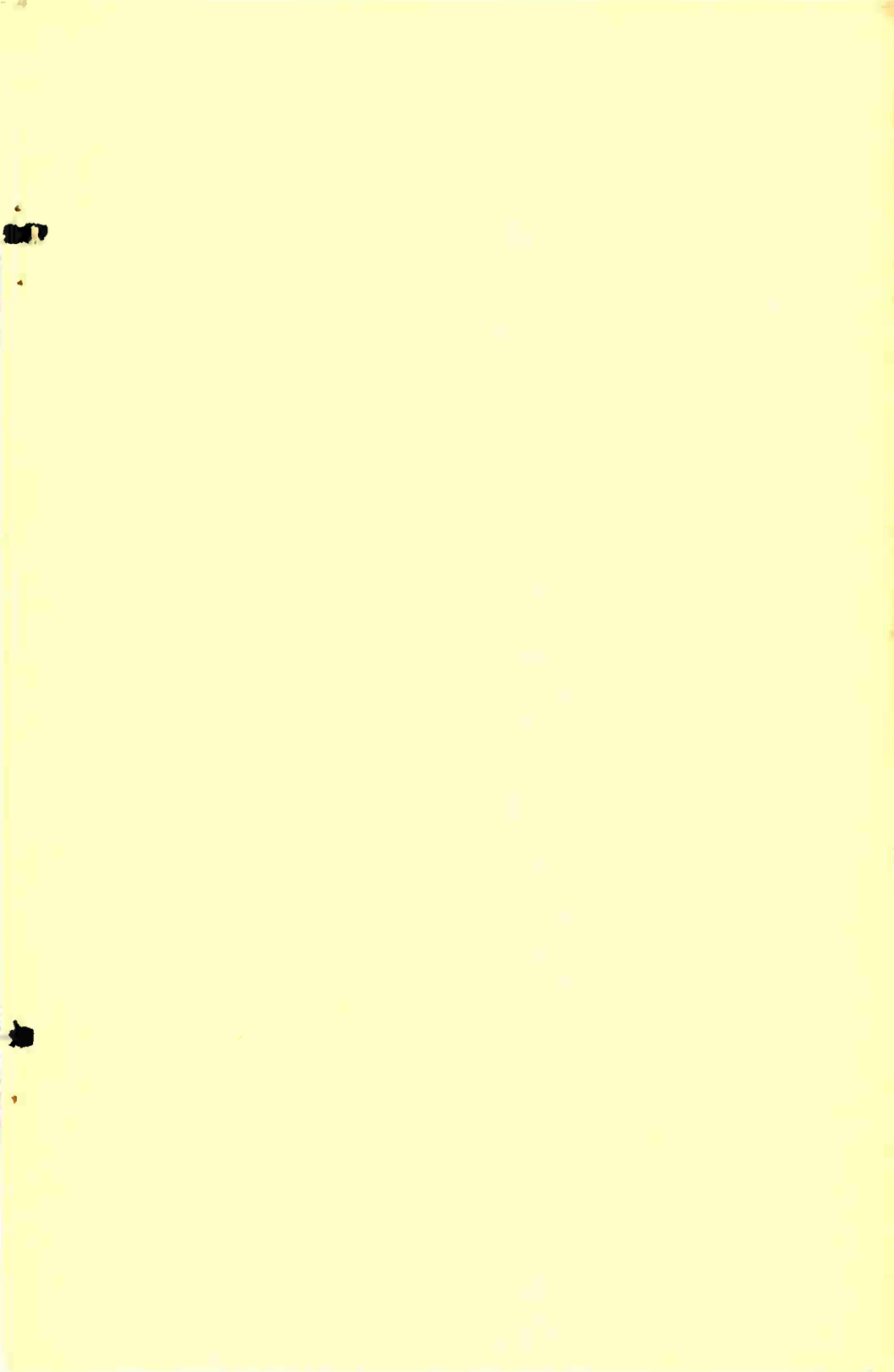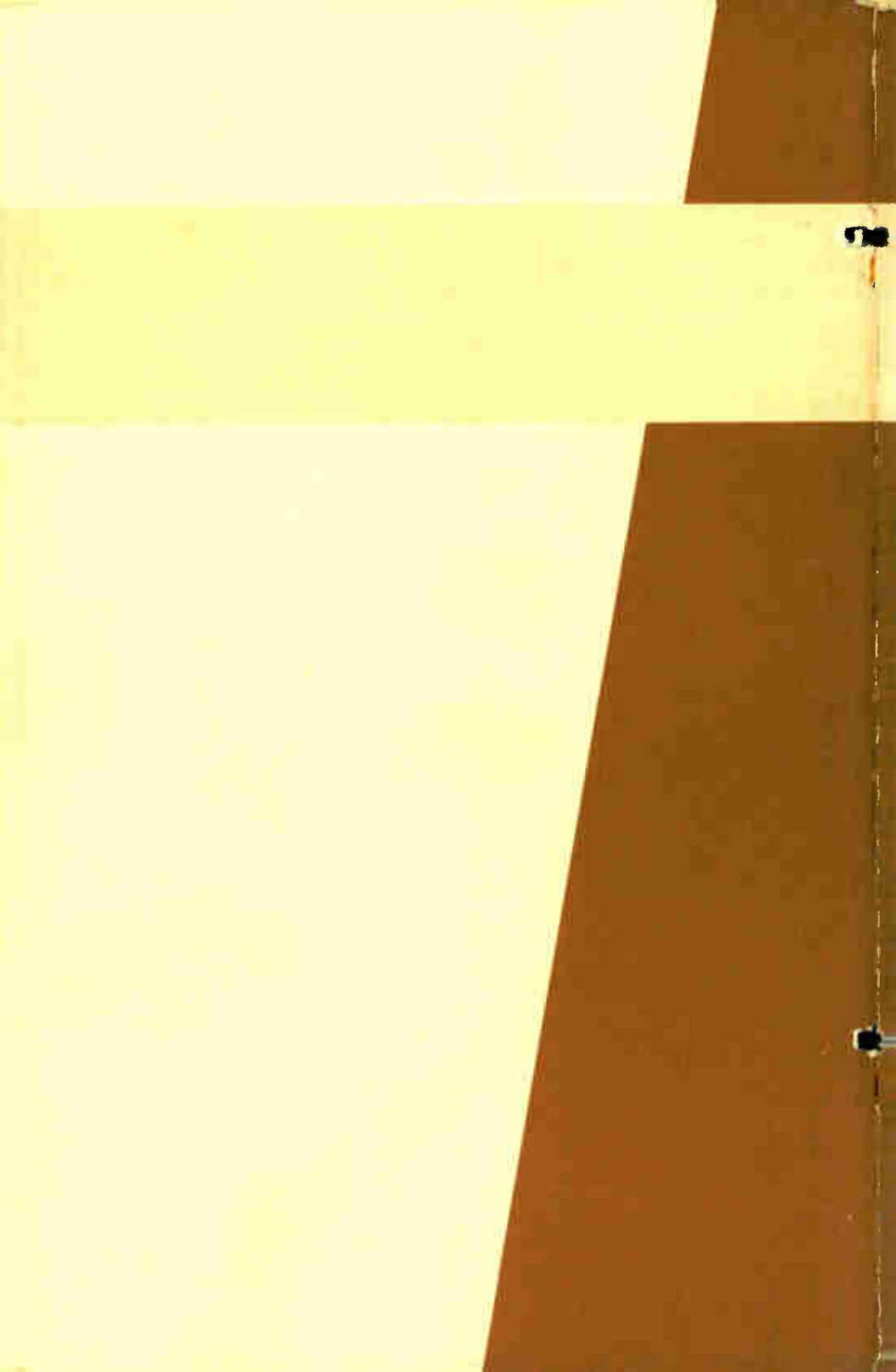
DEDICATED TO PROGRESS THROUGH EDUCATION

INTEGRATED CIRCUIT DESIGN CONSIDERATIONS

Lesson 5516A
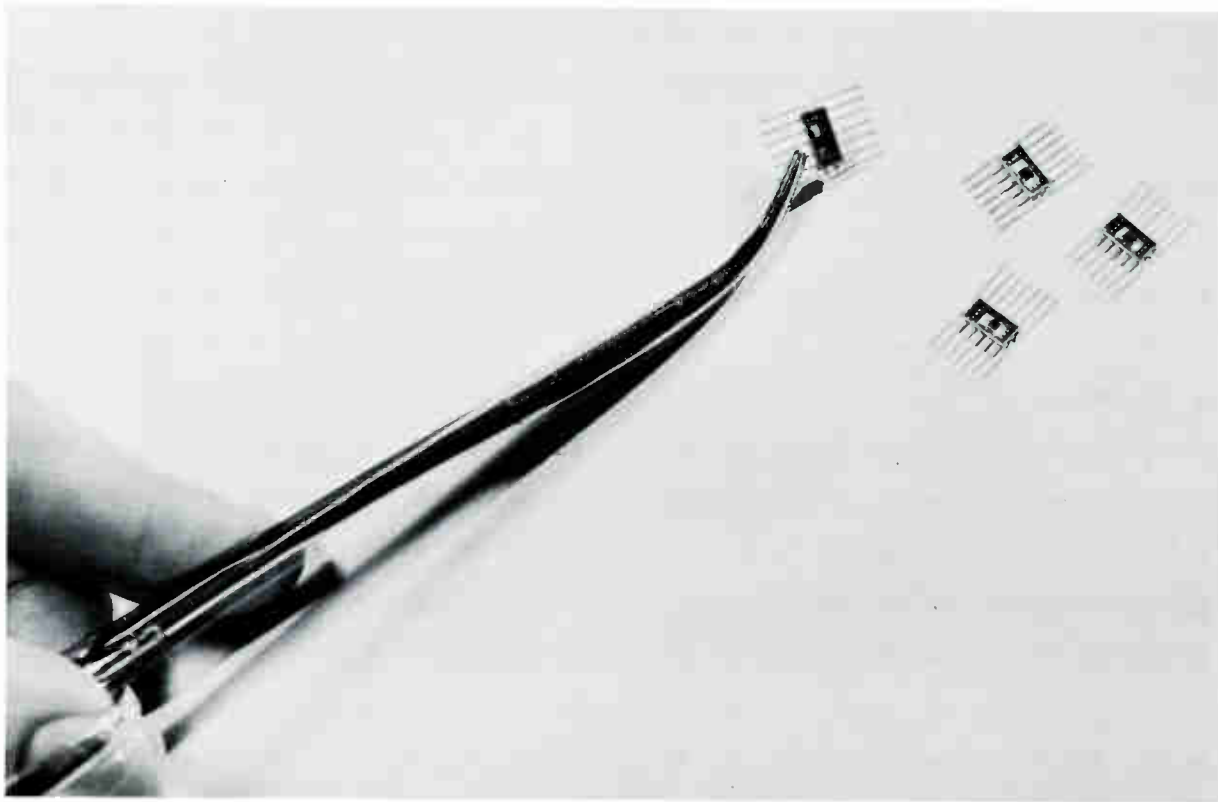
DeVRY Technical Institute

CHICAGO   TORONTO

INTEGRATED CIRCUIT DESIGN
CONSIDERATIONS

OPPORTUNITY

As shown in this photograph, integrated circuit chips are very small. Since the components are very close to each other, temperatures are essentially the same from component to component. As a result the components have excellent electrical and thermal tracking characteristics.

Courtesy Siliconix, Inc.

INTEGRATED CIRCUIT DESIGN CONSIDERATIONS

Contents

Today you are where your thoughts have brought you.
Tomorrow you will be where your thoughts take you.
—J. Baldwin Bruce

INTEGRATED CIRCUIT DESIGN CONSIDERATIONS

In the design of a monolithic integrated circuit, all components must be considered as a group. They are fabricated simultaneously—rather than being made individually, selected, and then assembled into the desired circuit configuration. The method of fabricating the components and the control exerted over the fabrication process largely determine the range and tolerance of the components produced. In addition, the effects of subsequent processing contribute to variations in component values. Good design requires that this be considered in determining the proper process sequence.

PARASITICS

The two most significant differences between integrated components and discrete components are their geometries and the parasitics associated with them. A **PARASITIC** is an undesired or unwanted interaction with other components, with the substrate or the atmosphere, or with other parts of the system. Parasitics frequently present more serious problems with integrated circuit components than with discrete components. This is largely because the integrated circuit components are placed so close together in a single substrate.

*　　　　　*　　　　　✧

1. What is a parasitic?

*　　　　　*　　　　　*

The most significant parasitic in integrated circuits arises from the electrical isolation provided for each of the components. Since isolation is most commonly achieved by means of reverse-biased PN junctions, the capacitance and leakage of such a junction constitutes the most significant components of the parasitic. The voltage sensitivity of these parasitics must also be considered.

*   *   *

2. The most significant parasitic in integrated circuits results from the _____ _____ provided for each of the components.

*   *   *

The sizes and effects of parasitics depend upon the technique employed in fabricating the integrated circuits. Monolithic integrated circuits have larger parasitics than either thin-film or multi-chip circuits. Those in which isolation is accomplished by the use of reverse-biased junctions have the largest parasitics. These parasitics must be taken into careful consideration during the circuit design and layout.

The use of dielectric isolation largely reduces the amount of parasitic capacitance. These capacitances effectively are each composed of two capacitances in series. The resultant parasitic capacitances are smaller than those associated with a PN junction and do not vary as a function of the applied voltage.

*   *   *

3. Why do monolithic integrated circuits usually have larger parasitics than the other types of integrated circuits or discrete component circuits?

*   *   *

Compatible thin-film circuits have approximately the same types of parasitics as monolithic circuits using dielectric isolation. In thin-film circuits the thin glass (SiO_2) layer insulates the film components from the surface of the silicon wafer, while in the monolithic circuits it separates the isolated areas from each other. This SiO_2 layer acts as the dielectric of a capacitor coupling the film component to the sub-strate or coupling the isolation islands together.

By comparison, thin-film circuits on passive substrates are even less affected by parasitics since the insulating nature of the substrate minimizes interaction between the components due to parasitic cou-

pling through the substrate. The close spacing of components, however, provides other parasitic problems that arise from the coupling through space because of their closeness to one another.

*   *   *

4. **What causes the major parasitic associated with the film components of a compatible or dielectrically isolated monolithic circuit?**

5. **The parasitics associated with a thin-film circuit are (a) greater than, (b) less than those of a discrete component circuit, but (c) greater than, (d) less than those of a monolithic integrated circuit.**

*   *   *

Of all the types of integrated circuits, multi-chip integrated circuits have the least parasitics. They approach that which is achievable with discrete components. This might be anticipated, since each component in a multi-chip circuit is the same as an individual unpackaged discrete component. Parasitics in multi-chip circuits are only slightly higher than those of equivalent discrete component circuits because the components are brought closer together in a single package rather than being packaged individually. This closeness results in closer coupling.

The saving in space achieved with multi-chip circuits permits shortened lead lengths. Parasitics due to long leads are frequently more limiting than those resulting from close spacing. Hence, multi-chip circuits may provide a net improvement over both monolithic and discrete circuits as far as total parasitics are concerned.

*   *   *

6. **Compared to discrete component circuits, multi-chip circuits have larger parasitics due to closeness of components, but smaller parasitics due to shorter lead lengths. True or False?**

*   *   *

INTEGRATED RESISTORS

For convenience we will consider the three basic types of integrated circuit resistors individually. They will each be compared with their discrete counterparts as well as with one another. Diffused resistors will be considered first because of their popularity.

Diffused Resistors

Diffused resistors are most widely used in integrated circuits. They may be recognized from photographs of integrated circuits as the stripes which are sometimes folded back and forth to achieve the desired resistance value. Most diffused resistors are formed during the same diffusion used to fabricate the bases of transistors.

The diffusion is designed primarily to produce the desired characteristics of the transistor base (depth of diffusion, etc.). Its effect on the sheet resistance is of secondary consequence. The sheet resistance determines the ohmic values of the resistors. Also, the base diffusions with which they are usually associated range between 50 and 250 ohms per square.

Low value resistors are usually formed simultaneously with the emitters of the transistors. As you might expect, control of the emitter characteristics is much more critical than control of the emitter diffusion resistance values. Emitter diffusions typically range between 2 and 5 ohms per square. These fabrication considerations usually limit diffused resistor tolerances to about $\pm 15\%$ for base diffused units and $\pm 10\%$ for those formed during the emitter diffusion.

*   *   *

7. How could you identify diffused resistors in monolithic structures?

8. When are most diffused resistors formed in integrated circuit fabrication? When are the low value diffused resistors formed?

*   *   *

The equivalent circuit of a diffused resistor is shown in Figure 1. The resistance value (R) of the resistor depends upon: (1) the sheet resistance of the diffusion which forms the resistor, and (2) its geometry (length-to-width ratio). The resistor represented in Figure 1 is formed by a P-type base diffusion into an N-type collector or isolation region. Thus, a PN junction is formed between the resistor and its isolation region. This junction completely surrounds the resistor and
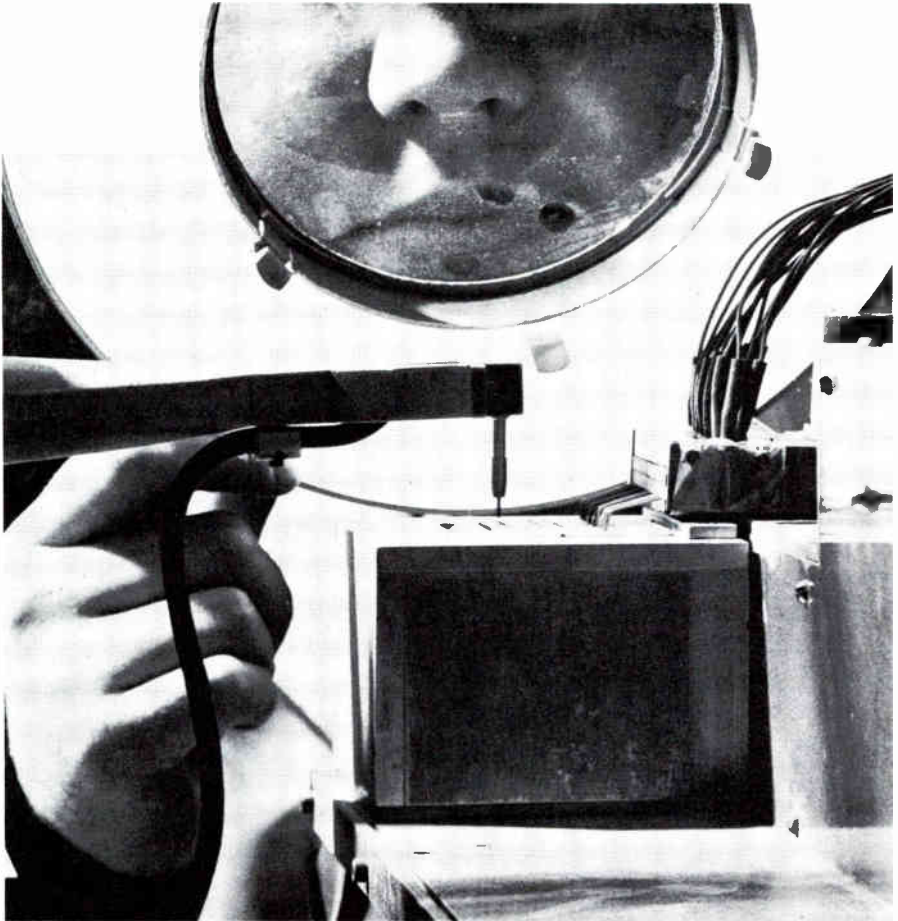
Probes monitor the resistance value of the tin oxide resistor film as its value
is tailored to the desired amount.

Courtesy Corning Glass Works

has the capacitance C_{p_1} associated with it. This capacitance is the largest parasitic associated with a diffused resistor.

A PN junction acts as a diode. The reverse breakdown voltage of the PN junction diode limits the maximum voltage that may be applied across the resistor. Since this breakdown voltage is typically about 20 volts and the circuits are generally designed to use lower supply voltages (less than 10 volts), this seldom causes difficulty.

*   *   *

9. **What is the source of the largest parasitic associated with a diffused resistor?**

*   *   *

To accurately determine the parasitic capacitance (C_{p_1}), the total area occupied by the resistor and also the side walls of the diffused region must be measured. A good approximation with resistors 1 mil wide is to add 20% to allow for this factor. Thus, this parasitic capacitance could be physically reduced without changing the resistor's value by reducing the area of the resistor. Both the length and width of the resistor should be decreased by the same proportion.

While this size reduction is desirable to reduce the parasitics, there are practical limits on the minimum size. Control of the resistor value during the fabrication processes becomes much more difficult as the size of the resistor becomes smaller. Reasons for these control difficulties are the photo mask tolerances, etching rates, and undercutting during the formation of the windows in the SiO_2. These windows are used to control the diffusion and mask alignment during the photolithographic procedures.

Diffused resistors in most high volume production integrated circuits are typically 1 mil (0.001 inch) wide. Occasionally 0.5 mil widths have been used. Recently, commercial availability has been indicated for circuits employing between 0.2 and 0.3 mil resistor widths. Much

more care must be used to manufacture the latter group. In general, the thinner the resistor, the harder it is to obtain good process yields.

*   *   *

10. **How may the parasitics of a diffused resistor be reduced without changing the diffusion process used to form it?**

11. **What factors determine the minimum size of a diffused resistor?**

*   *   *

Capacitance C_{p_1} results from the junction capacitance of the PN junction. Therefore, it is voltage sensitive. As the voltage drop across the resistor varies, the capacitance associated with it (C_{p_1}) also varies. The capacitance is maximum when the voltage across the resistor is minimum.

The resistor has an additional parasitic capacitance which results from the PN diode junction formed between the N-type collector or isolation region and the P-type substrate. As shown in Figure 1, this capacitance is labeled C_{p_2}. The value of C_{p_2} is determined by the total junction area of the isolation region (including sidewalls) in which the resistor is located. This parasitic is also voltage sensitive.

Both the isolation region and the substrate are normally held at fixed potentials, to assure back biasing. Depending upon which region is P-type or N-type material, they are the most negative and the most positive supply voltages. This assures that the maximum voltage available is impressed across the isolation-to-substrate junction and, hence, minimizes the value of capacitance C_{p_2}.

Typical ranges of parasitic capacitance in Figure 1 are 0.1 to 0.3 pf/sq mil for C_{p_1} and 0.05 to 0.2 pf/sq mil for C_{p_2}. The values of C_{p_1} and C_{p_2} both depend upon the areas of the junctions involved and the bias voltages applied to them. C_{p_2} provides about half of the capacitance of C_{p_1} per square mil because of the large bias voltage employed.

*   *   *

12. Which junctions produce C_{p_1} and C_{p_2} in Figure 1?

13. The junction producing capacitance C_{p_2} of Figure 1 has a larger area than that associated with C_{p_1}, but the capacitance of C_{p_2} is usually less than that of C_{p_1}. True or False?

*   *   *

A set of curves illustrating the variation of P-type diffused resistor temperature coefficients with temperature and resistance ratio is shown in Figure 2. **TEMPERATURE COEFFICIENT (TC)** of resistance is expressed in percentage change of resistance per degree Centigrade. Materials can have either positive or negative TC. The TC of pure silicon is positive, showing that the resistivity of silicon rises with increasing temperature.

Figure 2 shows the relationship of the actual resistance to the resistance at room temperature of resistors formed by a 3 micron P-type diffusion. Note that the higher the sheet resistance of the diffusion (Ω/sq), the greater its rate of resistance change with changes in temperature. For example, at $-40°C$ a resistor made of 500 Ω/sq material will have about .75 of its resistance at room temperature (25°C). At $-40°C$ a resistor made with 100 Ω/sq material will have about .9 of its resistance at room temperature.

Variations in resistance can be caused by aging, voltage fields, high ambient temperatures or by oxidation or other chemical reactions. These changes may be permanent and may be accelerated by high operating or ambient temperatures.

*   *   *

14. The temperature coefficient of silicon is negative, since its resistivity rises with increasing temperature. True or False?

*   *   *

Compatible Thin-Film Resistors

The equivalent circuit of a compatible Nichrome (NiCr) resistor is shown in Figure 3. R is the useful resistance, while C_p is the parasitic capacitance. This equivalent circuit would apply to any compatible thin-film resistor if the proper ranges of resistance values were used. While Nichrome films of from 40 to 400 ohms per square are currently the most widely used for this purpose, tin oxide (SnO_2) and tantalum (Ta) have been used with sheet resistances ranging up to 500 Ω/sq. As in the case of the diffused resistor, the component's actual resistance value is determined by the product of the length-to-width ratio of the thin-film path and the sheet resistance.

The value of the parasitic capacitance (C_p) depends primarily on the thickness of the silicon dioxide (SiO_2) upon which the Nichrome re-
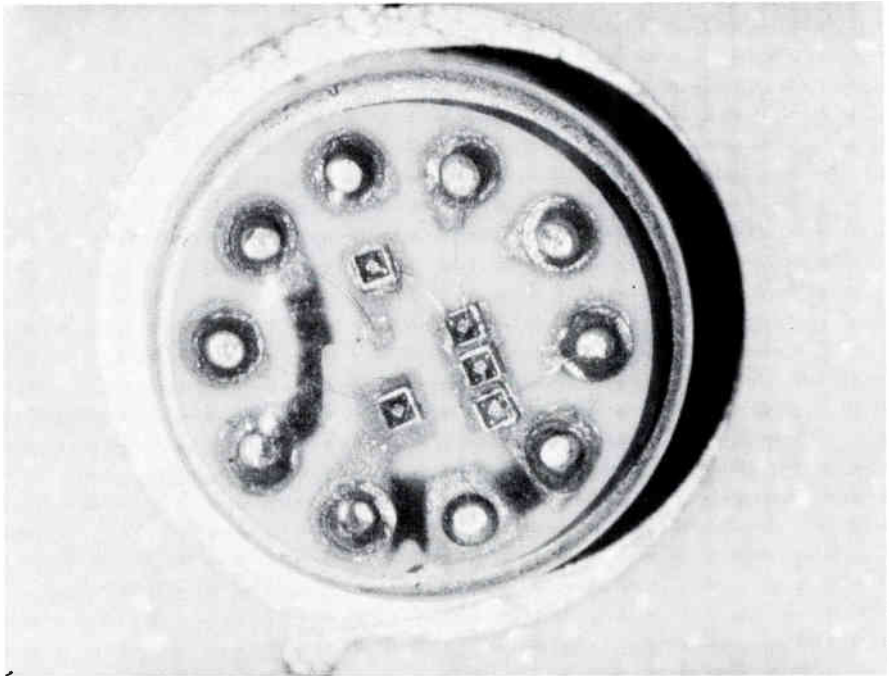
Five chip resistors and three Cermet resistors are combined in this hybrid circuit. The circuit is shown on a TO-5 header.

Courtesy CTS Corporation

sistor is deposited. This thickness is typically about 10,000 Å. The total shunt capacitance is determined by multiplying the parasitic capacitance by the area occupied by the resistor itself. This capacitance is not voltage sensitive as are the capacitances associated with a diffused resistor.

The parasitic capacitance represented by C_p of Figure 3 (typically about 0.02 pf/sq mil) is only about 1/5 to 1/15 the value of C_{p_1} associated with the diffused resistor of Figure 1 (0.1 to 0.3 pf/sq mil). Large reductions in parasitics can result from the use of film resistors which combine the higher sheet resistance of thin-film materials with smaller capacitance per unit area.

*   *   *

15. What sheet resistance can be obtained with compatible thin-film resistors?

16. Why isn't the parasitic capacitance associated with compatible thin-film resistors voltage sensitive?

*   *   *

Since these parasitics (C_{p_1} and C_{p_2} of Figure 1 and C_p of Figure 3) act as shunting capacitors, their effects become more pronounced both as the operating frequency increases and as the resistance increases. For this reason, compatible thin-film resistors are superior to diffused resistors for both high frequency operation and where high values of resistance are required.

Compared to diffused resistors, thin-film resistors have these advantages:

1. lower parasitic capacitance

2. larger range of component values

3. lower temperature coefficient

4. tighter control of tolerance

Aging is the tendency to increase in resistivity, deteriorate, or otherwise change characteristics. This is usually associated with tolerance control. Aging may occur because of high temperatures used during assembly, or because of chemical reactions or exposure to high intensity electric fields. Thin-film resistors are generally more susceptible to aging than diffused resistors.

Nichrome, Cermets and tantalum have temperature coefficients of the order of 50 to 600 parts per million per degree C. These temperature coefficients are considerably improved over diffused types. Although performance of compatible thin-film resistors is better than that of diffused resistors, the additional processing costs may not justify their use.

*   *   *

17. How do thin-film and diffused resistors compare with regard to temperature coefficient, tolerance, high frequency response, aging characteristics and ranges of values?

18. Since compatible thin-film resistors generally have better performance characteristics than diffused resistors why aren't they used more often?

*   *   *

Thin-Film Resistors on Passive Substrates

Thin-film resistors deposited on passive substrates can usually be produced more economically, and with characteristics as good as or better than compatible resistors. They must, however, be interconnected into the circuit by separate operations. The associated parasitic capacitance of such thin-film resistors is negligible when compared to either diffused or compatible resistors (greater than a 10:1 improvement). The cost of the assembly operations necessary for adding active components separately and making the necessary interconnections usually offsets these advantages, particularly when large volume production is involved.

*   *   *

19. Why are compatible or diffused resistors preferred to thin-film resistors on passive substrates for large volume applications which also require transistors and diodes?

*   *   *

INTEGRATED CAPACITORS

The three basic types of integrated capacitors are the PN junction capacitor, the Metal-Oxide-Silicon (MOS) capacitor, and the deposited thin-film capacitor. The natures of these capacitors will be reviewed, and they will be compared with discrete capacitors and with each other. The order of their consideration reflects only the order of their appearance in monolithic integrated circuits. As will be explained, the order of appearance doesn't reflect their popularity.

PN Junction Capacitors

When reverse-biased PN junctions are employed as capacitive elements, they are influenced by several parasitic effects. Most important of these is the variation in the capacitance resulting from changes in voltage across the junction.

Figure 4A shows the cross-section of such a capacitor formed by a P-type diffusion into an N-type isolation or collector region. In the equivalent diagram of Figure 4B, capacitance C is the useful capacitance, while C_p is a parasitic capacitance.

The graph of Figure 4C indicates the variation of the ratio of capacitance C to capacitance C_p as a function of the potential at point B with respect to the substrate voltage. This reflects the usefulness of the capacitor and may be viewed as a "quality factor".

Figure 4C contains two curves: one is plotted with 0 volts across C, and the other with 5 volts across C. These two plots indicate that the voltage applied directly across the capacitance C also causes the ratio

of C/C_p to vary. Thus, both the voltage across C and the voltage from point B to the substrate must be known to make accurate determinations. As with diffused resistors, the values of C and C_p are also proportional to the areas of the junctions to which they are related.

<div align="center">*   *   *</div>

20. What is the significance of the ratio of C/C_p in Figure 4C?

<div align="center">*   *   *</div>

The value of the resistance (R) in the equivalent circuit of Figure 4B arises from the current path through the N-type material under the junction, which is effectively the bottom plate of the capacitor. As shown in the cross-sectional diagram of Figure 4A, this is N-type material with a 0.5 Ω-cm resistivity. The resistance of this material is relatively high due to its relatively long length and its resistivity compared to that of a metal plate.

For the range of capacitors most commonly used (20 to 100 pf), this resistance varies from about 50 to 10 ohms. The value of R decreases as the physical size of the capacitor is increased.

The contact lead for the N-type plate is aluminum metalization connected to the N+ diffused area at the right side of the cross-section (Figure 4A). The other plate of the capacitor is the aluminum metalization on top of the diffused P-type material. This metalization contributes such a small amount to the resistance (R) that it may be neglected without appreciable error.

<div align="center">*   *   *</div>

21. Why is the resistance associated with the bottom plate of a PN junction capacitor relatively high?

<div align="center">*   *   *</div>

The breakdown voltage of a PN junction capacitor usually must be low (approximately 7 volts) to obtain high capacitance per unit area.
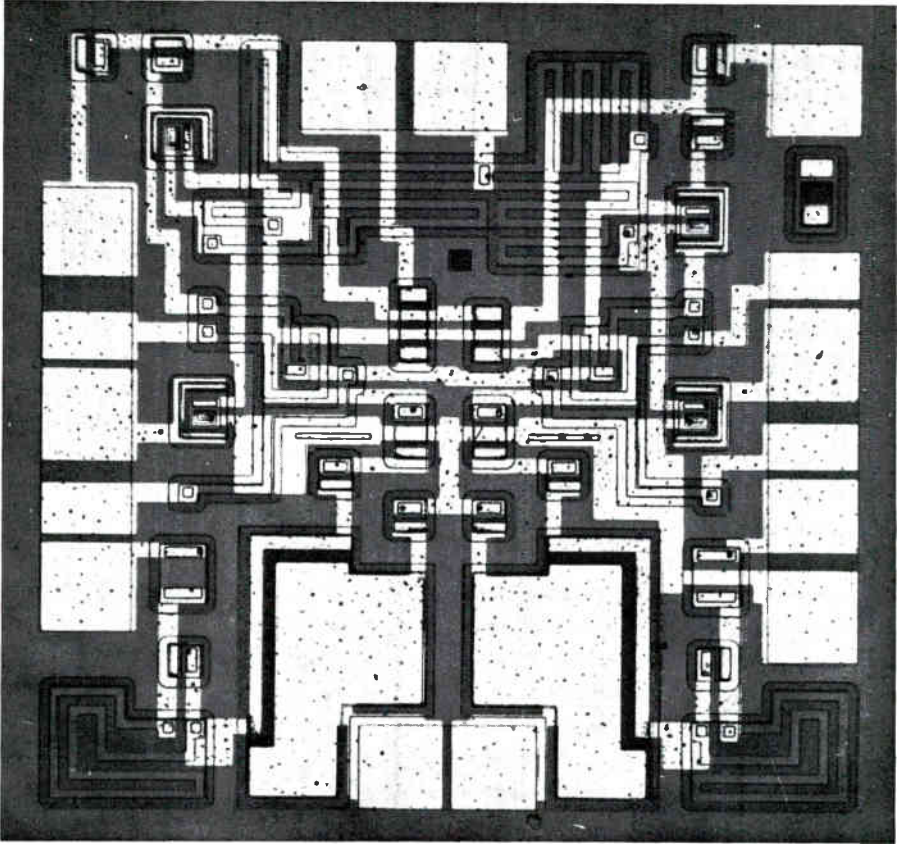
Several MOS capacitors are fabricated on this monolithic circuit. They are shown at
the lower center section of this photograph.

Courtesy Signetics

The junction is usually biased so that the maximum voltage variation
(signal) will never forward bias the junction. A desirable arrange-
ment would be to have the maximum signal voltage bring the junction
to zero bias.

As a general rule, integrated circuit design is arranged to avoid or
minimize the use of capacitors whenever possible. If this can't be
done, the other types of integrated capacitors are preferred to the
PN junction type.

Since the voltage across the capacitance C varies as a function of the signal voltage and the biases applied, this type of capacitor has only limited use in integrated circuit applications.

*   *   *

22. The PN junction capacitor is the most desirable form of an integrated capacitor. True or False?

*   *   *

Metal-Oxide-Silicon (MOS) Capacitors

A metal oxide silicon (MOS) capacitor represents the best compromise between operating characteristics and economy of fabrication. For this reason, it is the type most widely used in integrated circuits today. Figure 5A shows the construction of an MOS capacitor. MOS capacitors employ silicon dioxide (SiO_2) for their dielectric. The SiO_2 thickness varies between 500 and 1000 Å. A 700 Å oxide thickness has an approximate capacitance of 0.3 pf/sq mil.

An equivalent circuit for the MOS capacitor is shown in Figure 5B. Resistance R represents the series resistance of the current path through the N+ diffused region which serves as the bottom plate of this type of capacitor. This N+ region is normally diffused simultaneously with the emitters of the transistors and has a value between 2 and 3 Ω/sq. To determine the actual size of this resistance, the sheet resistance and the length-to-width ratio must be measured. To minimize the size of R, the contacts should be arranged so that the width is greater than the length.

As in the case of the diffused junction, the top aluminum metalization has some resistance, but this represents so small a fraction of the total that it can be neglected without causing appreciable error.

*   *   *

23. What causes the series resistance (R in Figure 5B) of an MOS capacitor?

*   *   *

The shunt or parasitic capacitance for the MOS capacitor is produced by the PN junction between the collector or N-type isolation region and the substrate. This is C_p in the equivalent circuit of Figure 5B. In normal construction, this capacitance ranges from one-third to one-fifth the size of the useful capacitance, C. In the typical example of Figure 5B, the value of C would be about 0.2 to 0.4 pf/sq mil, and C_p would be about 0.05 to 0.15 pf/sq mil. Since the useful capacitance and the parasitic capacitance both increase proportionally as the area increases, the ratio of C to C_p remains constant and depends only upon the area occupied by the capacitor.

*   *   *

24. What is the typical ratio of C to C_p for an MOS capacitor?

*   *   *

Thin-Film Capacitors

Of all of the integrated capacitors, the all-deposited thin-film capacitor has the smallest amount of parasitics. This advantage is obtained at the expense of extra processing steps. Two aluminum metalizations are required instead of one. All-deposited thin-film integrated capacitors require three depositions. A layer of dielectric material is placed between the metal layers. Its thickness must have uniform composition and must be very thin—usually less than 1000 Å. Typical dielectric materials are SiO_2, Al_2O_3-Si, Ta_2O_5 and SiO.

The equivalent circuit of the compatible thin-film type of capacitor is shown in Figure 6. The useful capacitance (C) is approximately 0.1 to 0.5 pf/sq mil. The primary parasitic is a shunt capacitance to the substrate, represented by C_p in Figure 6. In the case of a compatible technique where the substrate is active silicon, C_p is calculated to be approximately 0.02 pf/sq mil (for 10,000 Å thickness). Since this is a distributed capacitance, its effective value is about one half or 0.01 pf/sq mil. This parasitic diminishes to almost zero when a passive substrate is employed.

*   *   *

25. What parasitics are associated with a compatible all-deposited thin-film capacitor? A thin-film capacitor on a passive substrate?

*   *   *

The use of metalization for the bottom contact plate will not provide as much improvement over the MOS type capacitor as might first be indicated. Though this material is a metal with a far lower resistivity than silicon, the lower electrode of a thin-film capacitor has to be relatively thin (approximately 2000 Å) so the dielectric material will not fracture as it is deposited over the metal film. Fractures can result if there is a large difference between the coefficients of expansion of the metal and dielectric material.

Because of the extreme thinness of this metalization, it has a relatively high sheet resistance (R in Figure 6), ranging between 0.5 and 1.0 Ω for typical deposited thin-film capacitors. This still represents an important improvement over the series resistance characteristic of the MOS type capacitor.

*   *   *

26. The bottom plate of a thin-film capacitor is metal, hence its resistance is so low that it may be neglected without causing any error. True or False?

*   *   *

INTEGRATED TRANSISTORS

Integrated transistors are different from their discrete counterparts because of the different method of making contact to the collector, and the additional parasitic capacitance which results from the PN junction between the collector and substrate. All of the contacts must be made from the top surface in order to separate or isolate the elements from each other.

Integrated transistors potentially have a major advantage over discrete transistors. Each one may be custom designed to obtain optimum performance in the specific circuit application in which it is to be used. Discrete transistors, on the other hand, are usually designed to satisfy a number of different circuit requirements. In many cases the circuit applications are first designed, and available transistors are evaluated until one is found which satisfies the requirement.

TRANSISTORS AFFIXED
AT THESE POINTS
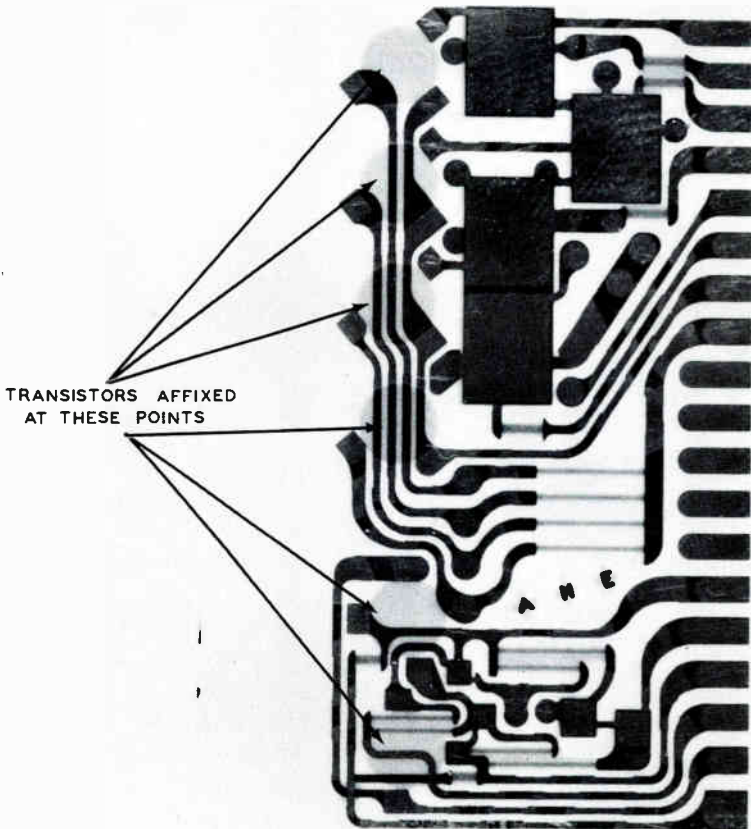
This 2" × 2" ceramic substrate contains thin-film resistors and capacitors. Circles indicate where six transistors are to be offixed.

Courtesy Alpho MicroElectronics Co., Inc.

The longer path from the collector to the collector contact causes higher series resistance when compared to a discrete transistor. The **SATURATION RESISTANCE** (R_{sat}) of an integrated transistor ranges between 10 and 100 Ω for a typical transistor geometry in a fully integrated form as compared to 5 to 10 Ω for its discrete counterpart with the same geometry. The series resistance shows up in the saturation characteristics of the device.

The parasitic capacitance of the integrated transistor may be of the order of 2 to 5 pf. This capacitance does not exist in conventional units. In most monolithic circuits, it shows up between collector and ground, thus affecting high frequency performance.

An equivalent circuit of an integrated circuit transistor is shown in Figure 7. The saturation resistance (R_{sat}) and its associated capacitance (C) are shown in this figure. The actual calculation of the saturation resistance can be illustrated by taking a typical transistor geometry and cross-section as shown in Figure 8. The following relationship is used:

$$R_{sat} = \frac{\rho_c l}{tw}$$

where R_{sat} is the saturation resistance in ohms,

$\quad\quad$ ρ_c is the resistivity of the collector material in ohm-mils,

$\quad\quad$ l is the distance from the emitter edge on the base side to the edge of the collector contact in mils,

$\quad\quad$ t is the thickness of the collector material in mils, and

$\quad\quad$ w is the width of the emitter-to-collector path in mils.

We shall assume the resistivity of the collector material to be 39.4 ohm-mils. Using the information in Figure 8, we find

$$R_{sat} = \frac{39.4 \times 2.5}{0.5 \times 2}$$
$$= 98.5 \text{ ohms}$$

The collector-to-base breakdown voltage may be increased by increasing the resistivity of the collector material, but at a sacrifice of R_{sat}. Generally, the use of lower resistivity collector material (0.1 ohm-cm) will result in higher frequency response.

<p align="center">*   *   *</p>

27. **Can transistor geometries be optimized for specific integrated circuit applications?**

28. **Why are the saturation resistance and parasitic capacitance characteristics of an integrated transistor inferior to those of a discrete transistor having the same geometry?**

<p align="center">*   *   *</p>

INTEGRATED DIODES

In the formation of a monolithic integrated circuit, there are at least three junctions formed. Only two of these junctions are useful as integrated circuit diodes. These two configurations are shown in Figure 9. The collector-substrate junction, because it is used for isolation, cannot be used as a diode. The emitter-base junction of a transistor (Figure 9A) provides a diode with low reverse breakdown voltage. The base-collector junction of the transistor (Figure 9B) makes a higher or medium voltage type diode. Both types may be designed to have any desired junction area.

Since the emitter-base diode is part of a normal transistor type structure, it is common practice to short the base-collector junction when this type of diode is desired. This minimizes the effective capacitance of the base-collector junction, and eliminates the possibility of transistor action. If this junction were not shorted, transistor action might develop as a parasitic effect if both junctions were properly biased; e.g., forward bias on the emitter-base junction and reverse bias on the base-collector junction (the standard transistor biasing arrangement).
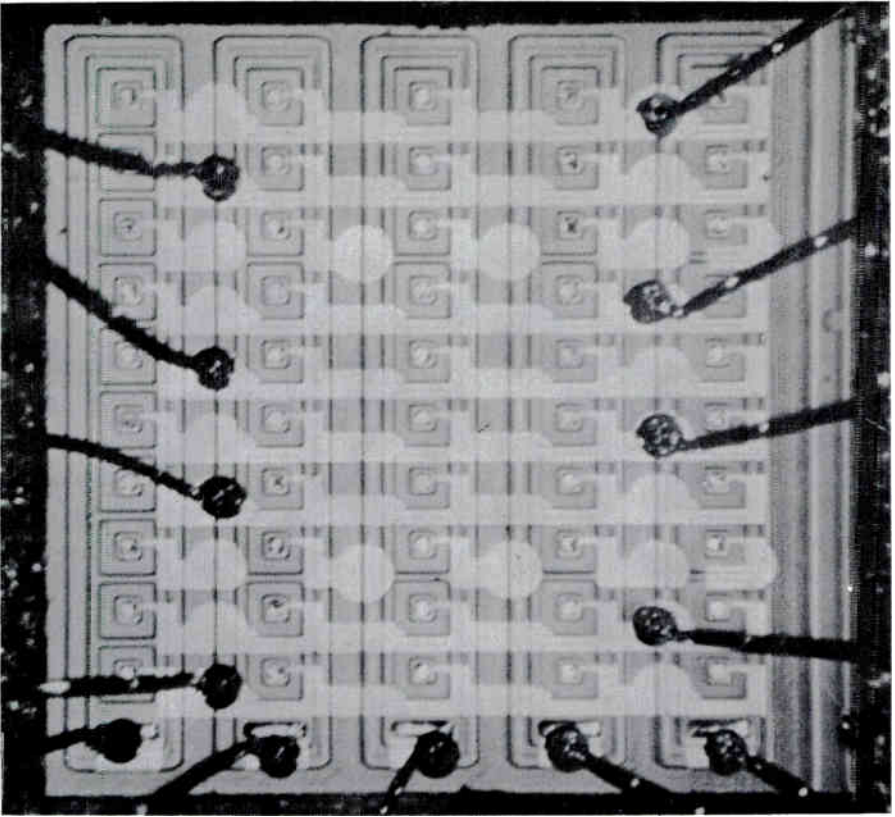
A diode matrix which uses dielectric isolation.
Courtesy Radiation, Inc.

The base-collector junction used by itself provides a diode with higher breakdown voltage than the emitter-base diode. This configuration is generally less desirable than the emitter-base diode. Under certain bias conditions, transistor action may result from this junction and the collector-substrate junction. This transistor action would magnify the diode's parasitics and might couple parasitic or oscillatory effects to other areas of the circuit. The possibility of this effect can be minimized by making the collector thickness (separation between the base-collector and collector-substrate junctions) as large as possible (greater than 0.5 mil).

*   *   *

29. **How can parasitic transistor action be caused in an emitter-base integrated diode structure?**

30. **Compare the characteristics of the emitter-base and base-collector diode structures.**

*   *   *

MONOLITHIC DESIGN FLEXIBILITY

The effects of parasitics can frequently be offset by the use of special design considerations that are available to monolithic integrated circuit fabrication and which are not used in discrete component design. Each of the integrated circuit components is fabricated side by side on the same wafer during the same processing. Consequently, they have much better electrical and thermal tracking capability, one with another, than might be possible with isolated discrete components.

Component Matching and Tracking

Even without special care, the characteristics of monolithic integrated components are more closely matched than could normally be achieved by sorting discrete components. Not only that, but during circuit operation, the heat generated by the operation of one component will also heat the others in the same chip so that each will be operating at nearly the same temperature. Thus, any shift in characteristics of one integrated component is accompanied by corresponding shifts in the characteristics of the other components, so that the relationship between the component values remains reasonably constant.

This type of matching applies to virtually all transistor characteristics. For example, Figure 10 shows matching characteristics for V_{BE} offset voltage for all transistors on a single wafer. The OFFSET is the difference in the V_{BE} characteristics between any two transistors in a typical batch of transistors. The PERCENT OF UNITS LESS THAN ORDINATE is a convenient method of indicating the distri-

bution of the batch. This term indicates the variations within a batch in terms of percentage of the batch. According to Figure 10, 50% of the transistors fabricated in the batch will have V_{BE} characteristics which vary from each other by no more than 1 mv.

It is almost impossible and also very expensive to select discrete transistors at random and achieve as close a match of their characteristics as shown in Figure 10. On the other hand, the characteristics of integrated transistors match closely, and they also track with one another over the entire range of operating temperatures employed.

*   *   *

31. **Why might the characteristics of components within an integrated circuit be closely matched?**

32. **Will matched integrated components track well over a wide temperature range?**

*   *   *

Component Ratios

While resistors of tight tolerances are difficult to fabricate in monolithic diffused integrated circuit form, it is relatively easy to maintain the ratio of values of two resistors. Figure 11 shows on one plot the distributions of absolute values and ratios of values of a group of monolithic diffused resistors fabricated on one wafer. These are typical distributions.

Note that 93% of the units (between 2 and 95%) fall within a $\pm 20\%$ variation of the absolute values of all units on a given wafer. The ratio plot using the same axes shows that if one unit were selected at random and the others on a given die compared to it, the variation of their ratios would be less than $\pm 5\%$ for $98\frac{1}{2}\%$ (between $\frac{1}{2}$ and 99%) of the units.

Of equal importance is the fact that, unless the diffusion itself is very tightly controlled, the distribution could shift to a different level. This

might shift the center of the distribution and cause a larger tolerance variation on the absolute value. It would not, however, in any way affect the distribution of the ratios of the individual resistors.

The ease of component matching suggests the desirability of designing the circuits to make use of this advantage. Where possible, integrated circuit designs should use the ratio of resistors rather than their absolute values.

Figure 12 demonstrates one of many different uses of this principle. The overall gain of this circuit is controlled by maintaining a ratio of feedback by means of the R_1 to R_2 ratio. The gain with feedback is determined by the following relationship:

$$\frac{V_{out}}{V_{in}} = \frac{Gain}{1 - Gain \left(\dfrac{1}{\dfrac{R_1}{R_2} + 1} \right)}$$

Thus, if the absolute values of R_1 and R_2 change by the same percentage, the ratio of R_1 to R_2 remains constant, and the gain will remain constant. This same principle should be used in networks employed to control bias on transistors, differential input and output characteristics, etc.

*   *   *

33. Why can ratios of resistor values be held more tightly than absolute values of resistance?

34. Give one example of how ratios of values can be used in integrated circuit design.

*   *   *

LATERAL TRANSISTORS

We have indicated that NPN transistors in P-type substrates are the most desirable and easiest to fabricate. However, upon occasion it is

desirable to have a high gain PNP transistor. This type of transistor is not easily fabricated using the process that we have indicated for producing NPN transistors. The procedures would have to be modified and a different arrangement made unless special means were provided to achieve the equivalent of a high gain PNP transistor.

An interesting component that can be achieved by the special technique of integrated circuit design is the **LATERAL PNP TRANSISTOR.** This is shown in Figure 13. It uses a low gain PNP interconnected with a high gain NPN to obtain the equivalent of a high gain PNP transistor.
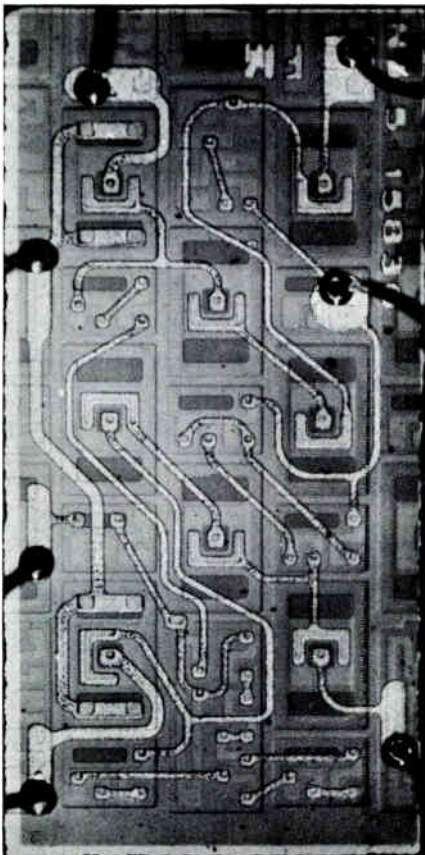
This chip contains two switching circuits using a total of four diffused resistors, six diodes and two transistors.
Courtesy General Electric
Semiconductor Products Dept.

NPN transistors with very high gain can be achieved by standardized NPN fabrication procedures. In this way, narrow base widths are achieved as indicated in cross-sections below the silicon surface. The low gain PNP transistor is obtained by laying out laterally across the surface two P-type regions very close to one another (the P regions are separated not more than 0.1 to 0.2 mil by an N region). Both P regions are diffused simultaneously. The limit on how close these regions can be placed to one another is dependent upon mask tolerances, etc. Yields drop rapidly when sufficient tolerance is not allowed.

This provides a PNP transistor with a gain of approximately 3 to 10, which in most cases is too low to be useful. While closer spacings

are desirable, they are impossible to attain without serious yield reductions. However, by coupling the low gain PNP transistor to an NPN transistor with a much higher gain, as shown in Figure 13, the equivalent of a very high gain PNP transistor is achieved.

The composite unit will operate much the same as a high gain PNP transistor with the exception of a slight offset voltage which results from the extra diodes involved in this arrangement. There will also be a limitation to the high frequency performance of this composite transistor compared to a high gain NPN transistor. This type of PNP transistor has been used in commercial integrated circuits to achieve complementary symmetry circuits with NPN transistors formed in the same substrate.

<div align="center">*   *   *</div>

35. What is a lateral PNP transistor?

36. How can a high gain equivalent PNP transistor be obtained by using a low gain lateral PNP transistor?

<div align="center">*   *   *</div>

INTEGRATED CIRCUIT COST CONSIDERATIONS

Three major factors which contribute to the cost of integrated circuit components are:

1. area requirements

2. tolerance as it affects the circuit yield

3. fabrication processes

Cost vs Area

Area requirements refer to the space needed to fabricate the particular component. Once the area for a total circuit is above a certain minimum value, the cost per unit area is nearly linear. Figure 14 shows the area required for a diffused resistor and its cost as a function of resistance value (assuming 100% yield). Note that the ver-

tical axis on one side is calibrated in area; on the other side, in cost. Since 100% yield is assumed, cost and area are linearly related.

Figure 15 shows a similar type of graph for MOS capacitors with a given dielectric thickness. Notice the steeper slope as compared to that of Figure 14. This results from the additional processing required to fabricate an MOS capacitor.

The upward slope in both graphs is because an increase in the component value requires a larger amount of space. As the amount of space increases, the total number of circuit chips which can be placed on a single wafer decreases proportionately. The total cost per chip for larger size chips increases because the cost of processing a wafer is approximately the same even though the number of chips is less.

<p align="center">*   *   *</p>

37. Assuming 100 percent yield, how are cost and area requirements related?

<p align="center">*   *   *</p>

Yield vs Area

In Figures 14 and 15, 100% yield was assumed. This situation normally does not exist since random defects occur in the material and result from the processing. These variations are reflected in the graph as a band rather than a line. While these defects may be few in number, their effect on the overall die yield increases greatly as larger die areas are required for each individual circuit.

Figure 16 shows a typical plot of the yield of monolithic circuits as a function of die area. Note how, as the circuit area increases, the yield decreases. The probability of a random defect occurring in a larger number of dice increases as the die area increases. Consequently, this factor adds to the cost of large area resistors and capacitors, and combines with the curves of Figures 14 and 15 to increase the rate of change of their slope.

*   *   *

38. In actual practice, how are yield and area requirements related?

*   *   *

Relative Component Costs

With discrete component circuits, the active elements are invariably among the highest cost elements, hence their number is minimized. The cost of most standard passive components (resistors and capacitors) has little relationship to their size. Because of area considerations, integrated circuit transistors cost no more than other circuit components. In many cases, they cost considerably less than large resistors and capacitors. This also accounts for the trend toward using larger numbers of transistors in integrated circuits, particularly when this can be accomplished while reducing the physical size or number of the associated passive components (capacitors and resistors).

In addition, each monolithic circuit may have its own custom transistor design. Transistor sizes and geometries may be adjusted to fit the particular circuit requirements. This is different from discrete component applications, where economy is normally achieved by using standard components which have a large variety of applications.

In electronic designs using discrete components, the active components (vacuum tubes and transistors) were invariably the most expensive components. Their cost dictated the type of design. For economic reasons, it was desirable to achieve the desired function with the minimum number of active components. Little consideration was given to the passive components (particularly the inexpensive resistors or capacitors).

This method generally does not produce the best economic arrangement in the integrated circuit design. Frequently, more extensive use of transistors is desirable because of the net saving in area which may
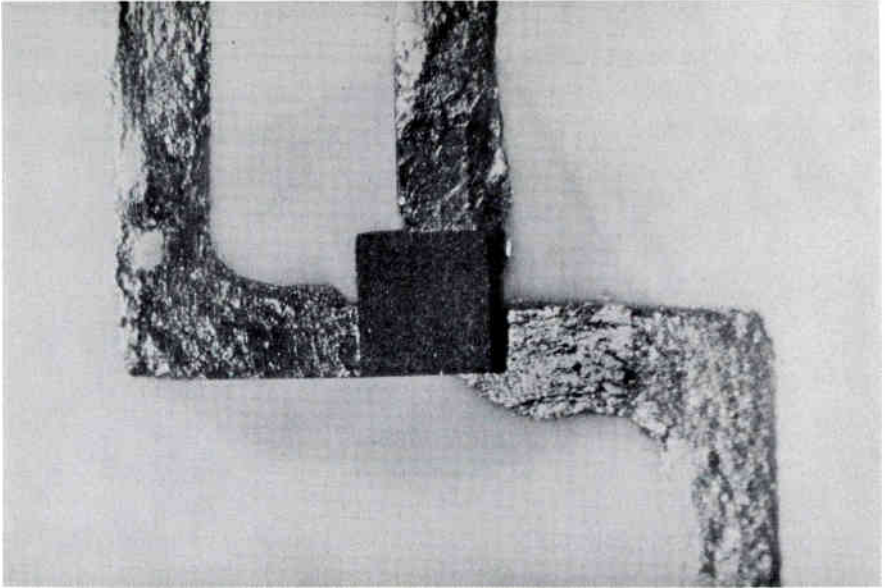
This photograph shows a transistor attached to a metalization pattern
by flip-chip methods.

Courtesy CTS Corporation

be achieved by replacing larger passive components with smaller transistors.

In one specific example of this, a capacitor in an early integrated circuit was replaced with a total of twelve components, eight of which were transistors. Despite the increased total, a net area saving resulted from this exchange without any sacrifice in performance.

          *   *   *

39. How is economy achieved in discrete component circuits, considering only the components?

40. Do integrated circuit transistors cost more than other circuit components?

          *   *   *

Component Tolerance vs Yield

As we have already seen, large die areas tend to reduce yield. Another factor that reduces yield is overly tight tolerance specifications. Since the components are fabricated together in a single monolithic substrate, one out-of-tolerance component could cause the entire integrated circuit to be rejected. Very tight tolerances on individual components can drastically reduce yield.

*   *   *

41. What are two major causes of yield reduction?

*   *   *

Each additional processing step usually requires its own photoresist mask, photoresist process, etching, and diffusion or other related processing. With the addition of each processing step, there is an increased cost associated not only with processing itself, and handling, but also as a result of yield losses in the processing step. These yield losses are due to improper handling, carelessness, etc.

Let us summarize by comparing integrated circuits with discrete and thin-film (compatible and noncompatible) components. In the case of integrated circuit resistors, the basic tolerance is a result of the fact that the process is adjusted to achieve the transistor characteristics desired.

Figure 17 shows the resistor tolerances that would result in NPN integrated circuits using a P-type substrate. Base diffusion resistors are shown in the first column, and resistors resulting from the emitter diffusion are shown in the second column. The third column, labeled NiCr, pertains to compatible thin-film resistors. Tin oxide (SnO_2) and other forms of thin-film resistors are shown in columns four and five. In the last column, a conventional molded carbon resistor is presented.

*   *   *

42. Are Nichrome integrated resistors available in the same range of values as the conventional molded carbon type?

*   *   *

Figure 18 makes the same comparisons for different forms of capacitors. In the first column are the junction capacitors; in the second column, the MOS type, labeled SiO_2. The third, fourth and fifth columns are thin-film capacitors in which three depositions are involved.

*   *   *

43. According to the data in Figure 18, can junction integrated capacitors be used in compatible types of integrated circuitry?

*   *   *

Figure 19 compares the characteristics of typical small-geometry silicon transistors. The first two columns reflect the selection of substrate material, whereas the third column is a commercially available discrete transistor type with the same geometry for the basis of comparison.

Notice that collector substrate capacitances are present in the case of the integrated transistors, but do not exist in discrete transistors. The saturation resistance (R_{sat}) of the integrated circuit transistor also is larger when compared to the discrete component. Notice also that the maximum frequency of operation (f_T) is comparable, so that with careful design, it is possible to achieve characteristics good enough so that there is little sacrifice in performance capability.

*   *   *

44. What is the major characteristic difference between monolithic and discrete transistors?

*   *   *

ECONOMICS OF THE VARIOUS INTEGRATED
CIRCUIT CONSTRUCTIONS

Since economics frequently dictate the way in which an electronic system is to be implemented, consideration of the basic construction techniques from this point of view is important. In this review only the integrated circuit forms (monolithic, multi-chip and thin-film) will be considered and compared to one another.

Monolithic Integrated Circuits

The monolithic integrated circuit is by far the most economical when it is produced in large volumes with high yield. To achieve high yield, however, it is frequently necessary to accept components with wider tolerance than might be necessary with other techniques. For this reason, the compatible integrated circuit has been developed.

In the compatible form, thin-film passive components are deposited on the surface of the monolithic integrated circuit. The extra processing costs associated with the thin-film depositions usually must be justified. The reasons for using this method are based upon higher yield or better operating characteristics achievable with the passive thin-film components.

*   *   *

45. For what reason can the extra costs associated with compatible thin-film integrated circuits be justified?

*   *   *

Thin-Film Circuits

By comparison, the **HYBRID THIN-FILM CIRCUIT** (a circuit in which the active components are assembled after the fabrication of the thin-film components) may be more economical in small quantities. It is found that the thin-film component fabrication itself is relatively economical. The higher cost factors of hybrid thin-film

circuits arise from the necessity of separately assembling and inter-connecting the active components on the passive substrates.

Certain suppliers have found that this technique is almost as econom-ical as the monolithic fabrication because of the higher yields achiev-able. This is made possible by assuring, before the assembly opera-tion is begun, that all of the active components are adequate and the passive substrates are acceptable. By further automating the process of assembly, further cost advantages can be achieved as the result of this higher yield situation.

*   *   *

46. Is thin-film component fabrication economical in a hybrid thin-film circuit?

*   *   *

Multi-Chip Integrated Circuits

The maximum yield frequently can be achieved by use of a **MULTI-CHIP ASSEMBLY.** Each of the individual chips can be thoroughly checked and evaluated before the assembly is made, and with highly trained operators there will be very little loss during assembly.

Figure 20A shows the electrical arrangement of such a multi-chip layout, and Figure 20B shows its physical assembly. Figure 21 shows a photograph of another multi-chip arrangement that minimizes the need for extremely complex processing. This is done by using a num-ber of integrated circuits and separate discrete transistors to achieve the total circuit function. In this arrangement the four smaller chips on the top and bottom of the left hand side are high power discrete transistors. This particular assembly is designed for 6 watts of out-put power showing that integrated circuits are not limited to extreme-ly low power operation.

It should be noted that the multi-chip assembly is one of the most expensive from the assembly point of view. Each of the chips must be mounted on the substrate, and the interconnections made as a
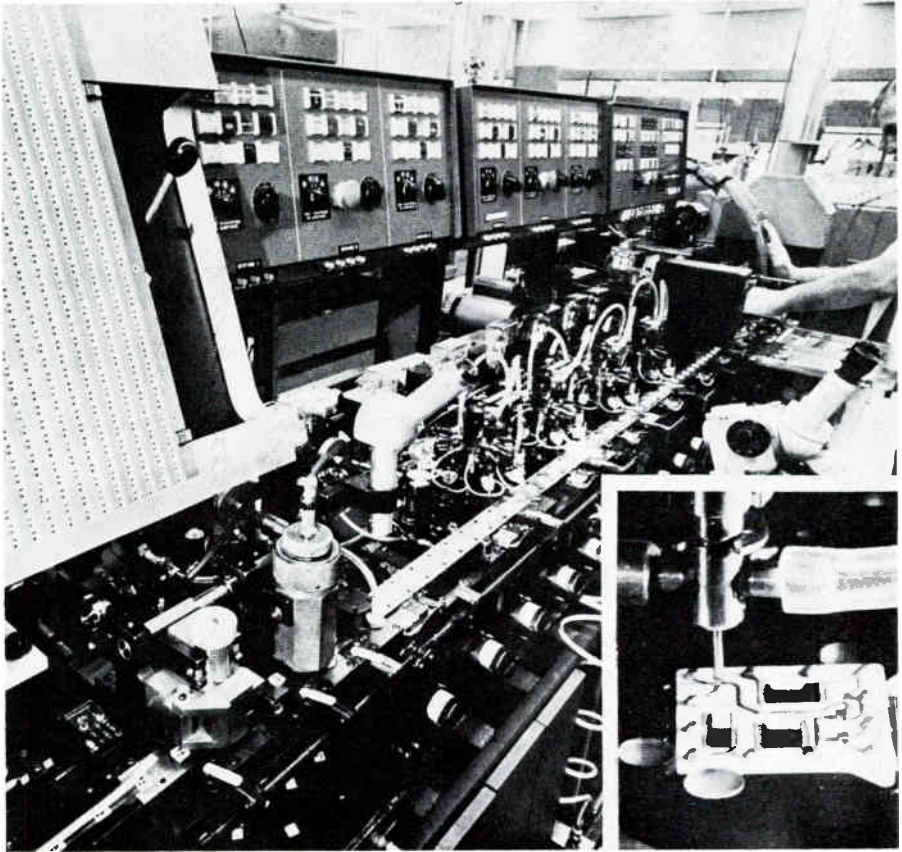
Automatic machines position transistor and diode chips on passive substrates. Hypo-
dermic-like vacuum needles position these chips at the rate of about six every 1 ½
seconds. The inset shows a chip being placed on the substrate.

Courtesy IBM Corporation

separate operation. While multi-chip arrangements have the advan-
tage of high yield, they also have extremely high assembly costs.
These costs can be justified for any one of the following reasons:

1. To minimize the amount of complex processing (as indicated
   in Figure 21). Several different, simple integrated circuit
   fabrication processes can be brought together in final assem-
   bly without modifying an already successful process.

2. To produce limited quantities as might be required for pro-
   totype design work. Generally, where high yield can be
   achieved, quantities in excess of one thousand circuits would
   change the economic advantage from multi-chip to monolithic
   circuits.

3. Multi-chip circuits can frequently be used as aids in design-
   ing monolithic circuits, since the individually diffused compo-
   nents can be used and the parasitics associated with them can
   be simulated in a multi-chip arrangement. Multi-chip ar-
   rangements can provide almost the same size advantage as
   some of the integrated circuits can, but with a shorter design
   cycle. The reason for this is that most of the discrete compo-
   nents needed can be obtained and assembled more rapidly
   than designing a new monolithic integrated circuit.

                   *   *   *

47. Must multi-chip integrated circuits be used in low power applications only?

48. What is one cost disadvantage of multi-chip circuits?

                   *   *   *

SUMMARY

Two major differences between integrated and discrete components
are their geometries and parasitics. The size or shape of discrete com-
ponents (within limits) is not a major consideration. The size of
discrete components in a system may vary slightly and may be com-
pensated for in design layout with little appreciable change in the
system cost. However, the area taken by an integrated component
directly relates to cost of the circuit. The larger the area of the com-
ponent, the larger the area required for the chip, the lower the num-
ber of chips from a wafer, and the higher the cost per chip. There-
fore, large area integrated components are avoided where possible.

Because integrated components are closely spaced on a chip, they tend to interact with each other. This results in parasitics. The electrical isolation between components produces parasitics in the form of capacitance and leakage currents. Some of these parasitics are voltage sensitive. Inductive parasitics due to the lead lengths of discrete circuits are minimized by the short paths between integrated circuit components.

Diffused resistors are the most common integrated resistors. Most are formed during the base diffusion. Low resistance values are produced during the emitter diffusion. The resistance value of a diffused resistor depends on its geometry, the sheet resistance of the diffusion, and its temperature of operation. A parasitic capacitance results from the PN junction formed between the resistor and its isolation region. The value of this voltage sensitive capacitance depends on the voltage across the resistor and its area.

Compared to diffused resistors, thin-film resistors have lower parasitic capacitance, larger range of component values, a lower temperature coefficient, and tighter tolerance control. Also, thin-film capacitance parasitics are not voltage dependent.

Reverse biased PN junction capacitors are voltage sensitive. These capacitors also have a parasitic capacitance which is dependent on the area of the capacitor and the applied voltage. Leakage current is another parasitic of PN junction capacitors.

MOS capacitors are the most widely used integrated circuit capacitors. They require an additional processing step but have less parasitics than the diffused type. Their parasitics depend upon the area required by the capacitor and are the result of a voltage sensitive PN junction.

Thin-film capacitors have the least parasitics. However, they are also the most expensive to fabricate. As a result they are not very widely used on silicon wafers.

Integrated transistors have a much higher saturation resistance than their discrete counterparts. This is a result of the longer path from the collector to the collector contact. Integrated transistors also have a parasitic capacitance. These affect the high frequency performance.

Integrated circuit diodes are usually made during normal wafer processing. Base-emitter junction diodes have a low reverse breakdown voltage. The collector-base junction diode makes a medium voltage type diode.

Since integrated components are fabricated close together, electrically and thermally they track closely. Thus, the relationship between component values remains relatively constant.

Costs of integrated circuit components are determined by the area, component tolerance, and fabrication processes required. Large sized components require large die areas. This tends to reduce yield and increase the processing cost per good chip. Overly tight tolerance specifications reduce yield. Each additional processing step has a cost associated with it. In addition, each step tends to increase yield loss.

Monolithic circuits are the most economical when produced in large volumes with attendant high yield. The addition of thin-film components permits the use of tighter tolerances. However, the additional processing steps result in a reduction of yield. When only a small number of circuits are needed, hybrid thin-film or multi-chip techniques may be the least expensive.

IMPORTANT DEFINITIONS

HYBRID THIN-FILM CIRCUIT—A circuit in which the active components are assembled after the fabrication of the thin-film components.

LATERAL PNP TRANSISTOR—An integrated transistor made in such a way that the transistor action is laterally across the surface of the diffusions rather than vertically through the N and P diffusions.

MULTI-CHIP ASSEMBLY—An assembly in which each chip is mounted on the substrate and the interconnections are made as a separate operation.

PARASITIC—[PAIR uh SIT ik]—An undesired interaction with other components, or with the substrate, the atmosphere, or other parts of the system.

SATURATION RESISTANCE (R_{sat})—The resistance of the material which comprises the path of the collector current from the emitter contact.

TEMPERATURE COEFFICIENT (TC)—Percentage change of resistance per degree Centigrade.

STUDENT NOTES

PRACTICE EXERCISE SOLUTIONS

1. A parasitic is an undesired or unwanted interaction with other components, with the substrate or the atmosphere, or with other parts of the system.

2. electrical isolation

3. Monolithic integrated circuits usually have larger parasitics than the other types of integrated circuits or discrete component circuits because they normally obtain electrical isolation by means of reverse-biased PN junctions.

4. The glass (SiO_2) layer which insulates the film components from the surface of the silicon wafer acts as a dielectric of a coupling capacitor. This forms the parasitic.

5. (a) greater than, (d) less than

6. True

7. Diffused resistors in monolithic structures may be recognized as stripes which are sometimes folded back and forth.

8. The majority of diffused resistors are formed during the same diffusion used to fabricate the bases of the transistors. Low value resistors are usually formed at the same time as the emitters of the transistors.

9. The largest parasitic is the result of the PN junction between the resistor and its isolation region.

10. The parasitics may be reduced by decreasing the area while keeping the length-to-width ratio nearly the same.

11. Control of the resistor associated with photo mask tolerances, etching rates, and undercutting during the formation of the SiO_2 windows — all will limit the minimum size of the resistor area.

12. C_{p_1} represents the junction capacitance of the PN junction formed between the base and isolation junctions. C_{p_2} results from the PN junction formed between the collector or isolation region and the substrate.
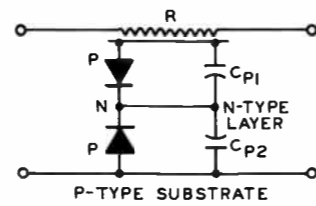
FIGURE 1
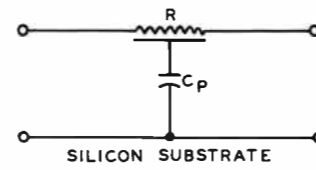
FIGURE 3
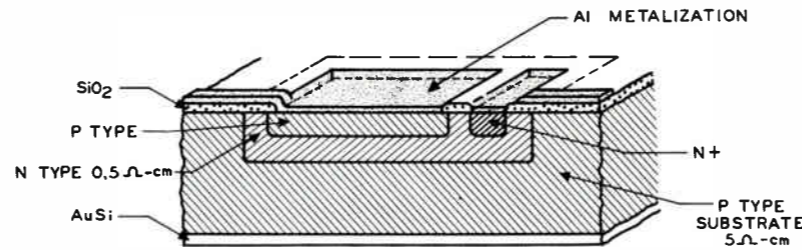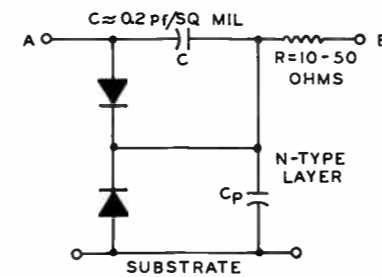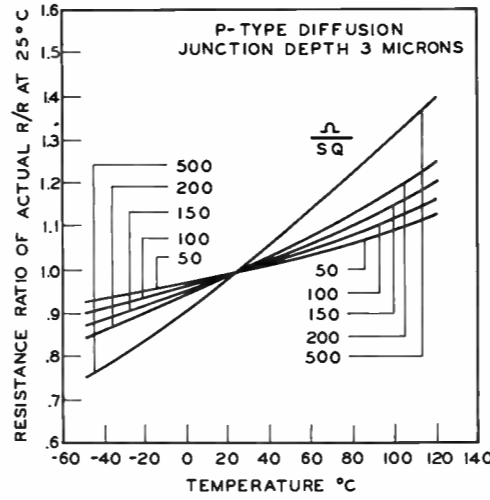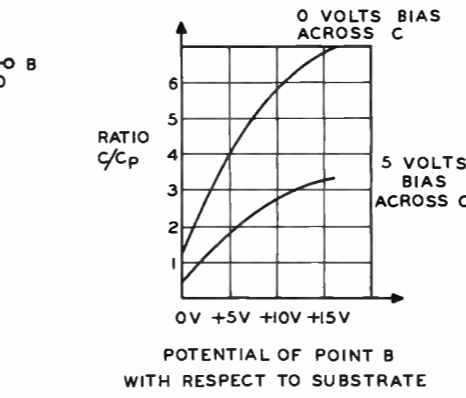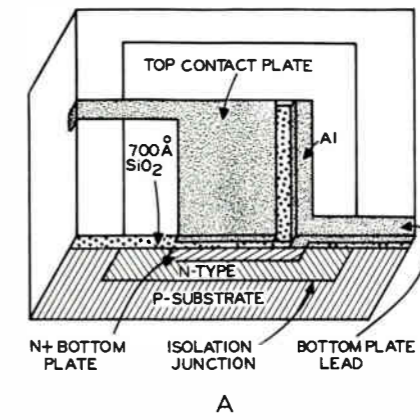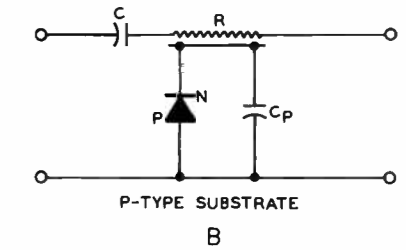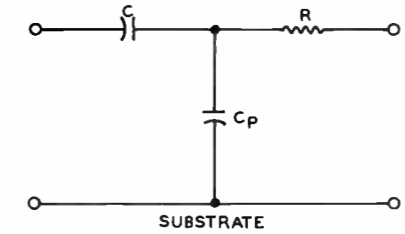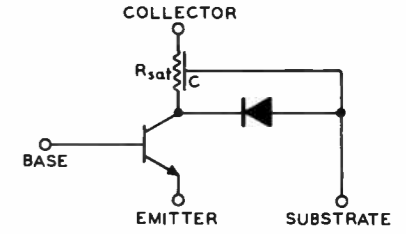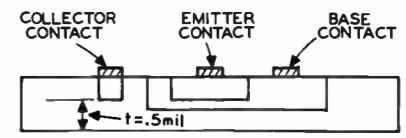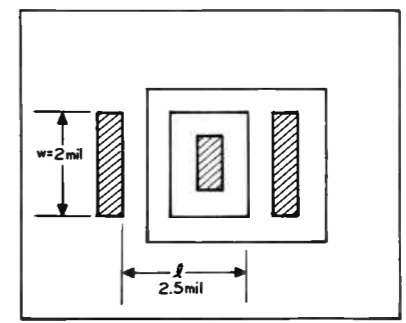
FIGURE 2

A

B

C

FIGURE 4

A

B

FIGURE 5

FIGURE 6

FIGURE 7

FIGURE 8

EMITTER-BASE DIODE
(BASE SHORTED TO COLLECTOR)

A

BASE-COLLECTOR DIODE

B

FIGURE 9

FIGURE 10

FIGURE 11

FIGURE 12

FIGURE 13

5516
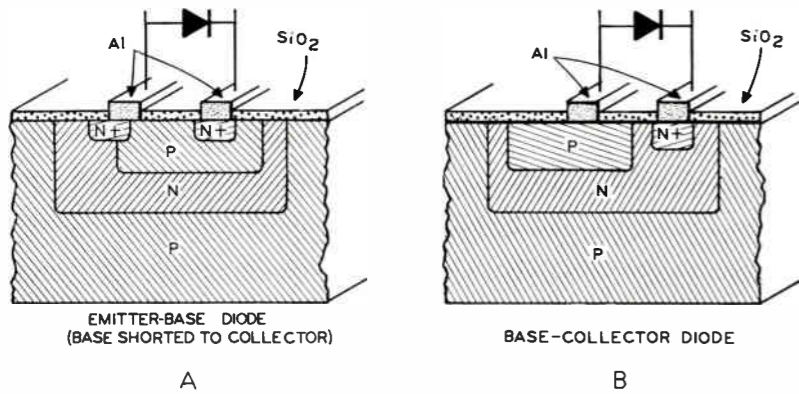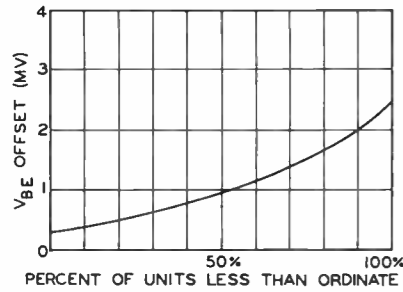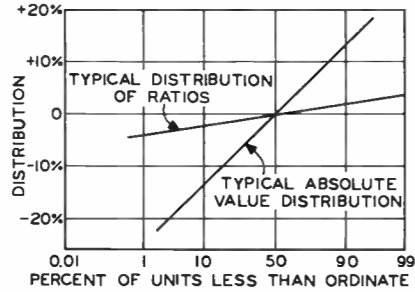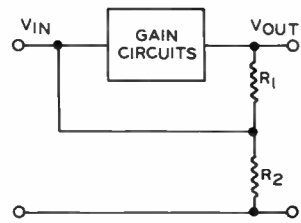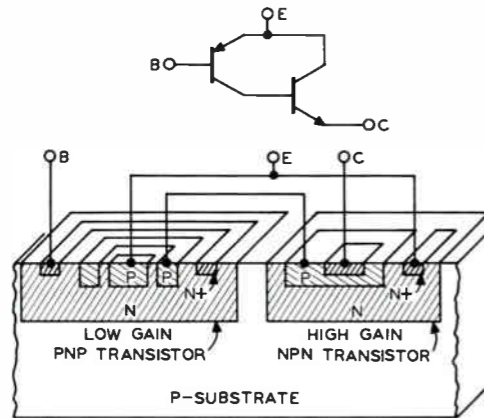
PRACTICE EXERCISE SOLUTIONS—(Cont'd)

13. True -- The junction producing C_{p_2} has a larger area than that of C_{p_1}. C_{p_2} provides about half the capacitance of C_{p_1} since the bias voltage between the isolation region and the substrate is larger than that between the base and isolation region.

14. False -- Since the resistivity rises as the temperature rises, the temperature coefficient is positive.

15. Sheet resistance obtainable with compatible thin-film resistors varies from 40 to 500 ohms per square.

16. The parasitic capacitance associated with compatible thin-film resistors is a function of the area occupied by the resistor and the thickness of the SiO_2 upon which the resistor is deposited. PN junction capacitances are voltage sensitive, but thin-film capacitances are not.

17. Thin-film resistors have lower temperature coefficients, tighter controls of tolerance, superior high frequency responses, poorer aging characteristics, and wider ranges of values.

18. Compatible thin-film resistors require additional processing steps. This raises their cost so their usage is not always justifiable.

19. The necessity and added cost of the assembly operations required for adding active components can become prohibitive when large volume production is involved.

20. The ratio of C/C_p is important as it relates the useful capacitance with the parasitic capacitance. This has the essence of a "quality factor."

21. This resistance is high since the material used has a high resistivity and the necessary current path is long.

22. False -- The breakdown voltage must be low to obtain reasonable capacitance values. These capacitors are also voltage sensitive. Other types of integrated capacitors are preferred to the PN junction if capacitors must be used.

PRACTICE EXERCISE SOLUTIONS—(Cont'd)

23. This is the series resistance of the current path through the N+ diffused region.

24. The typical ratio of C to C_p for an MOS capacitor ranges from 3/1 to 5/1.

25. The primary parasitic associated with a compatible all deposited thin-film capacitor is a shunt capacitance to the substrate. When a passive substrate is used, this parasitic diminishes to almost zero.

26. True

27. Yes -- Transistor geometries should be tailored for their specific functions in the circuit.

28. The characteristics of an integrated transistor are inferior to those of a discrete transistor because of higher saturation resistance and an additional PN junction parasitic of the integrated type. The different method of making contact to the collector causes the increased saturation resistance, while the need for isolation generates the added parasitic.

29. Transistor action can be caused in an emitter-base diode if the base-collector junction is not shorted and if both junctions are properly biased.

30. Base-collector diode structure provides a higher breakdown voltage than does the emitter-base junction. The emitter-base diode is generally preferred over the base-collector diode. Transistor action could occur in either junction under certain bias conditions, thereby causing parasitics to develop.

31. The characteristics of components in an integrated circuit could be closely matched because each component will be operating at nearly the same ambient temperature. Nearly all other transistor characteristics will also be matched as well.

32. Yes

PRACTICE EXERCISE SOLUTIONS—(Cont'd)

33. This ratio can be held more tightly because the resistors fabricated close to one another will exhibit similar characteristics despite process variations. From this, the ratios will remain nearly the same despite changes in absolute values.

34. The ratios of values can be used, for example, to control overall gain by maintaining a ratio of feedback through the ratio of two resistor values in a voltage divider arrangement.

35. A lateral PNP transistor is an integrated transistor which is made in such a way that the transistor action is laterally across the surface of the diffusions rather than vertically through the N and P diffusions.

36. A high gain equivalent PNP transistor can be obtained by coupling the low gain PNP to a high gain NPN to obtain the equivalent of a high gain PNP transistor.

37. Once the area for a total circuit is above a certain minimum, the cost per unit is nearly linear.

38. In actuality, the cost per unit area is not linear since random defects occur in the material and result from processing. The effect of the defects on the overall die yield increases greatly as larger die areas are required for each circuit. The probability of a random defect occurring in a larger number of dice increases as the die area increases. This factor then is added to the cost (shown on 100% yield curves) to increase the rate of change of the slope of the curves. Thus, the greater the die size, the smaller the percent of yield.

39. Economy is achieved in discrete component application by using the most inexpensive standard components. This usually dictates the use of a minimum number of active components.

40. No -- In fact, integrated transistors cost much less than many integrated circuit capacitors and resistors.
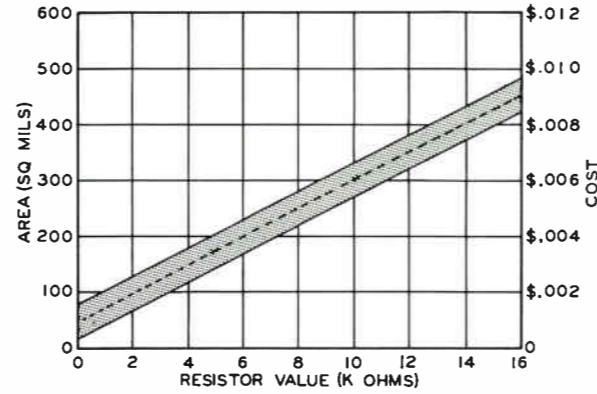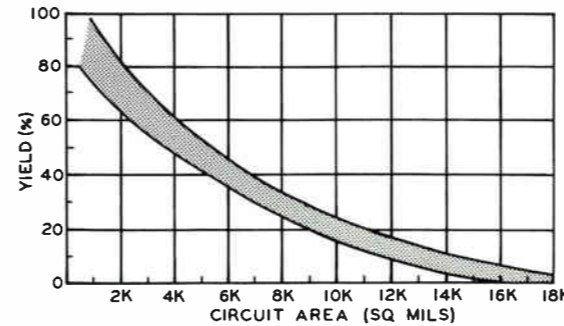

FIGURE 14
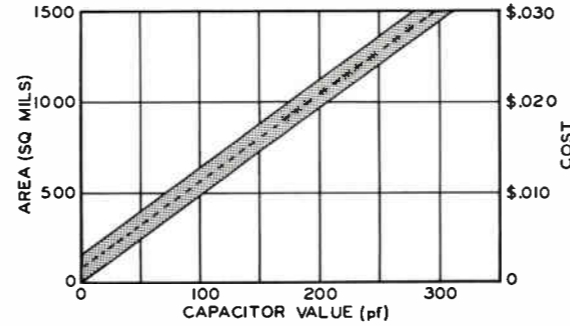
FIGURE 15

FIGURE 16

5516

PARAMETERS	Si P-TYPE	Si N+TYPE	NiCr	SnO$_2$	Cr–SiO (CERMET)	CONVENTIONAL MOLDED CARBON
1. RANGE (OHMS/SQ)	50–250	2–5	40–400	50–500	100–10K	–
2. MAX VALUE (OHMS)	25K	250	100K	100K	200K	22 MEG
3. MIN VALUE (OHMS)	25	5	20	25	50	0.24
4. TOLERANCE* (%)	±10%	±15%	±10%	±15%	±20%	±5%
5. MAX POWER (mW/SQ MIL)	3	3	2	2	2	2 WATTS TOTAL
6. MAX VOLTAGE (VOLTS)	±20	±5	±100	±100	±100	±750
7. AGING ALLOWANCE (%)	±2%	±2%	+3%	TO 4%	+5%	10%
8. TEMPEPATURE COEFF. (PPM/°C)	+50 TO +2500	+100	±100	TO–1500	±500	±1500
9. CIRCUIT APPLICATIONS						
a. MULTI-CHIP	YES	YES	YES	YES	YES	
b. Si–MONOLITHIC	YES	YES				
c. COMPATIBLE			YES	YES		
d. THIN–FILM			YES	YES	YES	
*UNADJUSTED						

FIGURE 17

PARAMETERS	JUNCTION	SiO$_2$	Al$_2$O$_3$–Si	Ta$_2$O$_5$	SiO
1. MAX VALUE (pf)	1000	250	1000	5000	100
2. pf/SQ MIL	1.2	0.25	0.3	2.5	0.2
3. TRANSFER RATIO (C/C SHUNT)	3	5	15	100	1
4. VOLTAGE COEFFICIENT	$V^{-\frac{1}{2}}$	0	0	0	0
5. BREAKDOWN VOLTAGE (BV)	7	30	30	20	30
6. TEMPERATURE COFFICIENT (PPM/°C)	–	+100	+125	+400	±110
7. DISSIPATION FACTOR (1 MHz) (%)	–	0.7	0.4	0.3	0.7
8. DIELECTRIC CONSTANT	13.7	3.78	≈10	25	≈6
9. CIRCUIT APPLICATION					
a. MULTI-CHIP	YES	YES			
b. Si–MONOLITHIC	YES	YES			
c. COMPATIBLE	YES	YES	YES		
d. THIN–FILM		YES	YES	YES	

FIGURE 18

PARAMETERS	MONOLITHIC 1 Ω-cm COLLECTOR	MONOLITHIC 5 Ω-cm COLLECTOR	HYBRID 2N834 TYPE
1. COLLECTOR, SUBSTRATE, BV$_{CSO}$ (VOLTS)	80	80	–
2. COLLECTOR, BASE, BV$_{CBO}$ (VOLTS)	20	40	40
3. BASE, EMITTER, BV$_{EBO}$ (VOLTS)	6	7	5
4. COLLECTOR, EMITTER, BV$_{CEO}$ (VOLTS)	12	20	30
5. COLLECTOR SUBSTRATE, CAP. (pf)	10	10	–
6. COLLECTOR BASE, CAP. (pf)	8	4	2.5
7. H$_{FE}$ AT I$_C$=10mA	40	40	40
8. R$_{sat}$ (OHMS)	20	80	10
9. V$_{CE}$ (sat) I$_C$=5mA (VOLTS)	0.3	0.55	0.15
10. f$_T$ I$_C$=10mA V$_C$=5 VOLTS (MHz)	550	500	500

FIGURE 19

KOVAR WASHER   BONDING ISLAND

COMPONENTS

WIRE

METALIZATION

85% Al₂O₃ CERAMIC

CIRCUIT SCHEMATIC

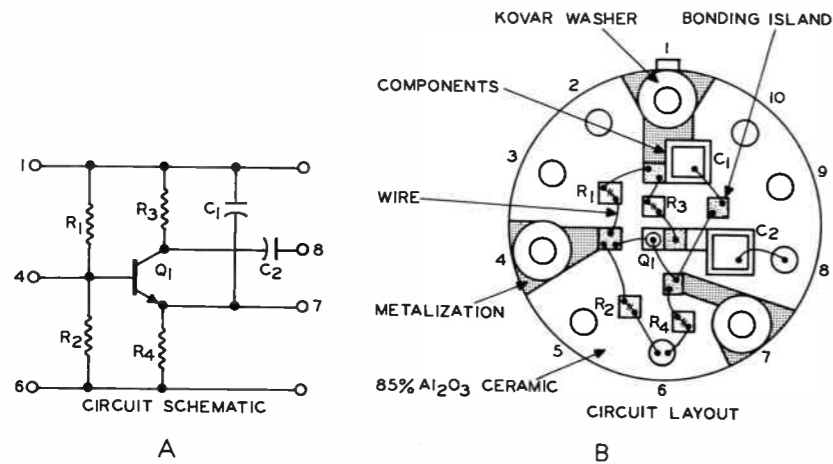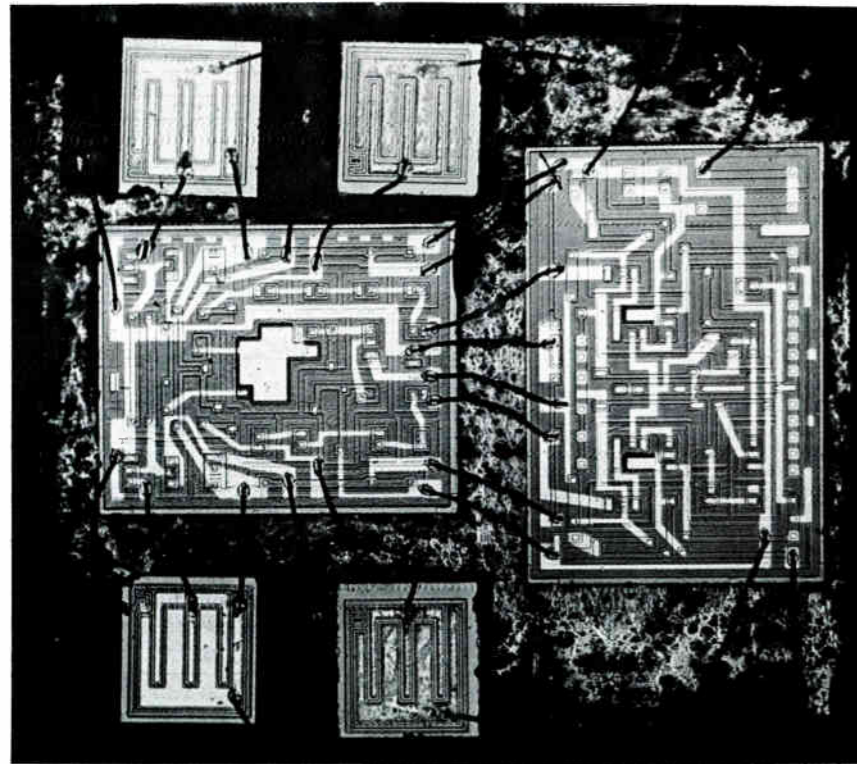CIRCUIT LAYOUT

A   B

FIGURE 20

Courtesy Norden

FIGURE 21

PRACTICE EXERCISE SOLUTIONS—(Cont'd)

41. Large die area and excessively tight tolerances are two major causes of yield reduction.

42. No -- The range of resistance values obtainable with carbon resistors is much larger than that obtainable with Nichrome resistors.

43. Yes -- Junction integrated capacitors can be used in compatible integrated circuits but usually aren't because of their poor characteristics.

44. The major characteristic difference between the two is that the saturation resistance of monolithic transistors is much larger than that of discrete transistors.

45. Either higher yield or better operating characteristics would justify the extra costs.

46. Thin-film component fabrication itself is relatively economical in the hybrid thin-film circuit. However, higher costs arise from separately assembling and interconnecting the active components on passive substrates.

47. No -- Multi-chip circuits can be designed to be used in moderately powered applications.

48. High assembly costs are one factor to be considered in the choice of whether or not to use a multi-chip circuit.

..=GRATED CIRCUIT DESIGN CONSIDERATIONS

QUESTIONS

IMPORTANT — These instructions **MUST** be accurately followed to avoid loss, or errors in grading.

Indicate your answer on this sheet by filling in the box for the most correct answer to each question, as illustrated in the example below.

When all questions have been answered, place the answer card in the proper position to line up the boxes on the card with the boxes on the sheet.

Next, copy the complete lesson code into the space provided on the card, and fill in the answer boxes to correspond with those previously filled in on this sheet.

Before mailing, be certain your correct student number, name and address appear on the card.

LESSON CODE

5516A

Example: Switzerland is a small country in

    A ■
    B
    C
    D

(A) Europe. (B) Asia. (C) South America. (D) Africa.

1. **A parasitic is**
(A) a defect caused by mechanical vibrations. (B) fungus growth on a wafer. (C) an undesired or unwanted interaction with other components, or with the substrate, the atmosphere, or other parts of the system. (D) an electrical defect caused only by exceeding breakdown voltage.

2. **The most significant parasitic in integrated circuits is the result of**
(A) mounting multi-chip circuits close together. (B) the use of voltages and currents too high for the circuits. (C) construction of large components in each wafer. (D) the provision of electrical isolation.

3. **The diffusion used in diffused resistors is designed**
(A) primarily with respect to its sheet resistance. (B) primarily with respect to the active element characteristics (depth of diffusion, etc.). (C) to form all resistances at one time. (D) to have low resistance only.

4. **Which of the following is true of a diffused resistor?**
(A) the resistance value depends only on sheet resistance, (B) the resistance value depends on the sheet resistance and its length-to-width ratio, (C) it is most commonly formed by diffusing an N-type diffusion into a P-type collector or isolation region, (D) it does not have any parasitics.

5. **Which of the following is true regarding the parasitics of a diffused resistor?**
(A) the largest parasitic is due to the PN junction formed between the resistor and its isolation region, (B) the parasitic capacitance is NOT voltage sensitive, (C) the parasitic capacitance will become minimum when the voltage across the resistor is minimum, (D) the parasitics decrease as the physical size of the resistance is increased.

6. **Which of the following is characteristic of thin-film resistors and capacitors?**
(A) higher parasitic capacitance, (B) larger ranges of component values, (C) higher temperature coefficients, (D) looser tolerance control.

7. **When reverse-biased PN junctions are used as capacitive elements (Figure 4),**
(A) they do not have any parasitics. (B) considering the equivalent circuit, C_p is the useful capacitance. (C) the breakdown voltage must be high to obtain higher capacitance per unit area. (D) capacitances of 20 to 100 pf are most commonly used.

8. **With respect to the MOS capacitor (Figure 5),**
(A) it employs SiO_2 dielectric which varies from 500 to 1000 Å in thickness. (B) R is the series resistance to the substrate through the N diffused region. (C) R always has a value greater than 10 ohms. (D) the useful capacitance and parasitic capacitance decrease as the area increases.

9. **Which of the following junctions cannot be used in the formation of an integrated circuit diode?**
(A) the base-emitter junction with the collector short-circuited to the base, (B) the emitter-base junction, (C) the base-collector junction, (D) the collector-substrate junction.

10. **Of the following considerations contributing to the cost of integrated circuit components, which one is relatively minor?**
(A) area requirements, (B) tolerance as it affects circuit yield, (C) fabrication processing, (D) the number of transistors used.