SECTION 2

ADVANCED
PRACTICAL
RADIO ENGINEERING

TECHNICAL ASSIGNMENT

POWER SUPPLIES

224D

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RECEIVER POWER SUPPLIES

INTRODUCTION

Since every electronic unit encountered in radio-service engineering must have a power supply of some kind, it is desirable to understand the theory and operation of such units. Every power unit likely to be encountered is discussed in considerable detail, beginning with the most fundamental and proceeding to the more intricate. The explanatory examples should be carefully studied to insure complete mastery of the material. The circuits included are, insofar as possible, taken from actual commercial installations, and hence the serviceman will probably come across them at some time in his career.

HALF-WAVE AND FULL-WAVE REC-TIFICATION.—The unilateral conductivity of the two element tube makes it ideal as a rectifier. The only current that can flow is due to (but not necessarily limited to, as will be explained later) electron emission from the cathode. When the plate is positive with respect to the cathode, emitted electrons are attracted to the plate and current flows through the tube and associated circuit. When the plate is made negative with respect to the cathode, electrons are repelled by the plate and hence, even though the emission is the same as before, no current can flow through the tube. Reverse current is prevented because the electron emission is from one element only, the cathode. Thus if a two element diode tube is connected in series with an alternator as shown in Fig. 1, plate current will flow only on the alternations which make the plate positive with respect to
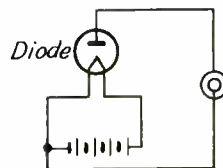
Fig. 1.—Rectifying action by a diode tube.

the filament. This is shown in Fig. 2.

In ordinary a-c power supplies the rectification of the a-c voltage
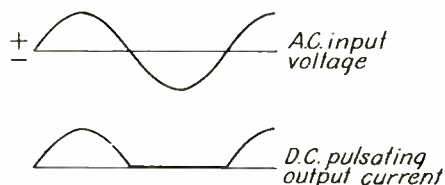
Fig. 2.—Only the positive half cycles of current flow.

is accomplished by one of the following methods:

The first method is half-wave rectification using a transformer, a diode rectifier, and a filter arranged as shown in Fig. 3. Since

Fig. 3.—Half-wave rectifier.

the diode conducts only on every other half-cycle of the a-c input voltage, the voltage at the filter's input is in the form of half-sine

wave pulses as shown in Fig. 4(B).
After the first section of the fil-
ter there is a smoother voltage but
a pronounced ripple at the supply
frequency shown in Fig. 4(C).
Finally after adequate filtering
there is a steady d-c voltage
available for the receiver that is
shown in Fig. 4(D).

No. 2 is negative, and plate No. 2
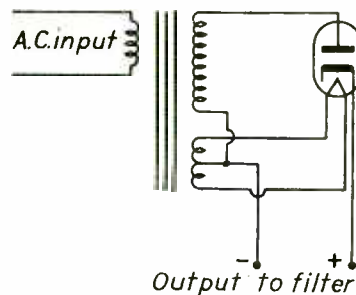is positive on the next half-cycle
while plate No. 1 is negative. This
delivers a series of pulses to the
filter as shown in Fig. 6(C). The
first section of the filter smoothes
them out somewhat like Fig. 6(D).
The "ripple" frequency is now at
twice the supply frequency, hence,
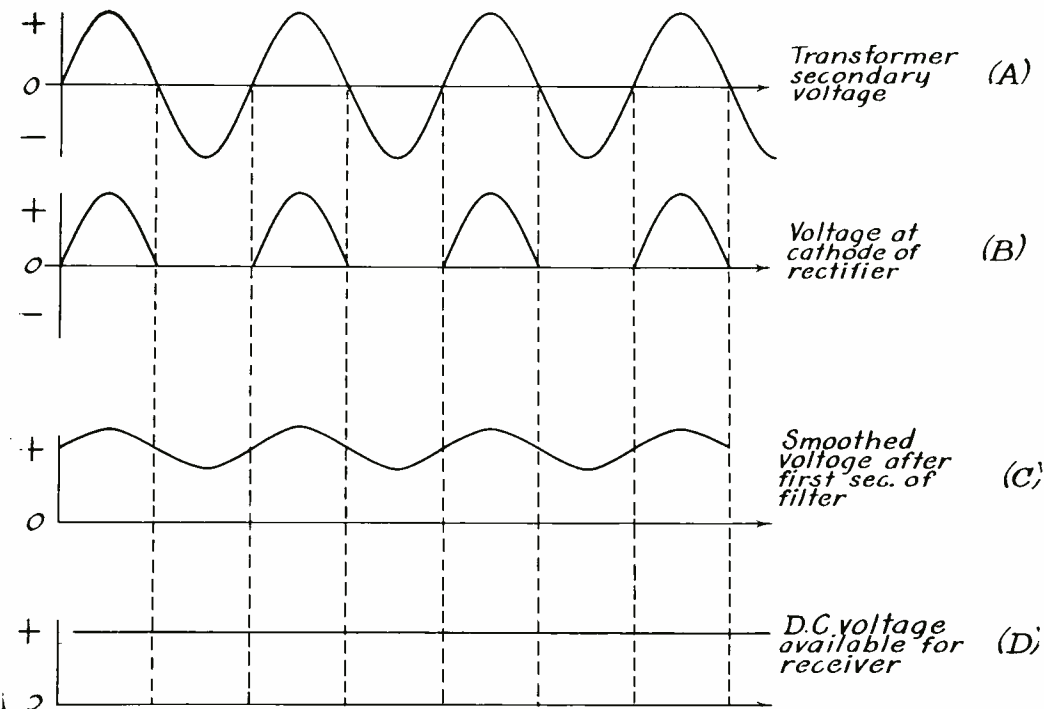
Fig. 4.—Oscillograms of different points in the rectifier system.

The second method is full-wave
rectification using two diodes and
arranged as shown in Fig. 5. In
this circuit, current is delivered
to the filter on every half-cycle of
the input voltage, as plate No. 1 is
positive with respect to the cathode
on the first half-cycle while plate

less filter is required for this rec-
tifier than for the half-wave recti-
fier whose ripple frequency was equal
to that of the supply. Finally, after
filtering there is available for the
receiver a steady d-c voltage as
shown in Fig. 6(E). Filtering is
discussed in greater detail further

on in this assignment.

SELENIUM RECTIFIERS.—In addition to rectification by means of
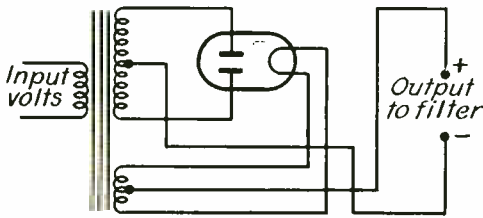
Fig. 5.—**Full-wave rectification using two diodes.**

vacuum tubes, there is another process, which is frequently referred to as *metallic rectification*. This method is based on the reactions which occur when certain metals (and alloys) are placed in contact with one another and subjected to pressure. One of the metallic rectifiers which has found wide application in the past few years is the selenium rectifier cell.

A cross-section illustration of a selenium-rectifier unit is shown in Fig. 7. The back electrode is simply a metal plate (made of aluminum, iron, or nickel-plated steel) which serves as a mechanical support for the entire unit. One side of this plate is coated with a thin layer of selenium (a semi-conducting material); the selenium coating must be thick enough, however, to withstand the high inverse voltage to

Fig. 6.—**Wave shapes encountered in full-wave rectification.**

which it is subjected.

A special metallic alloy, having a low melting point, is then applied on top of the selenium layer; this alloy coating is referred to as the front electrode. (See Fig. 7.)

Fig. 7.—Cross-sectional view of a selenium rectifier.

By certain electro-chemical processes, a so-called "barrier layer" is formed between the front electrode and the selenium layer. The complete plate is shown in Fig. 8.
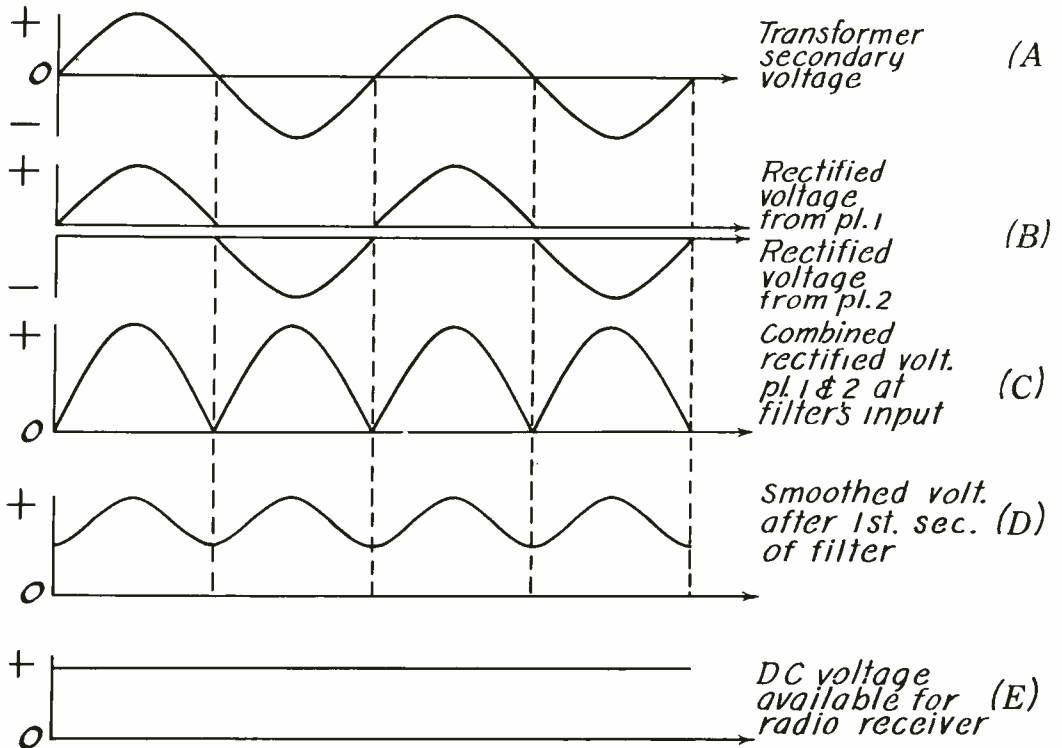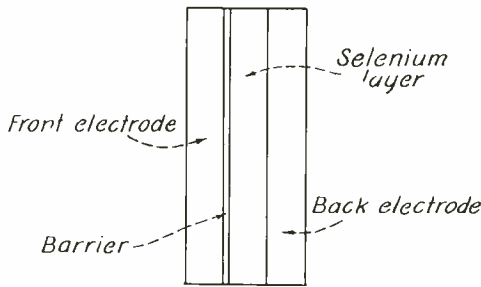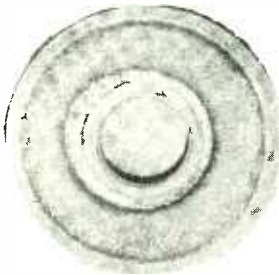

(Courtesy Westinghouse Electric Corp.)
Fig. 8.—Completed selenium rectifier cell.

In order to obtain various voltage and current ratings, the rectifier plates can be connected in series or parallel as desired. "Stacked" rectifiers, as shown in Fig. 9, are available for such purposes.

These stacks are obtained by

mounting the individual plates one above the other on a stud which passes through the plate's center. Spacing washers are inserted between adjacent plates. The maximum number of selenium plates which can be

(Courtesy Vickers, Inc.)
Fig. 9.—Selenium rectifier stack.

stacked in such a manner is about 35 to 40.

Normally series and parallel arrangements are obtained by inserting insulators between the cells and by introducing terminal lugs in the stack.

Although several theories have been advanced in attempting to explain the operation of the metallic or dry-plate type of rectifier, the best explanation has been offered by Schottky and is based on quantum mechanical considerations that are too involved to introduce here. This text will therefore merely describe the operation of such a unit. Current (electrons) can flow freely from the back electrode to the front electrode, but cannot flow in the reverse direction (i.e., from the front electrode to the back electrode).

In other words, a selenium rectifier can be thought of as a device offering very *low* resistance to cur-

rent which flows in a forward direction, but offering exceedingly *high* resistance to any current flowing in the reverse direction.

When a potential is applied across the rectifier unit, some current will flow in the reverse direction, (i.e., from the alloy coating toward the selenium layer), and this current is called *leakage current*. It is important that this leakage current be kept as low as possible; thus it is desirable to have the *reverse resistance* as high as possible.

The application of a potential to a selenium unit also results in a *forward voltage drop* due to the *forward current's* flowing through a resistance. This resistance (from the back electrode to the front) should be as low as possible in order to keep the forward voltage drop at a low value.

ADVANTAGES AND DISADVANTAGES OF SELENIUM RECTIFIERS.—The selenium rectifier unit requires very little mounting space on the chassis, and is comparatively light in weight. For these two reasons, selenium rectifier cells are used quite extensively in aeronautical radio equipment.

The selenium units can be made almost entirely immune to atmospheric variation in pressure and humidity, and will operate over a range of temperatures from about −40 to +70° C.

Although the life of the selenium rectifier is not as long as that of other rectifiers, it is less subject to aging; that is, to increase in its forward resistance and decrease in its reverse resistance, with time. With respect to vacuum tubes it has the advantage of not requiring any filament or heater power.

Although voltage overloads (high reverse voltage) cannot be withstood in these units, they are able to withstand current overloads for a short period of time without being permanently damaged. The plates are usually self-healing if the breakdown current does not exceed the normal value by too great an amount. However, even though the plate may heal when punctured by a current overload, the effective rectifying area of the plate is reduced by some small amount dependent upon the area of the healed puncture. The effective resistance (in the forward direction, and also the reverse resistance) will be increased as a result of the decrease in the effective cross-sectional area of the plate.

Since the front and back electrodes are separated by an insulating material (the barrier layer), it is evident that there will be a certain amount of capacity between the two plates. At low frequencies (up to about 1500 c.p.s.) this capacity between the front and back electrodes has negligible effect. However, at higher frequencies, the capacity between the two electrodes acts as a greater and greater shunt across the unit. The leakage owing to the capacitance between the rectifier plates will therefore act as a very low shunt to the high back resistance, and thus tend to reduce the rectifying action.

This, of course, is an undersirable condition. It can, however, be minimized by using rectifier plates of decreased cross-sectional area, since this procedure results in a decrease in the capacity and hence in the reverse current. Thus the rectifying action of the unit is improved and made to approach the effectiveness

of low-frequency operation. In some European receivers, which are taxed according to the number of tubes, rectifiers of small cross section have been used in place of diodes. The reduced area permits these rectifiers to function satisfactorily even at radio frequencies.

A long rectifier stack, having plates of small cross-sectional area, has been introduced into this country by the Federal Telephone and Radio Corp. for use in r-f and also surge deflection high-voltage power supplies. In these types of supplies the a-c power to be rectified is obtained from a vacuum tube, operating either as an r-f oscillator in the 100-200 k-c range, or as a horizontal deflection output tube, which only incidentally furnishes the high-voltage power.

In either case, the tube has to furnish in addition the heating power for the rectifier tube, and this represents a considerable portion of the total a-c power to be furnished. Where a rectifier stack is employed, such heating power is eliminated; the voltage drop in the stack is no greater than that in the rectifier tube; and the only disadvantages are increased bulk and expense. It will be of interest to watch the trend, if any, in this country as regards their use in high-voltage supplies.

Another application of wider scope is the use of a selenium rectifier instead of a tube rectifier in the small radio sets, particularly those that obtain their d-c power direct from the a-c supply without the use of a step-up transformer. The selenium rectifier in this case is more compact than the tube, and can be located in any convenient nook in the chassis, whereas the rectifier tube usually requires more ventilation, a socket located on the top of the chassis the same as those for the other tubes, etc.

In Fig. 10 is shown a typical circuit diagram of such a power supply. A half-wave rectifier is
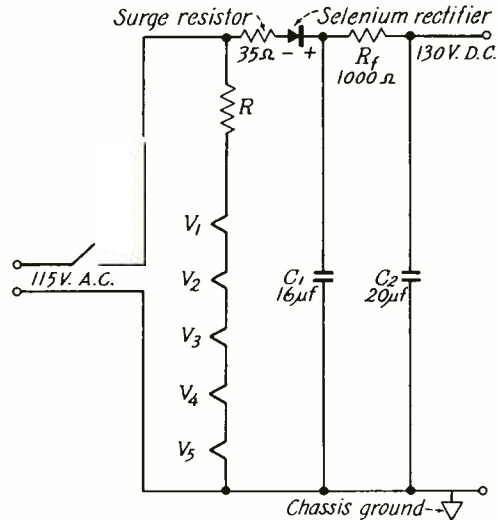
Fig. 10.—Typical power line plate supply.

normally used, since it replaces ordinarily a half-wave rectifier tube. The heaters of the amplifier tubes V_1 to V_5 are connected, in series with a dropping resistor R, across the a-c line. The rectifier is followed by an elementary filter composed of two capacitors C_1 and C_2 and a series resistor R_f. The values indicated on the diagram are representative, and refer to a current drain of perhaps 20 ma or so. For greater current drains, C_1 and C_2 will be larger and R_f will be lower, in order to prevent excessive voltage drop and yet obtain adequate filtering action.

Of interest is the surge resistor shown. This may be on either side of the rectifier, but must be

ahead of the first filter capacitor C_1. Its function is to limit the initial inrush current through the rectifier into C_1, when the set is first turned on and C_1 is completely discharged. If it were not used, the heavy current that would otherwise flow might damage the rectifier in the manner described previously.

FILTER CIRCUITS.—The difference in the wave forms of Figs. 4(B) and 4(D), and between Figs. 6(C) and 6(E), is due to the filter inserted between the rectifier and the receiver. Since every receiver must have such a filter, the design for the three most common types will be discussed.

CHOKE INPUT.—The choke input type of filter, although not as often used in radio receivers as other types, has wide application in amplifier and modulator design with mercury-vapor rectifiers and any other application where the current drawn by the load is variable. Such a design is shown in Fig. 11 which is the Power Unit for a 20-watt public address system amplifier designed by U.T.C. for Class A 6L6's. This filter usually occurs in either one or two sections, shown schematically in Fig. 12. The characteristic feature is that it starts with a series inductance. The calculation of the amount of ripple attenuation per section is given by formula (1):

amplitude of ripple at input
amplitude of ripple at output

$$= \frac{1}{4\pi^2 \ f_r^2 \ LC - 1} \qquad (1)$$

Since this is the attenuation of the filter per section, it is evident that if a two-section filter is used, the ratio of the ripple voltages

then becomes:

amplitude of ripple at input
amplitude of ripple at output

$$= \frac{1}{(4\pi^2 \ f_r^2 \ LC - 1)^2}$$

The designer must be careful to choose the proper value of choke and capacitor in this type of filter, as series resonance may occur at the ripple frequency and raise the ripple voltage in the output to a very high value. It can be seen from the formulas that as the resonant frequency of L and C affects f_r, the ratio of the ripple voltages becomes infinite. This resonance takes place in the first choke and the first filter capacitor, and can be avoided by the use of the resonance formula,

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

The frequency, f, in this case, *should be far below the ripple frequency.* The use of these formulas can best be demonstrated by an example. Assume a 15-henry choke and a 4-μf capacitor are connected to a full-wave 60-cycle rectifier in a single-section filter. What is the series resonant frequency of the combination, and what is the amount of ripple in percent of the input ripple that gets through such a combination? An application of the resonance formula yields,

$$f = \frac{1}{2 \times 3.14 \ \sqrt{15 \times 4 \times 10^{-6}}}$$

$$= 20.6 \text{ c.p.s.}$$

which is far below the ripple frequency. The percentage of the in-

put ripple voltage that gets through
this filter can be determined from
Eq. (1) for a single section filter

$$L = \frac{\text{load in ohms}}{500}$$

*Power Unit for 20-Watt Public -
Address Amplifier designed by
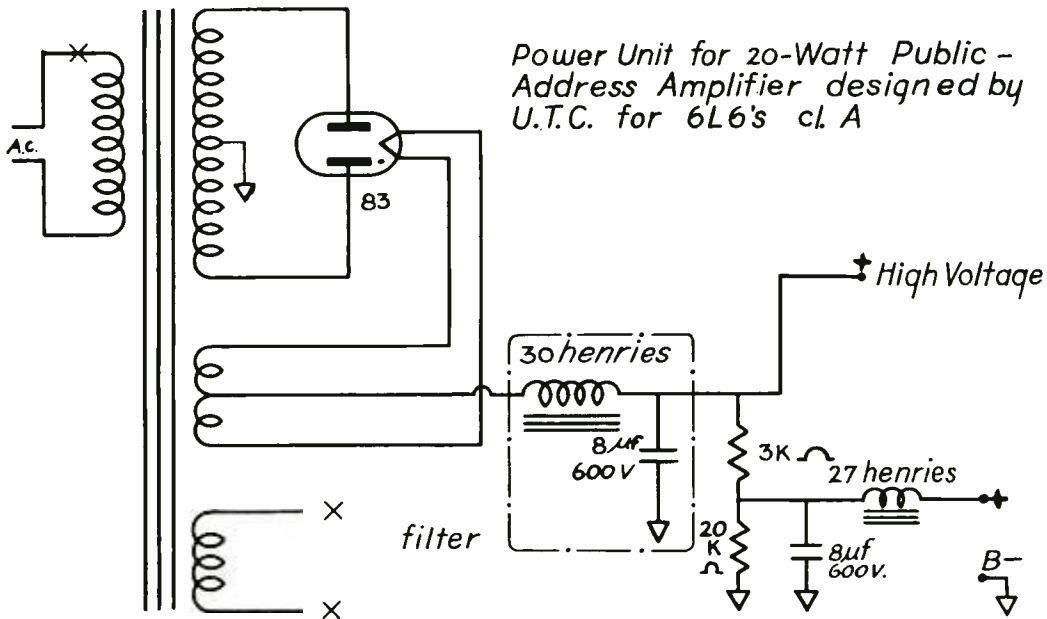U.T.C. for 6L6's cl. A*

Fig. 11.—The Power Unit for a 20-watt public address system amplifier
designed by the United Transformer Company for Class A 6L6's.

or

$$\frac{\text{ripple output}}{\text{ripple input}} = \frac{1}{4\pi^2 f_r^2 \, LC - 1} = \frac{1}{4 \times (3.14)^2 \times (120)^2 \times 15 \times 4 \times 10^{-6} - 1}$$

$$= 0.03 \text{ or } 3\%$$

The addition of another section
would yield $(.03)^2 = .0009$ or $9/100$
of 1%.

There is a value of inductance call-
ed the optimum value. An increase
in inductance beyond this value
gives no improvement in regulation,
although the ripple is lowered. The
optimum value, for a 120-cycle
ripple, is given approximately by

If the ripple frequency, f_r, is dif-
ferent from 120 cycles, then the
quotient, $120/f_r$, is multiplied by
the optimum value of inductance for
120 cycles. Hence, there exists an
optimum inductance for each value of
load resistance. In the case where
there is no load except the bleeder
on the power supply, the optimum in-
ductance required is very high; (how-
ever, much lower values of induct-
ance are satisfactory when the full-
load current is being delivered).

Since the inductance of a choke tends to rise as the direct current flowing through it is decreased, it is possible to effect an economy in

Fig. 13(B) illustrates the case where the *shunt capacitor* is tuned to *series resonance,* accomplishing the same result. The disadvantage
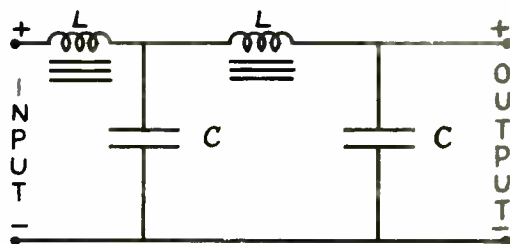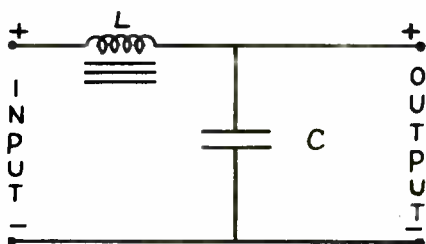

Fig. 12.—One-section and two-section filter.

materials by designing the choke to have a "swinging" characteristic, such that it has the required optimum inductance value with the bleeder load only, and about the optimum inductance at full-load. This type of filter gives almost perfect regulation. The power supply approaches a capacitor input power supply at high currents, for there the choke is of negligible inductance. A typical case would be one with a bleeder resistance of 20,000 ohms and the full-load resistance of 2,500 ohms; a choke which swings from 20 to 5 henries over the full output-current range would be satisfactory.

There are instances where tuning can be used to increase the attenuation of the ripple voltage. Thus, a filter choke can be tuned to the frequency of the ripple voltage, thereby greatly reducing the amplitude of the ripple at the output of the filter. This is shown in Fig. 13(A), where the *series inductance* is tuned to *parallel* resonance.

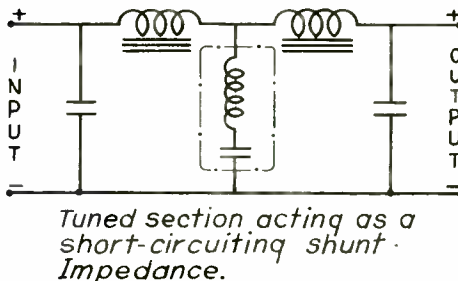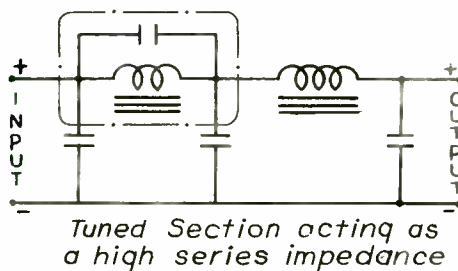of this method of filtering is the careful adjustment required of the

Tuned Section acting as a high series impedance

Tuned section acting as a short-circuiting shunt Impedance.

Fig. 13.—Use of tuned filter section for increased attenuation of ripple voltage.

constants to get effective attenua-
tion at the *fundamental* ripple fre-
quency. (The higher frequency
ripple components are effectively
attenuated even by an ordinary fil-
ter section). Since most iron-core
inductances vary markedly from one
to another in quantity production,
and since the inductance of any one
choke varies appreciably with the
current through it, this type of
filter is not generally employed in
large-scale production.

THE CAPACITOR INPUT FILTER.—
The capacitor input filter shown in
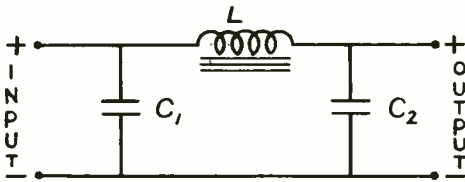Fig. 14 is probably the most often

Fig. 14.—Capacitor input filter.

used filter for ordinary a-c sup-
plies, and is characterized by a
shunt capacitor directly following
the rectifier tube. It is designed
to be used in conjunction with high
vacuum rectifiers, as mercury vapor
rectifiers have a nearly constant
resistance, and the large currents
needed to charge the input capacitor
puts a large IR drop across the tube,
thus accelerating the mercury ions.
These large, fast-moving ions strike
the cathode with such energy that
their impact causes disintegration of
the cathode. It is also true that
manufacturers set a maximum value for

the capacity of the input capacitor,
usually 40 μf, even in the case of a
high vacuum rectifier. This does
not mean that the rectifier itself
will be damaged by the large currents
needed to charge the input capacitor,
but that in the construction of the
tube the manufacturer has incorpor-
ated fuses in the cathode circuit
that blow when the large current is
drawn. These fuses are inserted to
protect the power line should there
be a short in the receiver power
supply. The designer must be care-
ful when these particular rectifier
tubes are chosen not to exceed the
manufacturer's recommendation.

This type of filter gives the
maximum voltage to the load for the
least amount of ripple, but it re-
quires a capacitor of higher voltage
rating than the supply voltage to
withstand the voltage peaks that
occur. For example, if a power sup-
ply is to deliver 400 volts d.c. to
the load, then the capacitor at the
input has to have a working voltage
rating greater than 535 volts or it
will break down on the peak voltages.
This is often the cause of trouble
in supplies using filters of this
type.

There is no simple formula for
the ripple voltage present as a
function of the circuit constants
used in Fig. 14, but it decreases
with increasing magnitudes of L, C,
and R. Fig. 15 is a graph of the
percentage of the d-c voltage
supplied; that is, ripple voltage
versus capacity. This graph is for
a 60-cycle line frequency and the
several curves are for different
load resistances. For example,
when the load resistance is 2,000
ohms and the input capacity is 10 μf,
the 120-cycle ripple is 8% of the
output voltage.

SPECIAL HIGH-VOLTAGE SUPPLIES

SIXTY-CYCLE POWER SUPPLIES.—
In the modern broadcast receiver the
problem of high voltage insulation
is not of any particular consequence.
With the advent of television,
radar, etc., the problem of high
voltage insulation becomes very seri-
ous as some of the circuits in these
applications use extremely high po-
tentials. The problem is aggravated
further by the requirement that the
units be small, thus limiting the
size of the power supply. Further-
more, it is necessary that the in-
sulation be as nearly "foolproof" as
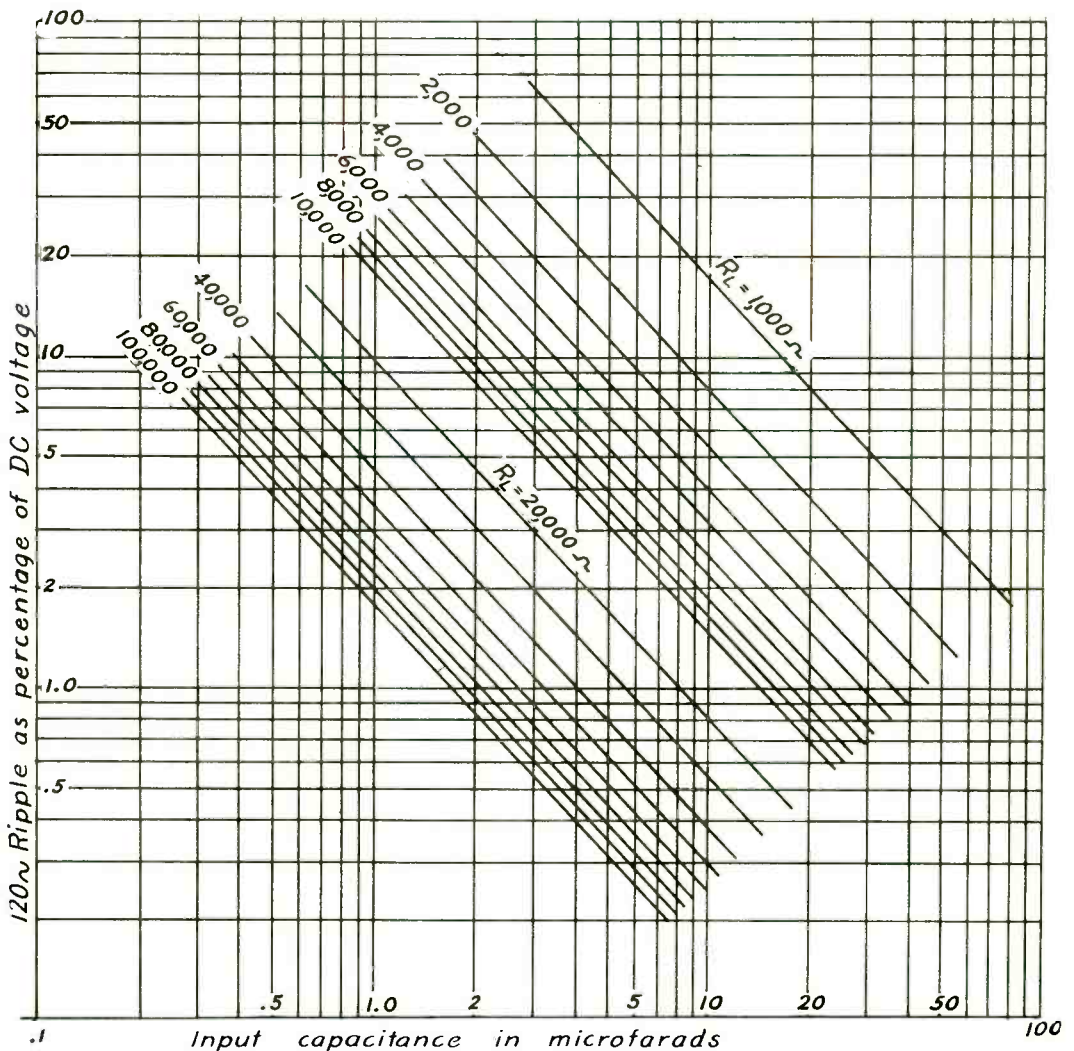possible, as the contact with volt-

Fig. 15.—Ripple voltage versus capacity.

ages of these magnitudes is often fatal. Danger of accidental contact is minimized by the manufacturer by the use of bleeders, shorting bars, and interlocks in the high voltage system. In addition, notices are sent with the equipment as well as signs on the equipment itself telling of the danger.

The insulation in the power transformer itself is the biggest problem, and manufacturers have designed such transformers with a considerable margin of safety. Even though care is taken in the design to see that there is an adequate safety factor in the supply, one will notice after a long time in service, with extremes of temperature and humidity, that much of the insulation has leakage paths for the high voltage. This is particularly prominent in a material such as bakelite, which is used in terminal strips in many supplies. The bakelite may show, in time, fine lines carbonized between the positive and negative terminals, and such current paths load the supply more and more while it is in service until complete breakdown occurs.

FILTERS.—The filter design for the special high voltage supplies is the same as for the lower voltage supplies when inductance-capacity filters are used. It is rare, however, that an inductance is used in a high-voltage filter unless there is a considerable current being drawn because, as was shown previously, the inductance necessary for proper filtering and regulation varies directly with the load impedance, and at low-current drain the load impedance, and hence the inductance, is necessarily high.

R-C FILTERS.—The filter most often used in high voltage, low-cur-

rent drain supplies, is the R-C type of filter. This is a low-pass filter in that its attenuation increases rapidly at the higher frequencies. The design of such a filter is rather simple, and the voltage drop is small due to the small current requirement of the load. The relation for the ratio of output ripple to input ripple for the circuit shown in Fig. 16 is given
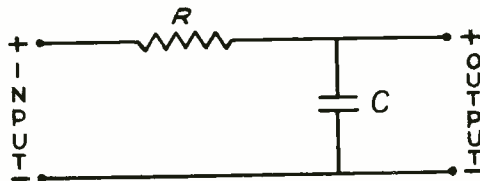
Fig. 16.—R-C filter system.

approximately by Eq. (2)

$$E_{out} \simeq \frac{E_{in}}{\omega CR} = \frac{E_{in}}{6.28 \times f_r CR} \quad (2)$$

where C = capacity in farads,
       R = resistance in ohms,
and f_r = ripple frequency in c.p.s.

Fig. 15 represents the ripple reduction from the use of a single capacitor across the power supply as a filter. The output ripple from this circuit acts as the input ripple to a filter, such as shown in Fig. 16, in the combined circuit of Fig. 17. In a solution the first step is to determine the output ripple across the 50 μf input filter capacitor. The percentage of the total voltage that the ripple represents is found in Fig. 15. Since the load is 120/.061 = 2000 Ω and the input capacitor is 50 μf, the ripple is found to be 1.5 percent for a full-wave rectifier reading directly from the curves. For a half-wave rectifier the ripple fre-

quency is halved and we use a capacitor value in the curves of $(60/120)50 = 25$ µf. This gives a value of 3 percent ripple which is the input ripple to the R-C filter. The ripple output is

$$E_{out} = \frac{E_{input}}{\omega CR}$$

$$\frac{3\%}{2 \times 3.14 \times 60 \times 30 \times 10^{-6} \times 1200}$$

$$= .225\%$$

where $C = 30$ µf
and $R = 1,200$ ohms.

These filters are used almost exclusively in the radio-frequency

BLEEDER RESISTANCES.—In high-voltage power units a bleeder is often necessary for one of the following reasons:

1. When the load is small, the bleeder will act as a steadying influence on the voltage helping to keep it constant should the load change slightly.

2. It prevents the voltage from surging to too high a value should the load be taken off; thus protecting the capacitors and insulation.

3. It protects the repairman by providing a means for the capacitors to discharge.

The design of bleeders is simply
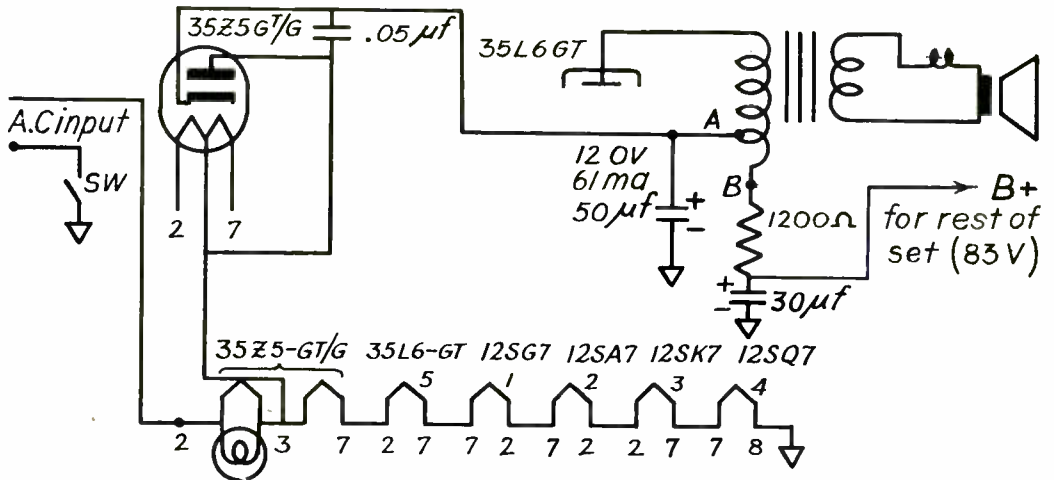
Fig. 17.—Power supply for RCA Victor 56X11 Receiver.

power supplies, discussed in a subsequent section, as their load current is small and their ripple frequency is high. They are also used in many transformerless supplies; for example, the RCA Victor Receiver whose power unit is shown in Fig. 17. A further use is for the decoupling of individual amplifier stages; this will be discussed in subsequent technical assignments.

an Ohm's law calculation with attention paid to the limitations of the power supply in power output, regulation, and the dissipation of the bleeder itself. This has been covered in an earlier assignment.

There is one important reservation that one must make in the design of bleeders for high voltage systems, and that is not to have the potential difference across any one

resistor higher than that recommend-
ed by the manufacturer. For example:
the manufacturer recommends a maxi-
mum of 1,000 volts on a particular
1-watt size resistor. If that maxi-
mum were not considered in design-
ing a bleeder using 2-megohm re-
sistors, enough voltage could be im-
pressed across each resistor to
equal one watt, or since

$$P = \frac{E^2}{R} = 1 = \frac{E^2}{2 \times 10^6}$$

from which

$$E = 1,414 \text{ volts}$$

Thus, the bleeder would break down
in service due to this excessively
high potential across the resistors.
So in high-voltage design two re-
quirements must be met: that of
dissipation and that of potential
difference in resistors. For very
high resistors the only significance
the wattage rating has is to indi-
cate the physical size.

One often encounters several
half-watt resistors in series as the
bleeder on a high-voltage supply.
This conforms to the manufacturer's
rating of *potential difference,* and
as a safety device. This latter
function is evident when there are
several resistors in series and one
of the resistors breaks down. The
voltage is then equally distributed
between the remaining resistors,
causing but a moderate rise in po-
tential for each of the resistors.

For example, if 4,000 volts are
to be measured by a voltmeter re-
quiring 0.5 ma for full-scale de-
flection, then a series resistance
of 4,000/.0005 = 8 megohms is re-
quired. The power consumed is
4,000 × .005 = 2 watts. Suppose 2

four-megohm, one-watt resistors in
series are employed. Then the pow-
er dissipated per resistor is 2/2 =
1 watt, which is within the power
rating. But the voltage drop per
resistor is 4,000/2 = 2,000 volts,
which exceeds the voltage rating of
1,000 volts. Hence, 8 one-megohm
resistors should be used in series,
in which case 500 volts will appear
across each resistor, and this is
well within the voltage rating.*

In the case of the 2 four-
megohm resistors, if one broke down,
then 4,000 volts would appear across
one resistor, and it would break
down and probably ruin the meter
movement before the fuse blew. On
the other hand, where 8 one-megohm
resistors are employed, if one broke
down, the voltage across each of the
other 7 would rise from 500 to
4,000/7 = 570 volts, and the volt-
age rating will still not be exceed-
ed. At the same time, the abnor-
mally high reading of the meter would
indicate that something was wrong
before any progressive breakdown
could take place and thereby ruin
the meter movement.

R-F POWER SUPPLIES.—The r-f
power supply is coming into wide-
spread use, as the requirements for
compactness, efficiency, economy,
and safety in television receivers
are most satisfactorily met by this
type of supply.

Its purpose is to generate
high-voltage, low-current r-f power
from a low voltage d-c source, and
to rectify this high-level r-f
voltage so it can be applied to cir-
cuits where high voltage and low

*The figure of 1,000 volts is
given by the manufacturer for the
sizes BT-1/2, BT-1, and BT-2 re-
sistors.

current are required. This has
several distinct advantages. One of
these advantages is the obvious pro-
tection of personnel: if a person's
body comes in contact with the high
voltage, he immediately loads the
circuit to such an extent that the
voltage falls to a very low and safe
value. This also obviates the dan-
ger of fire in the case of insula-
tion breakdown. Another advantage
is that there are no large filter
capacitors required in the filter,
since the ripple frequency is many
times that of the 60-cycle trans-
former-rectifier power supply.

The insulation problem is mini-
mized by being able to use air to
insulate the high-voltage step-up
transformer employed. This latter
feature makes it simpler to meet the
Underwriter's requirements. A pow-
er unit of this type is very compact
and takes up less room than the
transformer type. The cost of the
radio-frequency power supply is be-
low that of the transformer type
since it uses less expensive com-
ponents in rectifying and filtering.

The theory of operation of such
units can best be understood by re-
ferring to Fig. 18(A) which is the
power supply recommended by RCA for
the 1850-A Iconoscope. This unit
delivers 1,200 volts, but there are
units that are very similar to that
shown in Fig. 18(A) that deliver
30 kilovolts and higher for tele-
vision picture tubes. The radio-
frequency oscillator is a 6V6 beam
power tube using tickler coil feed-
back and operating at 300 volts d.c.
The primary coil P, has a very high
"Q" and hence generates a very high
r-f voltage. There is a further
step-up transformer action between
this primary coil, P, and the second-
ary coil, S. This high voltage

across coil S is rectified by the
8016 rectifier. Note that this
rectifier has its filament circuit
at ground potential, this allowing
the use of a low-voltage insulation

(A)

(B)
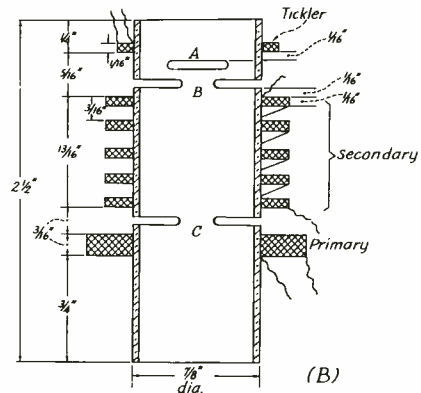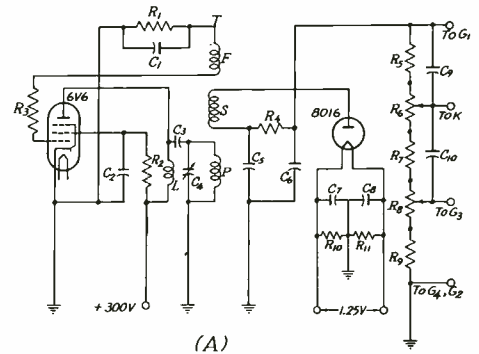
Fig. 18.—R-F power supply and coil
design for RCA Iconoscope.

filament transformer. The various
voltages for the electrodes of the
iconoscope are furnished by the
bleeder formed by resistors R_5
through R_9. C_4 is the tuning capa-
citor of the oscillator and serves
as a voltage control. If all three
transformer windings are wound in

the same direction and connected as shown in Fig. 18(A), an increase of C_4 past the point of maximum voltage yields the best regulation. The material and method for winding the coils used in the supply are shown in Fig. 18(B), which shows the simplicity, small size, and insulation of the high-voltage circuit. The overall efficiency of these units is 50 per cent when operating at a frequency around 200 kilocycles. Notice that the ripple frequency is also 200 kc as half-wave rectification is employed. The filter is made up of R_4, C_5, and C_6, which is a low-pass filter using a 0.2-megohm resistor and 0.01-μf capacitors.

This type of power supply presents certain disadvantages of adjustment and repair. The coils in the r-f circuit are necessarily of very high Q and the replacement of the coils or of parts near the coils must be made in such a manner as to preserve the original Q of the circuit, or the unit will not yield the correct voltages. It is also difficult for the serviceman to check the voltage in any part of the high-voltage circuit, as most commercial voltmeters load the circuit so that the indicated reading is not the true operating voltage. A very high impedance voltmeter is therefore necessary.

When such a voltmeter is not available some engineers use the unknown voltage to supply accelerating potential to a cathode-ray tube. A *known* a-c voltage is applied to the deflecting plates and the deflection sensitivity of the cathode-ray tube measured. This is found by dividing the length of the line of deflection by the peak-to-peak value of the deflection voltage, thus obtaining so many millimeters per volt. The

sensitivity of the tube is inversely proportional to the accelerating voltage, and hence the unknown voltage can be obtained from a table that is supplied with the type of cathode-ray tube used. Alternatively, the cathode-ray tube can be calibrated on a good r-f power supply and then used to test other such supplies.

TRANSFORMERLESS POWER SUPPLIES

The transformerless power supply is the most practical and economical power unit for the small or "midget" receiver. This unit is small in size and requires only a tube and filter. Tube manufacturers have designed special tubes for this purpose, thereby decreasing the size and cost of the small receiver considerably. The receiver operates at voltages in the order of magnitude of the line voltage, hence, the rectification can be simple half-wave. The ripple voltage has a lower frequency than the ordinary full-wave rectifier, but the filter can remove this ripple satisfactorily with large-capacity filter capacitors that are small in size and inexpensive.

Good voltage regulation is unnecessary, as the current drain of such a receiver is reasonably constant (Class A operation throughout), and, furthermore, of small magnitude, so that the rectifier system can be small. These features combined with the special design of circuits and tubes for this service have made the midget receiver the most popular radio on the market.

HALF-WAVE.—This rectifier is the same as the half-wave rectifier discussed earlier in this assignment.

A typical application is shown in Fig. 17, which is the schematic diagram of the power supply for the RCA Victor 56X11 Receiver. The 35Z5 GT/G is the half-wave rectifier. The 50-μf and 30-μf electrolytic capacitors are the filter capacitors; the 30-μf one is used in a low-pass filter with the 1,200-ohm resistor. The highest voltage is at the 50-μf capacitor and is applied to the 35L6 GT power output tube. The current for the rest of the receiver is drawn through a section, AB, of the output transformer, T_1. This introduces some ripple voltage across AB as the voltage has not been filtered by the R-C network consisting of the 1,200-ohm resistor and the

troduced by the output tube's supply voltage, and hence it can be eliminated with an adjustment by the manufacturer of the section AB of the transformer, T_1, considered as a hum-bucking winding.

The R-C filter offers very good filtering to the low-level stages, and the receiver has negligible hum appearing in the voice coil. The function of the 0.05-μf capacitor across the rectifier is to eliminate r-f interference, as it serves as a short circuit to the r.f. by having a low-impedance path back to the other side of the power line through the 50-μf capacitor. This capacitor could be put across the power line, but it is easier to mount (mechani-
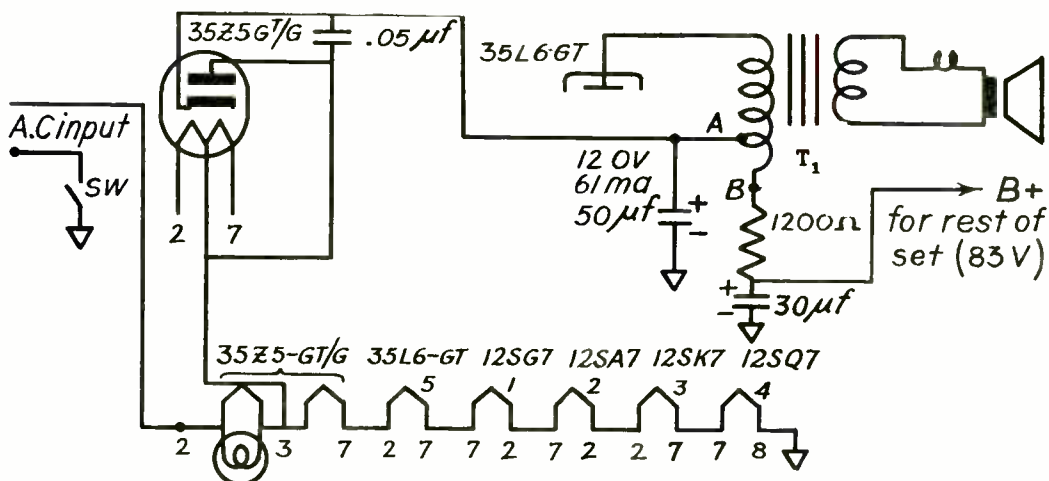

Fig. 17.—Power supply for RCA Victor 56X11 Receiver.

30-μf capacitor. Since the amplifier is a pentode and its plate current does not change with small changes in plate voltage, this amount of ripple present does not affect the operation of the amplifier. But if there is any ripple present in T_1, due to ripple appearing at the grid of the amplifier tube, it will be in phase opposition to that ripple in-

cally) in the set in the position shown.

This type of rectifier, though usually trouble-free due to its simplicity, has the disadvantage of needing a more elaborate filter due to the lower ripple frequency.

DOUBLER CIRCUITS.—This rectifier circuit gets its name from the fact that its output voltage ap-

proaches twice the peak value of the line voltage. A typical circuit is shown in Fig. 19. This is the recti-

the peak value of the positive swing of side A with respect to the other side of the line.   This is, in ef-
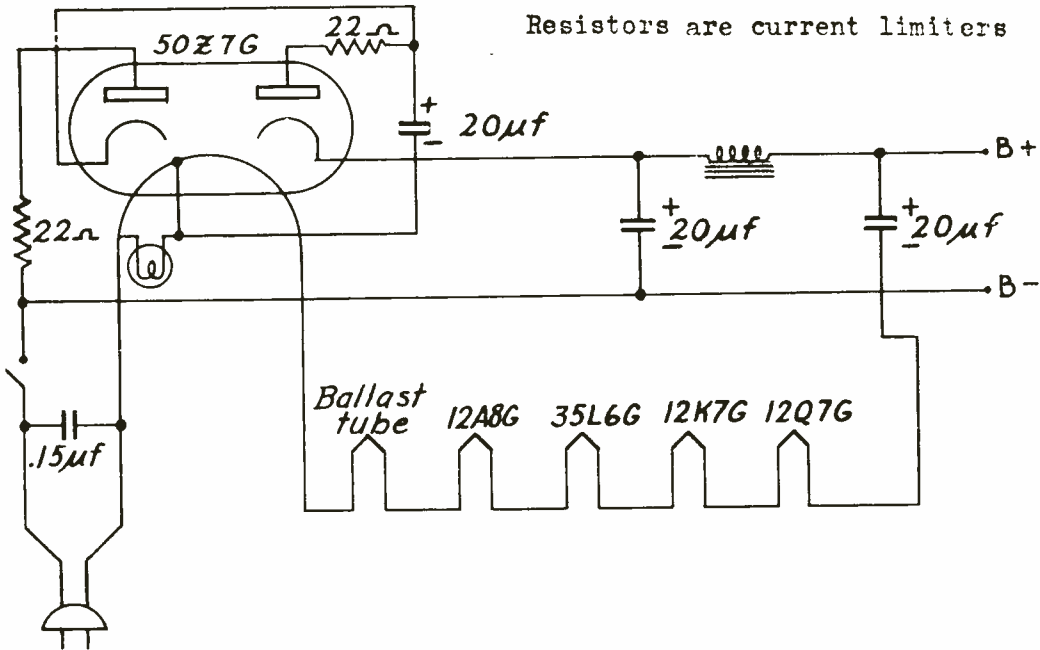
Resistors are current limiters

Fig. 19.—Rectifier unit for the Zenith Model 6P416 Home Receiver.

fier unit for the Zenith Model 6P416 Home Receiver. A simplified version of the rectifier is shown in Fig. 20 for ease of understanding. It operates in the following manner:

When side A of the power line is negative, with respect to the other side of the line, capacitor C_1 charges through diode D_1. On the other half-cycle, when side A is positive (with respect to the other side of the line), capacitor C_1 has the now positive potential of the line inserted in series with its voltage. It therefore causes diode D_2 to conduct, and charges input filter capacitor C_f to a voltage made up of the sum of: the voltage on C_1 (when side A is negative), and

fect, charging a capacitor, C_1, on one half-cycle, and on the other half-cycle putting this capacitor's voltage in series with the supply line to charge the filter capacitor, C_f. This is half-wave rectification, of course, as the load gets current from the rectifier only every other half-cycle.

This rectifier has the advantage over other types of doubler circuits in that one side of the power line can be grounded. Its regulation is not as good as the full-wave voltage doubler to be described subsequently, but it is often used for the advantage stated.

FULL-WAVE VOLTAGE DOUBLER.—The circuit, although it has much ap-

plication other than for small power units, is only occasionally encountered in broadcast receivers.
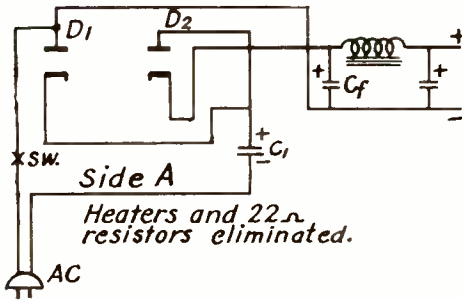

Fig. 20.—Simplified version of Fig. 19, Zenith Model 6P416 Home Receiver.

The basic circuit is illustrated in Fig. 21. Its operation is such that on positive voltage swings of side A, diode D_1 conducts and charges C_1. On negative voltage swings diode D_2 conducts and charges C_2. The voltages on the capacitors of the polarity shown are in series with re-
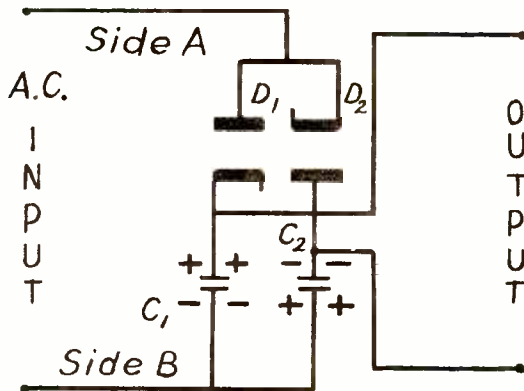

Fig. 21.—Full-wave voltage doubler.

spect to the load connected to them and less than *twice* the peak value of the a-c input. At the same time full-wave rectification is obtained,

since current is delivered to the load every half-cycle.

This doubler is seldom used for the following distinct disadvantages: As seen from Fig. 21, the d-c load circuits cannot be connected to an external ground or to one side of the a-c line. This operation above ground may cause hum in the receiver. This hum is introduced in the low-level stages due to the leakage resistance between heater and cathode of the vacuum tubes. Referring to Fig. 22(A) it is evident that if there is a leakage resistance R_L in tube 1, the equivalent of this circuit from a hum consideration can be represented by Fig. 22(B). This circuit shows how the ripple voltage e_r that appears across the filter capacitor, C_f, is introduced by this leakage resistance, R_{L_1}. If the impedance of R_{e_1} and C_{b_1} is a sizable fraction of R_{L_1}, tube 1 will be cathode modulated at the ripple frequency which is the frequency of the line. (Note that even though this is a full-wave rectifier, with respect to the load, and the load ripple is twice the line frequency, this filter capacitor, C_f, receives its charge at the frequency of the line, and hence its own ripple voltage *is at the line frequency*.) The cathode bypass capacitor usually is of low enough impedance to make the a-c voltage on the cathode of negligible level. But now if tube 2 is considered, the equivalent circuit of tube 2 becomes modified from that of tube 1 and is shown in Fig. 22(C). It is evident that the cathode of tube 2 now has the heater voltage of tube 1 added in series with the ripple voltage on the filter capacitor. This causes the cathode of tube 2 to have an a-c voltage on it greater than that of tube 1, and, in

a similar manner, there is an increase in the a-c voltage that is impressed on the cathodes of the tubes, as the positions of the tubes approach the rectifier.

Design engineers realize this

regulation of such rectifiers?" Fig. 23 is a graph of the output voltage of a half-wave rectifier and a voltage-doubler rectifier using typical tubes (25Z5's) and the usual values of filter capacitors (16 μf).
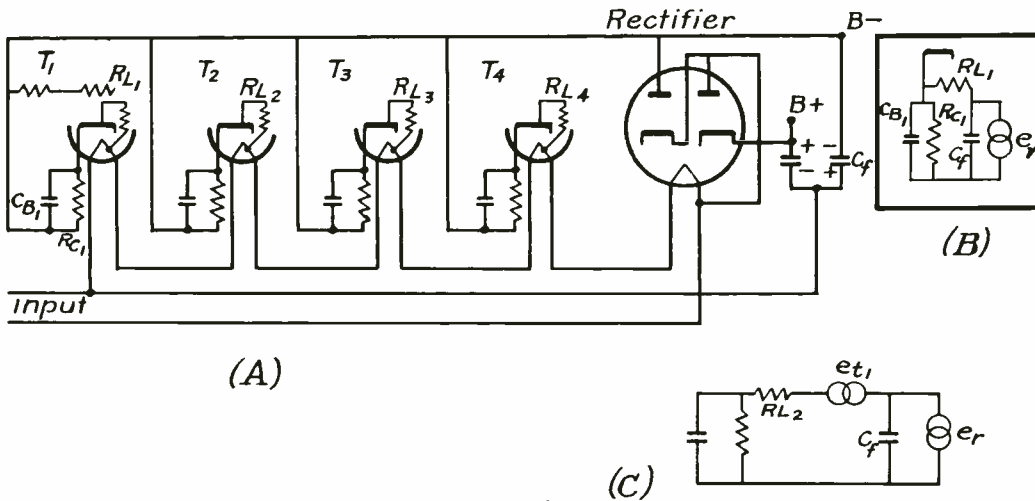

Fig. 22.—Full-wave voltage doubler heater connections.

and place the tubes most susceptible to hum nearest the side of the line that is connected to the junction of the two filter capacitors. The most satisfactory arrangement is to have the second detector-first audio stage in tube 1's position and to have the converter or i-f amplifier next (the former is preferable) with the tube nearest the rectifier being the output tube. This arrangement follows from a consideration of the signal voltage level at the grid; in general, the lower the level, the farthest from the rectifier must the tube's heater be.

As mentioned previously, the regulation of these transformerless supplies need not be good as the load is substantially constant (Class A operation). The question then arises, "Just how good is the

These curves were taken at a line frequency of 60 cycles. The reasons for the poor regulation are two: the
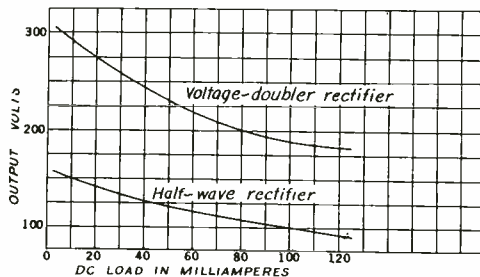

Fig. 23.—Graph of output voltage of a half-wave rectifier and a voltage doubler rectifier.

IR drop across the rectifier increases with load, allowing less of the rectifier voltage to appear across the load; and the filter capacitors have their charge removed at a higher rate with increasing load, leaving a lower average charge on the capacitors. This, combined with the higher charging resistors for the capacitors (i.e., that of higher rectifier resistance), leaves a lower average voltage on the capacitors.

REGULATED POWER SUPPLIES

GAS TUBE REGULATORS.—There is a frequent need for maintaining the voltage applied to a low-voltage, low-current circuit at a constant value. This can be done regardless of the regulation of the power supply, or (within certain limits) of variation of the load current, by using the gaseous tube type of regulator. Such tubes are the VR90/30, VR105/30, VR150/30, etc.; they have a constant drop over a moderately wide current range.

The basic circuit is shown in Fig. 24. The tube is connected in series with a limiting resistor, R, across a source of voltage, which must be higher than the voltage required for ionization of the gas in the tube. This starting voltage is about 30 per cent higher than the operating voltage. The load is connected in parallel with the tube, and for stable operation a minimum tube current of 5 to 10 ma is required. The maximum permissible current with most types is 30 ma; consequently, the load current cannot exceed 20 to 25 ma if the voltage is to be stabilized over a range from zero to maximum load current.

The value of the limiting resistor must lie between that which just permits minimum tube current to flow and that which just passes the maximum permissible tube current when there is no load current. The latter value is generally used to
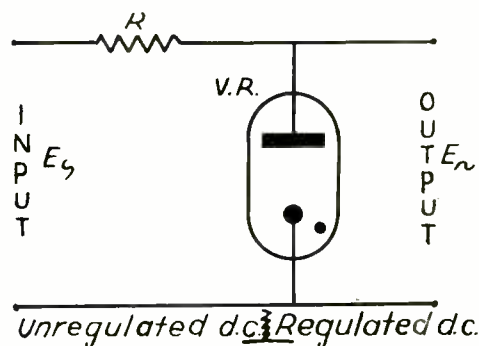

Fig. 24.—Gas tube voltage regulator.

determine the value of the limiting resistor and is given by the equation,

$$R = \frac{1000(E_s - E_r)}{I}$$

where R is the limiting resistance in ohms; E_s is the voltage of the source across which the tube and resistor are connected; E_r is the *rated* voltage drop across the regulator tube; and I is the maximum tube current in milliamperes.

Assume that 90 volts d.c. at a maximum drain of 22 ma is the desired regulated output to be obtained from an unregulated d-c source of 120 volts. The regulator tube can be the VR90/30. Substituting in the formula

$$R = \frac{1000(E_s - E_r)}{I} = \frac{1000(120 - 90)}{30}$$

= 1,000 ohms

Two tubes may be used in series to give a higher regulated voltage than is obtainable with one tube or to give two values of regulated voltage. This is shown in Fig. 25.
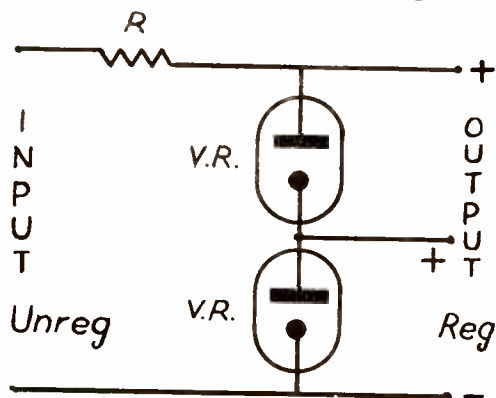

Fig. 25.—Two gas tube voltage regulators.

The limiting resistor may be calculated as above, using the sum of the voltage drops across the two tubes for E_r. Since the upper tube must carry more current than the lower tube, the load connected to the low-voltage tap must take a smaller current. The total current taken by the loads on both the high and low taps should not exceed 20 to 25 ma.

For example, assume a voltage source of 400 volts, and it is desired to have a regulated voltage of 300 volts at 20 ma. It is necessary to have two VR150/30's in series. Substituting in the formula for the value of the limiting resistor,

$$R = \frac{1000(E_s - E_r)}{I} = \frac{1000(400 - 300)}{30}$$

= 3,333 ohms

Alternating-current voltage may also be regulated with gas tubes when connected as shown in Fig. 26.
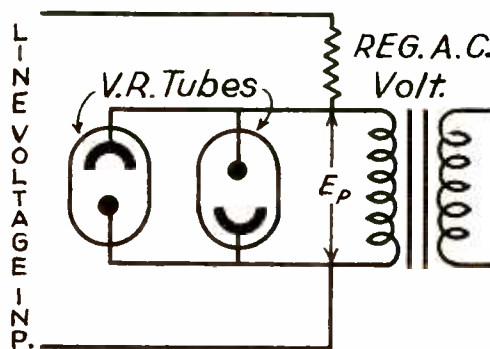
Fig. 26.—A-C voltage regulation with gas tubes.

This amounts to limiting the positive and negative swings on the line voltage. This can be seen from the wave-forms shown in Fig. 27. The
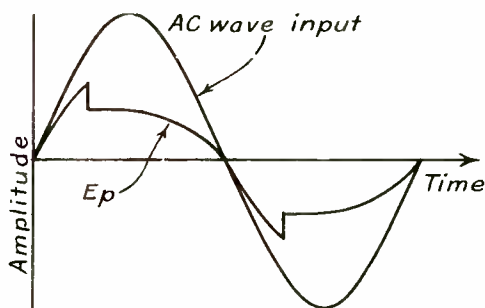

Fig. 27.—Wave-forms of d-c voltage regulator.

series resistance, R, is calculated in the same way as with the d-c analogue using the peak value of the a-c wave as E_s; i.e., for a line voltage of 110, the peak is 155 volts. If a VR105/30 is used, the load resistance is

$$R = \frac{1000(155 - 105)}{30}$$

$$= 1,667 \text{ ohms}$$

A gas tube regulator is used where the maximum drain is less than 25 ma. A typical d-c use would be that for the local oscillator in a superheterodyne receiver; another would be for a calibrated, variable-frequency oscillator used in a commercial radio transmitter; a third would be for obtaining constancy of calibration in a vacuum tube voltmeter. The regulation of such a tube is good to 1 per cent, and for many applications this is adequate.

ELECTRONIC VOLTAGE REGULA-TORS.—The electronic voltage regulator has found much favor in applications where the output voltage has to be kept constant over a very wide current range such as under variable load conditions. The fact that the output potential tends to be independent of the load placed on the system causes the output to act as though it had a very low internal impedance, and since the regulation can be made very good, this regulator has found considerable application in the fields of radio requiring high precision or very high amplification. A few of these applications would be: Radar and underwater-sound time measuring devices that have very finely calibrated timebases: the electron microscope; signal generators; the elimination of regeneration and motor-boating in multistage audio and particularly video amplifiers; and in the minimizing of coupling between different types of equipment operating from the same power supply.
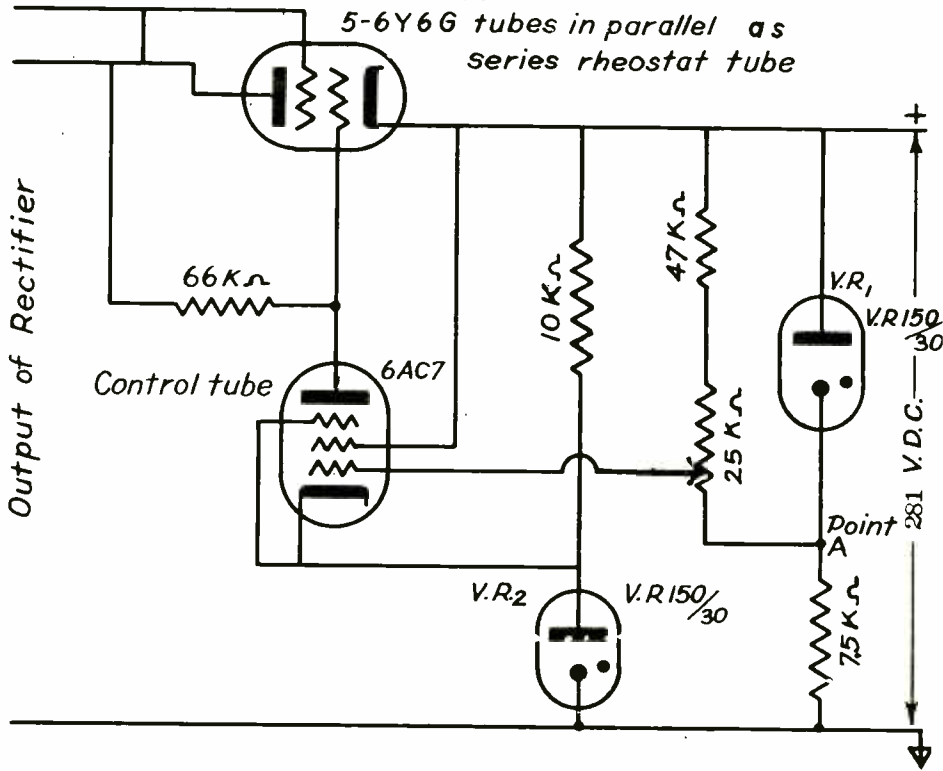
The electronic regulator can best be described by referring to Fig. 28. This circuit is the schematic of the RCA Voltage Regulator, Type 580-A. It contains five 6Y6's as series rheostat tubes that change their resistance as the voltage changes across the output. This resistance change is in a direction so as to restore the output voltage to its original value. The method of accomplishing this change in resistance in the series rheostat tubes is to have a control tube, in this case a 6AC7, take the change in output voltage, amplify it, and apply it to the grids of the series rheostat tubes as bias, thereby changing their resistance.

Assume the output voltage increased by one volt, which would be from the regulated value of 307 volts to 308 volts. Point A would move above ground by one volt more than it was previously. This is clear from the fact that as the gas tube, VR_1, keeps point A at a constant voltage below B plus, any change in the *total* voltage will equal the change in the voltage at point A with respect to ground. The grid of the control tube is either at point A or at a constant voltage from it, hence the grid of the control tube is raised above ground by the same amount the output voltage changed, namely, one volt. The cathode of the control tube is at a constant voltage *above ground* because of VR_2 and hence the one-volt change is impressed between the grid and cathode of the control tube. The one-volt increase in the grid voltage of the control tube causes this tube to draw more current. This current is supplied through the 66,000-ohm resistor in the plate circuit of the control tube. The increase in current causes the voltage at the control tube to decrease,

and since the plate of the control tube is connected to the grids of the series rheostat tubes, these

cathode of the control tube. This is owing to the fact that when the grid is returned to some point on

5-6Y6G tubes in parallel as series rheostat tube

Output of Rectifier

66Kᴧ

Control tube   6AC7

10Kᴧ

47Kᴧ

25Kᴧ

V.R₁

V.R150/30

281 V.D.C.

+

Point A

7.5Kᴧ

V.R₂   V.R150/30

(Courtesy RCA)

Fig. 28.—Simplified version of RCA Regulated Power Supply.

grids are then at a *lower potential* than before. As a result, the series resistance of these tubes *increases*, lowering the voltage at the output very close to the regulated value of 307 volts.

The 25,000-ohm potentiometer serves as a voltage control. Note the interesting result of placing the gas tube, VR₁, in the position shown. If it were left out entirely and an ordinary resistance voltage-divider used instead (as was done in many earlier designs), the entire output voltage change would not be impressed between the grid and the

the bleeder, then as the entire output changes by a certain percentage, every point on the bleeder changes by that same percentage. For instance, if the grid were half-way between the positive and negative terminals on the bleeder, then a change in the output voltage of one volt would produce a change of only a half volt at the grid of the control tube, thereby making the control less sensitive. When VR₁ is employed, the grid of the control tube varies with respect to its cathode by exactly the same amount as B+ varies with respect to B−; in

the above example, by 1 volt instead of 1/2 volt. Thus, greater control action is obtained.

Fig. 29 is the detailed schematic of the RCA Voltage Regulator,

oscillators with the resonant circuit being in the wiring and lead length in the tube itself. The capacitors across the gaseous regulator tubes are to short out any
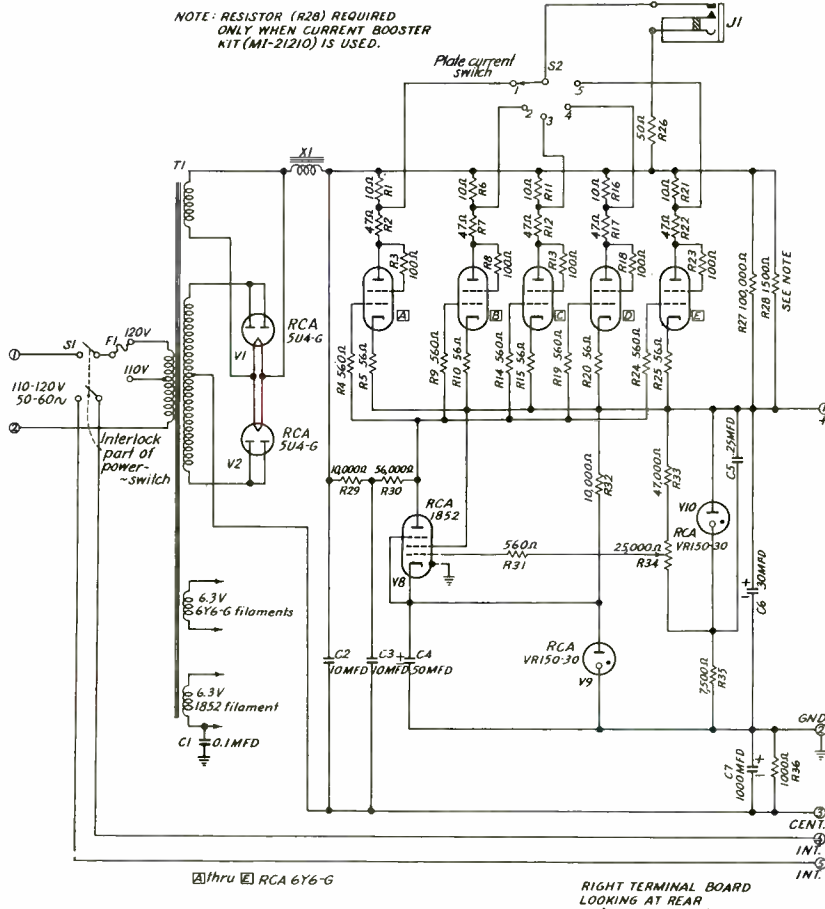
Fig. 29.—Detailed schematic of RCA Electronic Voltage Regulator.

Type 580-A. Several resistors and capacitors were left out of the simplified sketch, as they do not affect the basic theory of the regulator. For example, the series resistors in the grids and plates of the series rheostat tubes are called parasitic resistors and are there to prevent oscillations at high frequencies due to these tubes behaving as tuned-plate, tuned-grid

high-frequency oscillation building up in the gas tubes. This "fluttering" or motorboating can be observed in these tubes and can be eliminated in the above manner.

TRANSFORMER REGULATORS.—The constant-voltage transformer, as this type of regulator is often called, has a great deal of application where the a-c line voltage is to be kept constant. Examples

would be in precision radio and timing equipment, such as oscillators, multivibrators, and photo-electric devices. Some applications other than radio would be x-ray equipment, constant-speed motors, and temperature controlled devices.

It is possible to regulate over a range of 40-150 volts by suitable design of the transformer components. The design chosen is for line variations of plus or minus 15 per cent; or from 93.5 to 126.5 volts from a mean value of 110 volts. This allows more constant voltage output from the regulator than when it has to accomodate a wider range of line voltages.

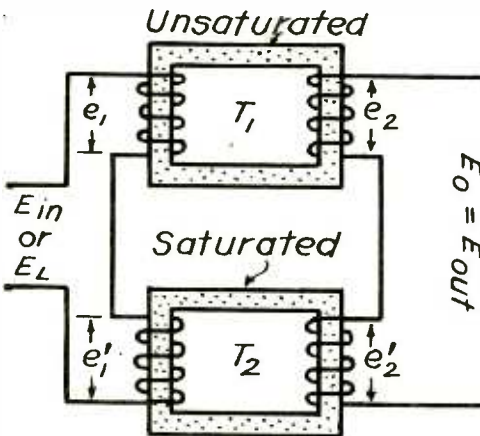The operation of such a regulator can best be understood by referring to Fig. 30. The line volt-

Fig. 30.—Transformer regulator.

age, E_L, is divided between the two windings, e_1 + e_1', which are wound on T_1 and T_2, respectively. T_1 is *unsaturated* over the range of line voltage for which regulation is expected; T_2, on the other hand, is *saturated* over this range. The line voltage is distributed across the two windings in proportion to their

reactances. This means that as the line voltage is increased from a low value, where neither transformer is saturated, there is a *proportional increase* in the voltage across *each* of the windings.

When saturation is reached, however, the voltage distribution across the two windings is no longer *in the same ratio*. The graphs of line voltage versus primary voltage are no longer straight lines as formerly, but the primary voltage (and the secondary also) of the unsaturated transformer is now concave upwards as shown in Fig. 31.
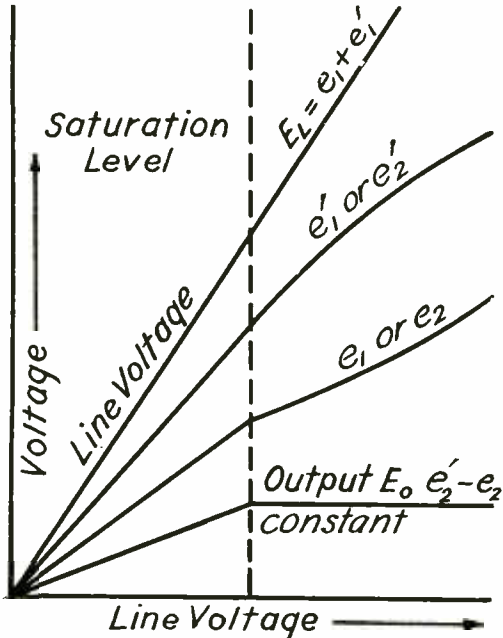

Fig. 31.—Voltage relations for schematic shown in Fig. 30.

The primary voltage (and the secondary also) of the saturated transformer is not concave downward as shown in Fig. 31. This is because the saturated transformer, whose reactance is now decreasing, takes a smaller and smaller proportion of the line voltage; the unsaturated

transformer consequently takes a greater and greater proportion. The *secondaries* of both the saturated and unsaturated transformers are connected in series, but in *phase opposition*, and the number of turns on each winding has been so chosen that the voltage difference between the saturated and unsaturated transformer secondaries is *a constant over the saturated range of line voltage.*

Fig. 32 shows a different design using the same principle. This is the schematic of an often-used commercial regulator known as the
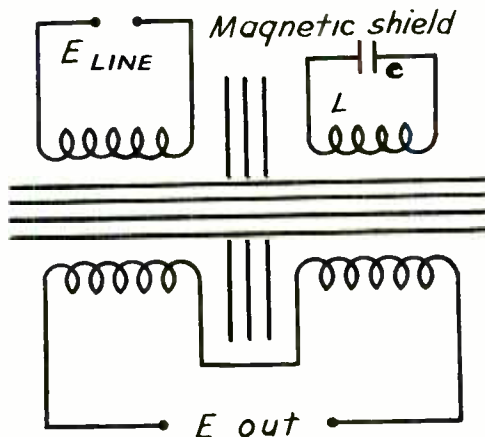

Fig. 32.—Sola Constant-Voltage Transformer.

Sola Constant-Voltage Transformer. It uses a circuit (L and C in Fig. 32) which is resonant at the line frequency to improve the wave-form of the output voltage. The regulation is within one per cent at constant *line frequency*. Its operation is such that *at constant line voltage* the output voltage changes 1.9 per cent for every one per cent *line frequency change*, making it less useful in installations where the line frequency is not constant.

VIBRATOR SUPPLIES

The improvements in circuit and tube design have made radio reception possible in such places as automobiles, airplanes, and boats. These circuits need power to run them, and one of the devices used in power units for portable operation is the vibrator. This unit changes low-voltage d.c. into high-voltage a.c. or d.c. with reasonable efficiency by essentially a switching action.

The vibrators used in such applications are either of two types:

1. Non-synchronous vibrators.
2. Synchronous vibrators.

NON-SYNCHRONOUS VIBRATORS.— This vibrator uses a rectifier tube to rectify the generated high voltage a.c. This high voltage is obtained by transformer action from an "alternating" d-c voltage of low amplitude. A simplified version is shown in Fig. 33.
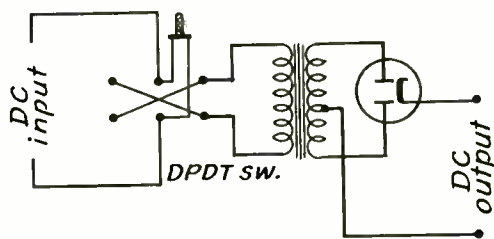

Fig. 33.—Simplified non-synchronous vibrator supply.

As the DPDT switch is thrown

back and forth, the direction of the current flow changes in the coil. This alternating current induces a high a-c voltage in the secondary coil, and this voltage is rectified by the rectifier.

One can accomplish the same result with an SPST switch by center tapping the coil and applying the voltage first to one side of the primary and then to the other side. This can be made automatic by using a magnetically driven reed arranged in conjunction with the center-tapped primary as shown in Fig. 34. Its operation is the same as that of Fig. 33. The coil is shunted across the contacts, and as voltage is applied to the vibrator, the coil is energized, pulling the reed, r, toward the magnet, m, and away from
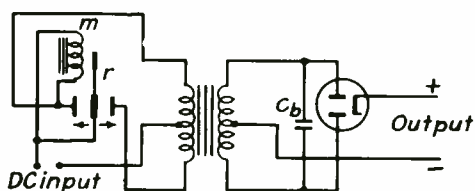

Fig. 34.—Vibrator power supply.

the center or normal position. As the reed approaches the magnet, the contact points short the coil, destroying the magnetic force, and the reed then returns past its center or normal position, owing to its inertia, and makes contact with the opposite contact point. The magnet coil could be mounted in series instead of shunt, and since this accomplishes the same result, it is

often employed. Most reeds are designed to have a switching frequency of 115 cycles per second.

C_b is called a buffer capacitor, as it is required to protect the circuit during the time the reed is moving from one set of contacts to the other, or, in other words, in the dead time. If no capacity were used, then when the contacts opened, not only would the battery voltage present at the contacts need to be broken, but an exceedingly high voltage of the same polarity would be induced in the transformer primary and secondary because of the sudden interruption of the current in the coil. This would cause severe arcing and failure of the vibrator unless some other component suffered voltage breakdown first. By connecting a capacitor across either of the windings of the transformer and adjusting the capacity to a predetermined value, the current flow from the secondary winding into the capacitor maintains the flux linkages set up by the primary until the contacts have separated sufficiently to prevent the possibility of the spark being established across the gap. Moreover, the dead time of the primary voltage is then filled in as the capacitor has become a tank in which energy is stored during the "on contact" intervals and which discharges into the transformer winding during the "off contact" intervals to supply energy to the transformer. This discharge is in the form of a damped oscillation in the circuit formed by the transformer winding inductance and the buffer capacitor; however, the first one-half cycle is never completed before the next pair of contacts close.

SYNCHRONOUS VIBRATORS.—This

type of vibrator is the self-recti-
fying vibrator. It is similar to
the non-synchronous type, except
that it does not use a rectifier
tube; instead it has an additional
set of contacts added to the reed
to rectify the a.c. A simplified
form of the circuit is shown in Fig.
35. It is clear that as the a.c. is

prevent radio interference (hash)
and mechanical noise. It also en-
ables the device to operate in rari-
fied atmospheres without brush dis-
charge, etc., such as in aviation
work.

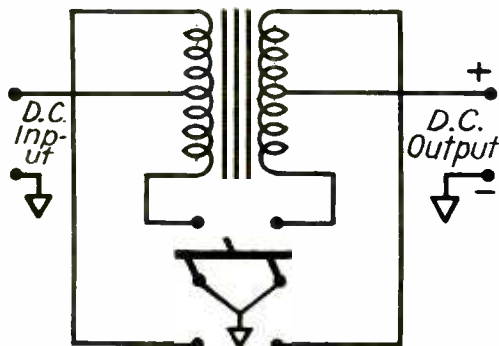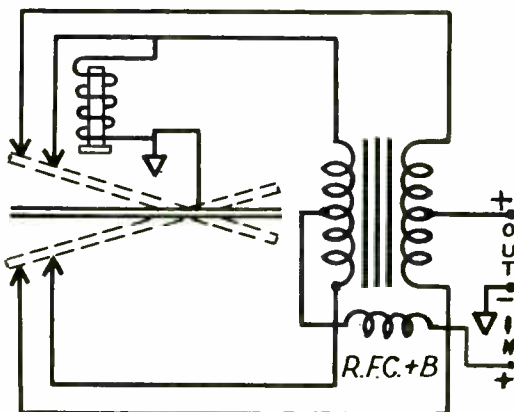Fig. 36.—Synchronous vibrator pow-
er supply.

Fig. 35.—Simplified synchronous
vibrator supply.

obtained from the d.c. by throwing
the switch, so at the same time is
the a.c. changed back into d.c. by
changing the polarity of the sec-
ondary voltage. Fig. 36 is a typi-
cal circuit of such a vibrator using
an electrically driven reed.

The mechanical features of both
types of vibrators are the same.
The least expensive and the most
trouble-free is the non-synchronous
vibrator. This is due mainly to its
simplicity. Both are usually mount-
ed in an electrically sealed, shock-
proof container with prongs pro-
jecting out of the bottom, so it
will fit into a vacuum tube socket.
These prongs carry the inputs and
outputs, so the units can be wired
under the chassis like an ordinary
vacuum tube. The sealing is done to

The overall efficiency of such
vibrators is around 60%. Failures
in the majority of cases are due
to:

1. Breakdown of the buffer ca-
   pacitor due to very high
   voltage surges.

2. Pitted contacts that stick.

3. Mechanical failure of the
   moving parts.

4. Operation from a weak bat-
   tery or while starting the
   car.

The replacement of the buffer
capacitor with a capacitor of the
proper value is important to main-
tain the proper operation of the re-
ceiver. The capacitor's value can
be checked by looking at the wave-

form of the a-c voltage on the cathode-ray oscilloscope; it should be almost square in form with no sharp peaks in it.

One is often called upon to suppress radio interference or "hash" from the vibrator. In the main this can be cured by:

1. Shielding of the vibrator or rectifier unit in the set.

2. Proper grounds in the vibrator unit and the set.

3. R-F filtering in the leads to and from the power unit.

4. Replacing faulty buffer capacitor.

5. Replacing sluggish vibrator.

BATTERY PORTABLE SUPPLIES

A brief survey of the various types of batteries most likely to be encountered in radio servicing work will now be given. The battery portable supplies to be discussed in this section include the dry-cell type, the air-cell type, and the storage battery.

DRY CELL TYPE.—The *ordinary form* of 1.5-volt dry cell is shown in Fig. 37. It can deliver electrical energy to an external circuit because of the fact that two electrodes of dissimilar metals show a potential difference between them when they are immersed in an electrolyte. The two electrodes in this case are the carbon rod and the zinc case. The electrolyte is sal ammoniac and is next to the zinc case in the blotting paper in the form of a saturated solution. The space between the blotting paper and the carbon

electrode is filled with a mixture of carbon, manganese dioxide (*the depolarizer*) and the electrolyte all forming a paste. The top is filled with sealing compound to prevent evaporation, since the cell
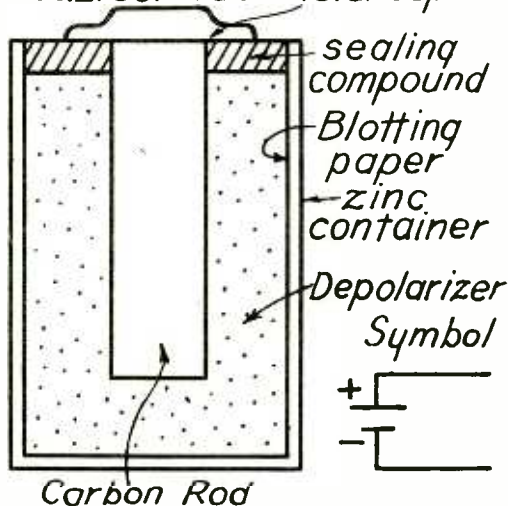

Fig. 37.—Ordinary dry cell.

will not work when the electrolyte dries.

The function of the depolarizer can be seen from the following considerations: When current is supplied to an external circuit, two principal effects occur within the cell. The negative electrode loses weight as its material is used up in furnishing energy, and hydrogen bubbles form on the positive electrode. Since the gas bubbles are non-conducting, their accumulation tends to reduce the effective area of the positive electrode and consequently reduces the current. The effect is cumulative, and eventually the electrode will be completely covered and no further current can flow. This effect is called *polarization*. If the bubbles are removed or prevented from forming by chemical means, polarization is reduced,

and current can flow as long as there is material in the negative electrode to furnish the energy. A chemical which prevents the formation of hydrogen bubbles in the cell is called a *depolarizer.*

AIR-CELL TYPE.—This battery was *developed* by the National Carbon Company *for the* purpose of maintaining a *constant voltage* over the greater part of the battery's useful life. This was necessary for battery model receivers to keep their performance constant over the life of the battery. The dry cells described previously, when used to supply filament voltage in battery receivers, would have a steadily decreasing performance throughout the life of the battery.

The air cell is similar to other primary cells in that it utilizes the potential difference between dissimilar metals, namely, carbon and zinc. It has an unlimited shelf life due to the electrolyte which is in solid form when shipped. To put the battery in service one simply adds water to each cell. The water dissolves the solid electrolyte without stirring, and the unit is in service.

The battery gets its name from the method of depolarizing. This type of depolarizing depends on the special carbon electrode. This electrode is porous and takes in oxygen from the air to combine with the hydrogen to form water. This is similar to the property of charcoal to absorb air into its structure, storing it at a very high pressure. The construction of this electrode is such that it will be ruined by excessive current flow, hence care must be exercised to prevent a large current for even a brief time. The terminal voltage for these batter-

ies is 2.5 volts, when new.

STORAGE BATTERY TYPE.—Storage batteries are secondary cells. The secondary cell is different from the primary cell in that energy must first be put in, and then this "stored" energy is available to external circuits, hence the name storage batteries. The process of putting the energy in is known as charging, and that of delivering energy to a load is known as discharging.

The simplest form of secondary cell is made by immersing two lead electrodes in a dilute solution of sulphuric acid, and then passing a current through the solution. When the charging current is removed, the cell will deliver current to an external load starting with a difference in potential of about 2 volts. The lead electrodes are changed to spongy lead and lead peroxide on charge, with the electrode that was connected to the positive side of the charging source becoming the lead peroxide. Discharge of the cell is accompanied by chemical action converting the lead peroxide and the spongy lead to lead sulphate; and since the electrodes are then of the same material, there is no difference in potential, and the cell is completely discharged.

This is the principle of the storage battery that is used in automobile starters and as a source of power for automobile radios. The construction of the cell is much more complicated. In the first place, to obtain large currents, it is necessary to use electrodes having a large surface area and to mount them very close together. The electrodes are made in the form of rectangular flat plates consisting of a lattice-work or grid of lead (or an alloy of lead). The spaces

in the grid are filled with a paste of lead oxide; the electrolyte is a solution of sulphuric acid in water.

When the cell is charged, the lead oxide in the positive plate is converted to lead peroxide, and that in the negative plate to spongy lead. To obtain high-current capacity; a cell consists of a number of positive plates, all connected together, and a number of negative plates also connected together. The plates are arranged as shown in Fig. 38, with the alternate negative and positive plates kept from, touching
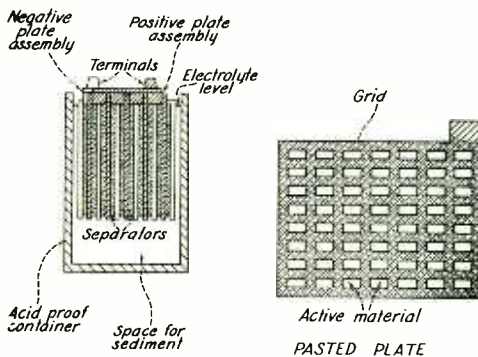

Fig. 38.—Arrangement of plates in the storage battery.

by means of thin separators made of hard rubber or wood. The extra negative plate is to keep the active material in the positive plates from expanding all in the same direction, thereby buckling the plates and distorting them out of shape.

Each cell has 2.1 volts when fully charged and 1.75 volts when discharged. If the cell is allowed to discharge further, an insoluble form of lead sulphate appears on the plates and prohibits recharging.

When the cell is on charge,

water in the electrolyte is used up, thus increasing the specific gravity of the electrolyte. This phenomenon is used to indicate the condition of the battery. A cell is considered fully charged when the specific gravity of the electrolyte is 1.300 and discharged when it is 1.150; these measurements of specific gravity are made with a hydrometer. Cells intended primarily for radio or sound motion picture work, etc., instead of for electric self-starters (as in an automobile), are often made to have a specific gravity of but 1.240 when charged, as such a battery is quieter in operation.

These batteries are rated for their current-carrying capacities by a number that gives the product of current to the load and the time the load is connected to the battery. For example, a battery rated at 100-ampere hours would deliver 12.5 amperes for eight hours, or 8 amperes for twelve and one-half hours. This rating becomes considerably smaller if the time for the discharge becomes very small, say, less than 1/2 hour. The charging rate is also calculated from the ampere-hour capacity.

There are many models of storage batteries on the market that can be (or are) designed to be used for radio power. They are made for both "A" service and "B" service with a vibrator. A very popular type is that used in the G.E. Model LB-530 Receiver (Fig. 39). This battery has a capacity of 20 ampere-hours and delivers 2 volts. It weighs only 3-1/2 pounds, and its dimensions are 3-31/32 × 3-1/2 × 5-1/2 inches. It is built in a transparent plastic container with colored indicator balls to indicate the state of charge at a glance. Special

electrolyte-retaining insulation and non-spill construction permit dry battery portability with storage battery life. The G.E. LB-530 Receiver has its own charging unit
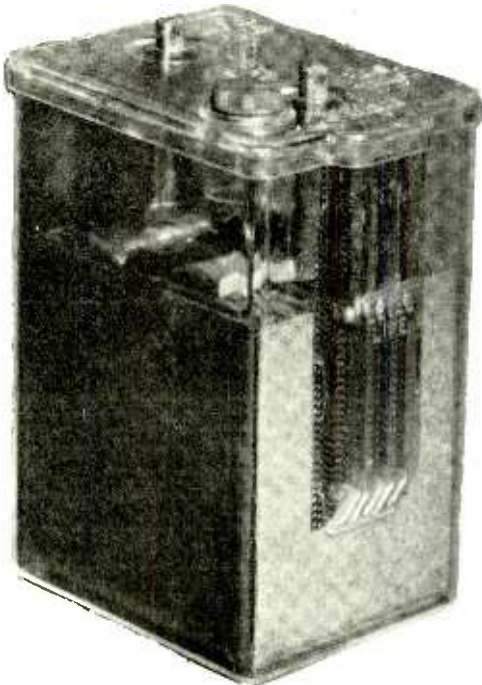
uilt in the set so the battery can e on charge when the receiver is in se on a.c.

MISCELLANEOUS TYPES

INVERTERS.—It is often neces-ry to change d.c. into a.c. to run me special equipment that would ordinarily require much rebuilding to have it operate at the d.c. available. This can be done in several ways, such as a special d-c

motor driving an a-c-generator, or using vibrators such as those described under Vibrator Power Supplies, or an arrangement of gas tubes. The latter method is one often used in radio power units that operate from 110 volts d.c. and give 110 volts a.c. at low or moderate powers.

Such a system is shown in Fig. 40. This circuit is similar to a push-pull audio amplifier except that it uses gas tubes or thyratrons. The frequency of the applied a-c voltage is determined by an *external* source. In the absence of this con-
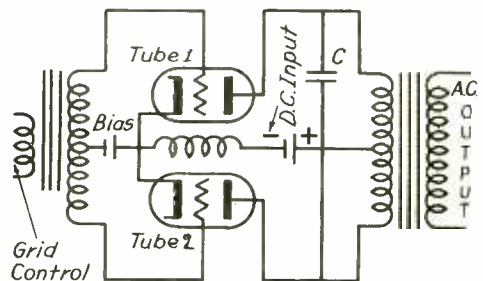

Fig. 40.—D-C to a-c inverter circuit.

trol voltage, the grids of the thyratrons are biased so that the tubes do not conduct, and there is no a-c voltage output. As the grid control voltage is applied at a certain instant, the grid of tube 1 is positive with respect to its cathode, and it will conduct. As it conducts, its plate voltage falls, charging capacitor C, .and causing the plate of tube 2 momentarily to fall to some lower potential. When the control voltage makes the grid of tube 2 positive with respect to

its cathode and the grid of tube 1
negative, it causes tube 2 to con-
duct and charges C in the outer di-
rection, pulling the plate of tube 1
down to a low value, thereby ex-
tinguishing it as its grid is nega-
tive. This causes an alternating
voltage to be set up in the second-
ary of the output transformer, due
to the change in direction of the
current in the primary of the output
transformer. This wave-form is not
a pure sine wave but is rich in har-
monics, the general form approach-
ing that of a square wave.

These converters are usually
built for special operations, and,
therefore no standard descriptions
of units are given in this assign-
ment. The thyratron tube is capable
of handling fairly large currents,
so that these units can furnish
relatively large amounts of power;
110 volts a.c. at ten or fifteen
amperes is not uncommon.

ROTARY CONVERTERS.—One of the
most common methods of current con-
version is that utilizing a *rotary*
or *synchronous converter,* such as
that found in a television system.
Although, in most cases, this machine
is used to convert alternating cur-
rent into direct current, it can be
used in the reverse manner, i.e., to
convert direct current into alter-
nating current. A diagram of a
simple two-pole rotary converter is
given in Fig. 41; its construction
is similar to that of an ordinary
d-c generator. The armature is the
rotating element, and the poles are
stationary.

In a previous assignment, it
was shown that an alternating cur-
rent is generated in the armature
coils. This is true in armatures of
both a-c and d-c machines; whether
the useful output is a.c. or d.c.

depends upon whether slip rings or a
commutator are used.

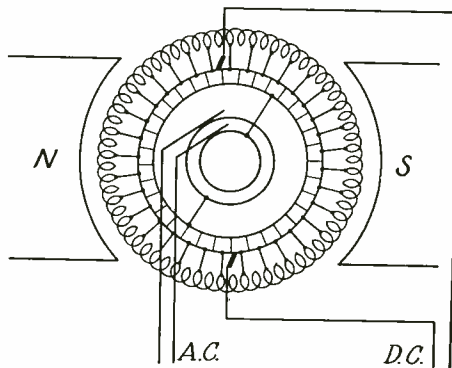As is evident from Fig. 41,
a.c. is fed to the slip rings, and

Fig. 41.—Two-pole rotary converter.

d.c. is taken off from the commuta-
tor via brushes. This represents
the usual method of operation of a
rotary converter; when operated from
a d-c source (and used to supply
alternating current), the machine is
known as an inverted rotary convert-
er. The power rating is the same in
both cases.

Such a machine, can be used to
convert large amounts of power, and
is usually more economical than a
motor-generator. The rotary convert-
er also has a comparatively high
efficiency.

GRID BIAS

*THE CONSTRUCTION OF BIAS
CELLS.*—The bias cells on the market
today are small acorn-shaped de-
vices 5/8 by 11/32 inches. They are
designed to deliver either 1 or 1-1/4
volts at negligible current drains.
They are mounted in metal containers

which constitute the negative elec-
trodes, and the black discs or cov-
ers for the containers are the posi-
tive electrodes. To differentiate
them, the higher voltage cell has
concave depressions in the disc and
shell, while the 1-volt cell does
not.

Characteristics.—The material
used in the cells and other basic
design data is a manufacturing
secret, but many operational curves
are available. Figs. 42, 43, and
44, represent the most important
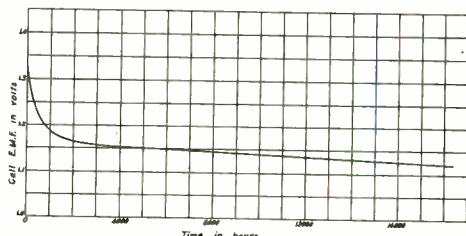characteristics of the cells. Fig.

Fig. 42.—No d-c load, voltage—ver-
sus-time, normal temperature for the
Mallory Bias Cell.

42 is the graph of voltage-versus-
time with no d-c load at normal
temperature. Fig. 43 is the cell's
output-versus-time for an intermit-
tent load of 2 megohms for 3 hours
each day. Fig. 44 is the fidelity
characteristics of the cells-versus-
cathode bias. It is evident that
the low-frequency response of a cir-
cuit using such a cell is consider-
ably improved with the incorporation

of a bias cell, as compared to self-
bias, inadequately by-passed. For
instance, in a circuit using cathode
bias obtained from a series resistor
of 3,500 ohms and a by-pass capacitor
of 1 μf, it is seen from the graph
that the output of the circuit at
50 cycles/second is 50% of what it
would be if the cathode were ground-
ed and the bias cell inserted in the
grid circuit as shown in Fig. 45.

These cells are of value in the
following applications:

1. The first audio stage of
radio receivers.

2. High-gain stages in volt-
age amplifiers (microphone and photo-
electric cell pre-amplifiers, etc.).

3. Minimum bias for automatic
volume control circuits in radio re-
ceivers.

4. Miscellaneous vacuum tube
circuits, where the tubes are op-
erating under Class "A" condition,
and where no appreciable grid cur-
rent exists.

A typical improvement in a
high-gain, low-level amplifier of
the type shown schematically in Fig.
46, would be the elimination of hum
and microphonics. Heater leakage
currents, flowing to ground through
any impedance in the cathode circuit,
build up a voltage which is impress-
ed between the cathode and grid of
the tube and therefore produces hum
in the output. With a bias cell
connected directly in the grid cir-
cuit and the cathode at ground po-
tential, all impedance is removed
from the cathode circuit, and hum
due to heater—cathode leakage is
eliminated.

Service Hints.—One can see
from the curves above that these
cells are not rugged when actually
in service, hence they can be the
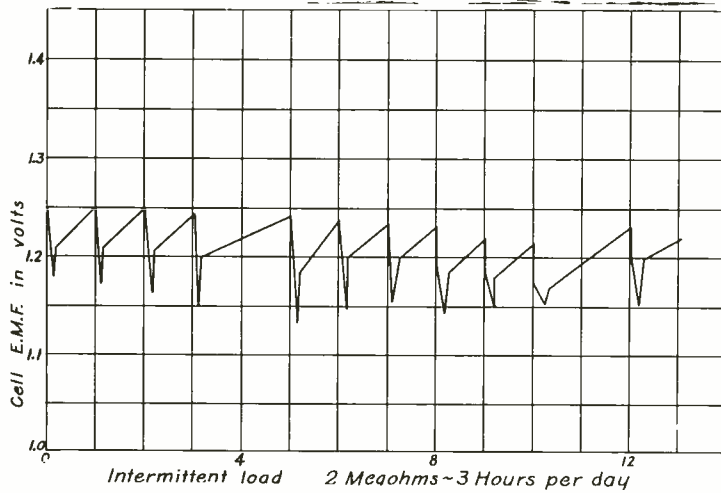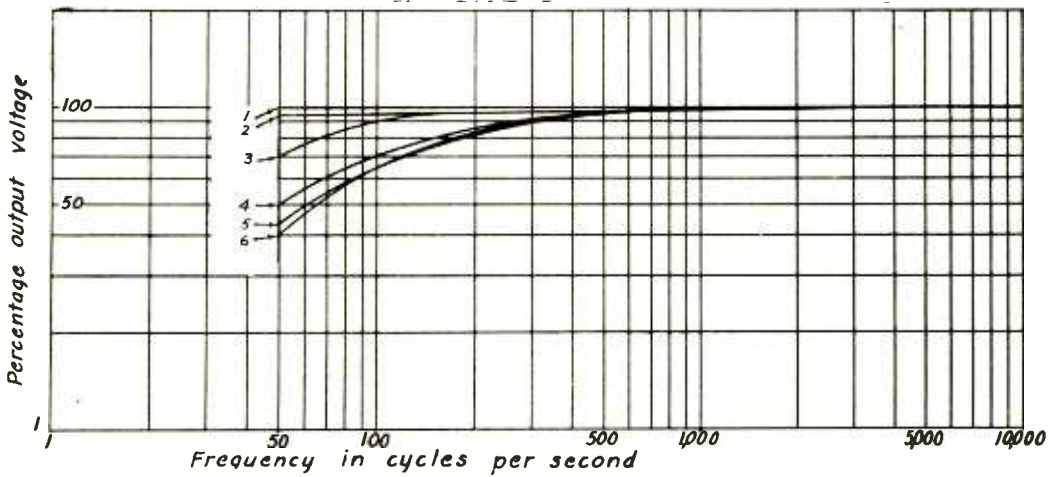cause of excessive tube current and

Fig. 43.—Intermittent load of 2 megohms for 3 hours per day for the Mallory Bias Cell.

FIDELITY CHARACTERISTICS

BIAS CELL–VERSUS–CATHODE BIAS

CURVE NO.	BIAS	CATHODE BY-PASS
1	Mallory Cell	None
2	3,500 ohm Cath. Res.	10 Mfd.
3	3,500 ohm Cath. Res.	2 Mfd.
4	3,500 ohm Cath. Res.	1 Mfd.
5	3,500 ohm Cath. Res.	.5 Mfd.
6	3,000 ohm Cath. Res.	.25 Mfd.

Fig. 44.—Bias cell-versus-cathode bias.

other phenomena that exist when a tube loses its bias. They can be checked, however, only with a very
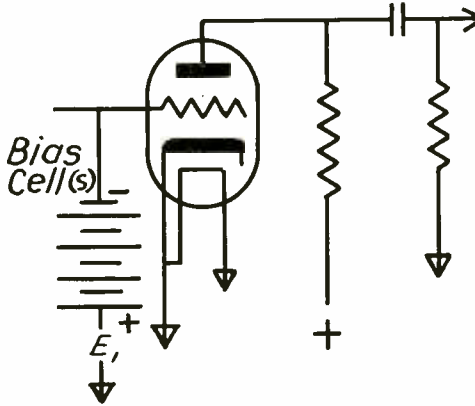

Fig. 45.—Bias cell as amplifier bias.

high resistance voltmeter. As seen from Fig. 43, a 2-megohm load drops the voltage from 1.25 volts to 1.2 volts, hence a very high resistance voltmeter is required to indicate the tube voltage of the cell. Intermittent shorts do not damage the cell permanently, as it returns to
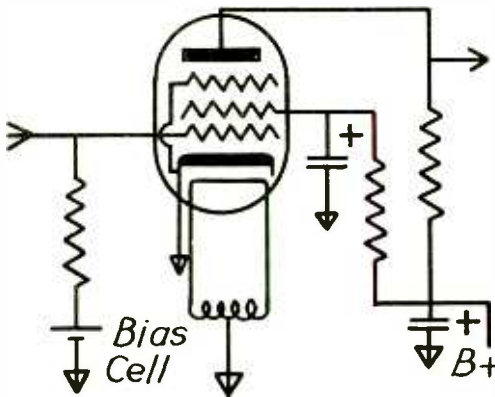

Fig. 46.—Elimination of hum with bias cell.

normal voltage after a time lapse of one day, hence, extraordinary care in the measurement need not be ex-

ercised.

SELF BIAS.—Systems of self-biasing arrangements today practically always take their voltage from the plate supply voltage. In bias for individual stages this is accomplished by a resistor between cathode and ground, as shown in Fig. 47. All the current drawn by the
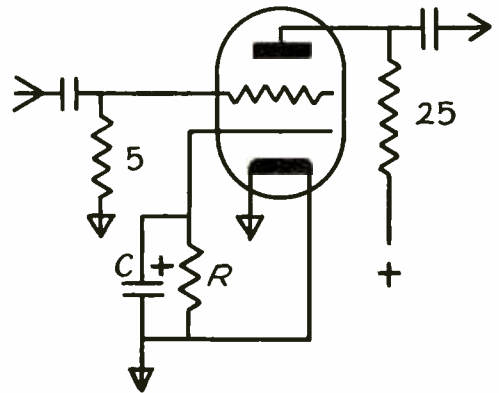

Fig. 47.—Cathode-biased amplifier.

tube passes through resistor R. The cathode resistor is by-passed with a capacitor, C, of such a value that the *alternating* voltage developed across the resistor is small (usually a tenth) compared to the signal voltage applied to the grid of the tube. When the capacity is too small, the voltage gain of the amplifier is less. This is known as degenerative or negative feedback, and the amount varies with frequency. The degeneration is a maximum at the lower frequencies, as shown by the graph in Fig. 44, because the reactance of the capacitor is higher, and it is therefore less of a shunt across the cathode resistor. It is evident that as the by-pass capacity is decreased, the gain is decreased at the lower frequencies. For example, at a frequency of 50 c.p.s., the voltage output of an amplifier

is doubled by increasing the by-pass
capacitor across the 3,500-ohm cath-
ode resistor from 1 to 10 μf.   A
further increase in the capacitor's
value would not result in an ap-
preciable gain at this frequency,
however, since the bias voltage is
practically constant, and there is
a negligible amount of alternating
voltage developed across the 3,500-
ohm resistor at this frequency with
10 μf or more.

There is another way of using
the plate supply for a bias source,
and that is by having *all the cur-
rent of the receiver flow through
a small resistor.*   (See Fig. 48)
This means the filter capacitors
cannot be grounded,* and a large
value of filter capacity across this
resistor must be used to eliminate
hum and interstage feedback.   The
grid returns of tubes biased in this
manner usually have decoupling re-
sistors and capacitors arranged as

R-C filters (discussed previously).
This prevents hum and coupling from
being introduced into the various
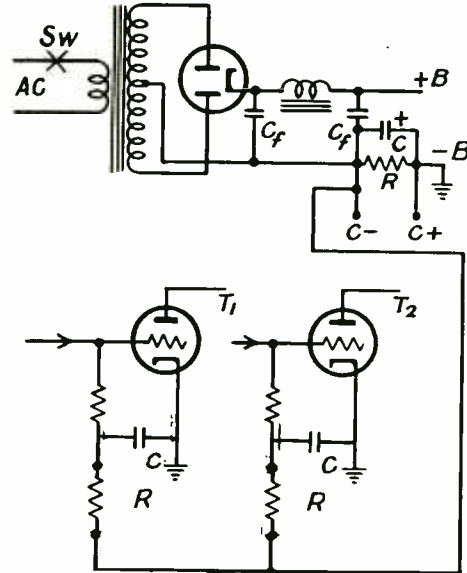

Fig. 48.—Grid decoupling circuit
for tubes biased from series resist-
or in power supply.

stages.   A typical schematic of
such a system is shown in Fig. 48,
where R and C play the same roles
as in the R-C filter discussed
under 60-cycle Power Supplies.

*If the filter capacitors are
grounded, then the cathode returns
must operate above ground; i.e.,
B- must be above ground.

EXAMINATION

1.   (A)   An a-c/d-c receiver uses three 12.6-volt 0.15-ampere heater tubes, a 50-volt 0.15-ampere heater tube and a 35-volt 0.15-ampere heater tube.   What series resistance is needed if these tube heaters are to be connected in series across a 220 volt power line?

(B)   Calculate the power dissipated by the series resistor.

2.   Refer to Fig. 48 of the text.   Assume the trouble is in a major component and not in the wiring.   Explain the most probable cause for the following different conditions.

2. (A) A check shows B+ voltage present from cathode of recti-
    fier to B- but no B+ voltage across output terminals. What
    component would you suspect? Explain.

    (B) When the power supply is switched on the plates of the
    rectifier get red hot. What component would you suspect?
    Why?

EXAMINATION, Page 3

2.   (C)   Assume this power supply is connected to a receiver. A high hum level in the speaker disappears when a 15 µf capacitor is placed across the output of the power supply. The trouble lies in the power supply; what is it?

3.   (A)   A (choke, capacitor) input type of filter delivers the highest output voltage.

(B)   Reference Fig. 5. The power line frequency is 60 cycles per second. The output ripple of the rectifier will be (30, 60, 90, 120) cycles per second.

(C)   Reference Fig. 17.   Identify the hum bucking coil.

(D)   Reference Fig. 17.   What is the purpose of the .05 µf capacitor across the plate and cathode. What should be its voltage rating?

EXAMINATION, Page 4

(A)   Reference Fig. 3. Assume a type 35W4 tube is to be used. What precautions must be exercised when selecting the power transformer as regards heater-cathode insulation?

(B)   What are the advantages of using a bleeder across the output of any power supply filter?

EXAMINATION, Page 5

5.   Reference Fig. 11.   Assume normal operation of power supply.

(A)   At the instant the top plate of the rectifier is posi-
tive, electrons will flow (up, down) through the top half of
the secondary high-voltage winding.

(B)   At this same instant, electrons will flow from (left to
right, right to left) through the 30 henry choke.

(C)   At this same instant, electrons will flow (in to, out
of) the lower side of the first filter capacitor.

6.   Refer to Fig. 48. The bias voltage normally developed across
resistor "R" in the power supply circuit is 12 volts, and
the total current flow through it is 90 ma.   Suppose "R"
opened and its value could not be determined by the code
markings on it.

(A)   What value of resistance is indicated and what commer-
cial value would be used to replace it?

(B)   What value of capacitance would be used to bypass this
resistor if X_c/R = .5.   Frequency = 100 c/s?

6.   (B) Cont'd.

7.   (A)   Reference Fig. 19.   Assume a 60 cycle power line fre-
quency.   The ripple frequency input to the filter is (30,
60, 90, 120) cycles per second.

       (B)   What purpose do thé two 22 ohm resistors serve?

       (C)   Reference Fig. 21.   When the plate of diode D_2 is posi-
tive with respect to its cathode, electrons will flow (out
of, into) the top output terminal.

       (D)   When the cathode of diode D_1 is negative with respect
to the cathode of diode D_2, èlectrons will flow (out of,
into) the lower side of capacitor C_1.

8.   Reference Fig. 29.

       (a)   Which tube or tubes serve as the series rheostat?

       (b)   Which tube or tubes act as the amplifier stage?

       (c)   What is the purpose of V-10?

       (d)   What is the purpose of V-9?

Reference Fig. 34. Assume left-hand terminal of d-c input is negative. *Use electron flow* to answer question!

(A)   When the reed has reached its extreme right position, what is the direction and path of the electrons through the primary circuit?

(B)   What is the direction and path of the electrons at the instant the reed is in the center position?

9.   (C)   What is the direction and path of the electrons when the reed has reached it extreme left position?

10.   (A)   Cracked or punctured sealing compound on a dry cell indicates a probable limited life.   Why?

10. (B) Consider a battery as shown in Fig. 38. Within the battery, electrons flow from the (positive to negative, negative to positive) terminals.

(C) How long would a battery rated at 85 ampere hours deliver 10 amperes?