The AEROVOX Research Worker

The Aerovox Research Worker is a monthly house organ of the Aerovox Corporation. It is published to bring to the Radio Experimenter and Engineer authoritative, first hand information on condensers and resistances for radio work.

VOL. 9, NOS. 8 and 9 AUGUST - SEPTEMBER, 1937

50c per year in U.S.A.
60c per year in Canada

RADIO RECEIVER POWER SUPPLIES

PART I

By the Engineering Department

AEROVOX
CORPORATION

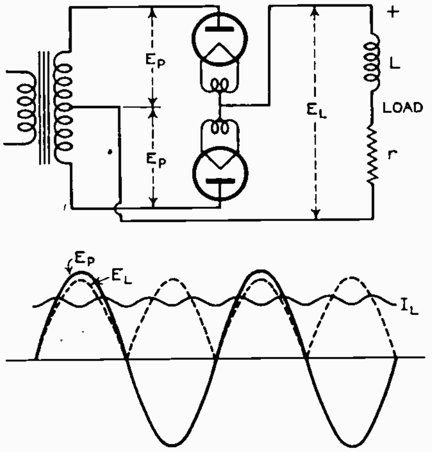
A paper delivered by the Engineering staff of Aerovox Corporation. In order to preserve the unity of the text, this material which is too lengthy to be included in the usual four page edition of the Research Worker, is being published in two eight page editions. The second part of the paper will appear in the October-November issue of the Research Worker.

AEROVOX PRODUCTS ARE BUILT BETTER

RADIO RECEIVER POWER SUPPLIES

Part I

THE study of receiver power supplies is made up of two parts—the rectifier and the filter. These two parts, however, cannot be studied separately as they are interdependent. The action of the rectifier depends on the load into which it works, while the filter required for any particular application depends on the rectifier used and the character of output required. There are four different types of rectifier circuits that may be used for receiver power supplies; the half wave rectifier, the full wave rectifier, the bridge type rectifier and the voltage doubling type rectifier. Each type has a definite field of application. The voltage characteristics of the various types are tabulated in Table I.



$$E_{DC} = \frac{\sqrt{2}\, E_p\, P \sin \frac{\pi}{P}}{\pi} \text{ VOLTS } = \frac{2\sqrt{2}\, E_p}{\pi} \sin 90^\circ$$

$= 0.909\, E_p$ FOR FULL WAVE

E_p = RMS VOLTS TO NEUTRAL
P = NUMBER OF ANODES
(1 FOR HALF-WAVE RECTIFIER
2 " FULL- " ")

HARMONICS

$$A_n = \frac{2E_{DC}}{n^2-1} = 0.667\, E_{DC} \text{ PEAK} = 0.471\, E_{DC} \text{ RMS}$$

AT MIN. FREQ. OF 2 TIMES FREQ. OF APPLIED VOLTAGE.

FIG. 1

In the analyses of receiver power supplies, the following features must be taken into account:

1. The output voltage required
2. The allowable ripple voltage
3. The static and dynamic regulation of the supply
4. The peak voltages across the condensers of the system

These various features depend on the type of circuit used and the constants of the circuit.

RECTIFICATION

Rectification as obtained by the use of the thermionic vacuum tube is a process in which the tube conducts current during half of the cycle when the plate is positive with respect to the filament. In certain tubes the tube does not begin to conduct until a threshold voltage has been reached. The tube current is limited by the space charge and filament temperature saturation. The current is also determined by the characteristic of the load into which the tube works. If the tube works into an inductive load the inductance tends to maintain the current flow after the tube has stopped conducting. Similarly, when the tube works into a capacative load, the charge on the condenser tends to maintain a current flow after the conduction period. In the inductive circuit the maximum DC voltage is limited by the choke coil and is approximately equal to the average value of the voltage wave applied. With the condenser input the maximum DC voltage, at no load, is equal to the peak value of the AC voltage applied. With the choke input, the voltage applied to the filter is equal to the AC plate voltage less the tube drop. The voltage regulation of the choke input rectifier depends on the tube drop and the IR drop in the choke coil. With the condenser input type rectifier the voltage applied to the filter input is equal to the AC plate voltage less the tube drop. Regulation with this type of rectifier depends not only on the tube drop but also the drop in the average condenser voltage due to the discharge of that condenser. Therefore, the condenser input rectifier will have a larger percentage of voltage regulation than the choke type of rectifier.

FULL WAVE RECTIFIER

The full wave rectifier is most commonly used for receiver power supplies

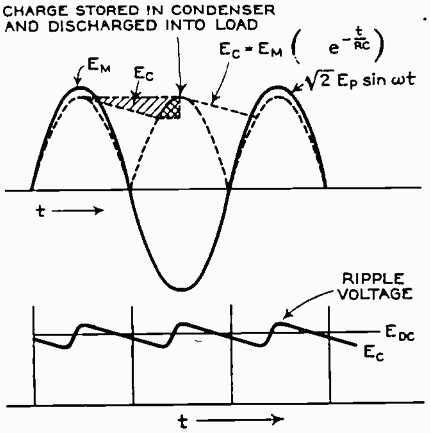


FIG. 2

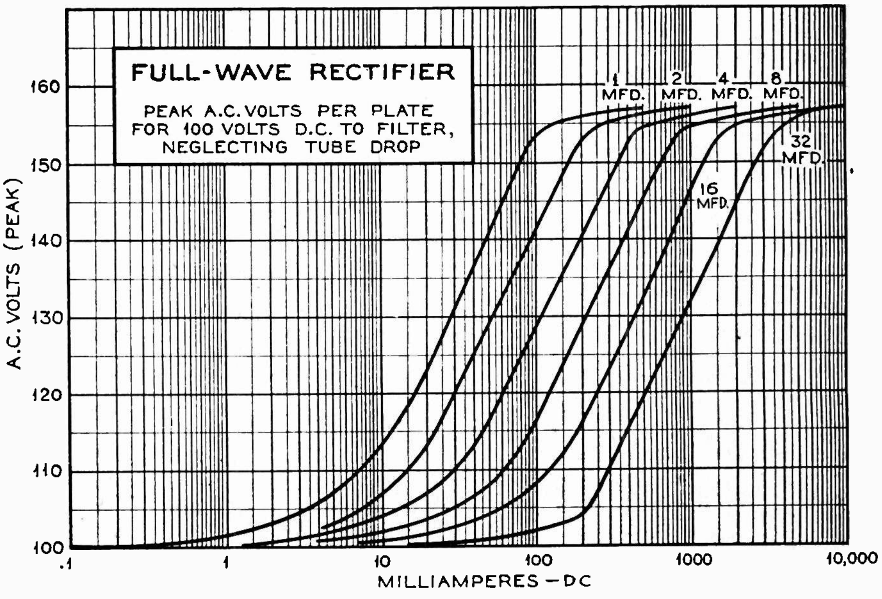


FIG. 3

and will be discussed in two separate parts:

1. Choke input filter rectifiers
2. Condenser input filter rectifiers

As explained above, the DC output voltage of the choke input filter rectifier into the filter is equal to the average value of the AC plate voltage less the tube drop. For a sine-wave applied voltage and a choke of infinite inductance the average DC voltage is equal to 90.9% of the RMS applied voltage per plate. The circuit and the wave shape of the full wave rectifier are given in Figure 1. The harmonic voltages existing in a full wave rectifier are of double frequency of the applied AC voltage and the RMS value of the ripple voltage applied to the filter input is 47.1% of the DC voltages.

TABLE I

	HALF WAVE FIG. 6	FULL WAVE FIG. 1	BRIDGE CIRCUIT FIG. 12	VOLTAGE DOUBLING FIG. 11
E_{dc}(av)	$0.458E_{ac}$	0.458_{ac}	$0.909E_{ac}$	—
I_{dc}	$0.318I_m$	1.41_{ac}	I_{ac}	—
E_{dc}(max.)	$1.41E_{ac}$	$0.707E_{ac}$	$1.41E_{ac}$	$2.83E_{ac}$
E_{ac} per plate	E_{ac}	$0.5E_{ac}$	$0.5E_{ac}$	E_{ac}
E inverse max.	$2.83E_{ac}$	$1.41E_{ac}$	$1.41E_{ac}$	$2.83E_{ac}$
I_{av} per tube	I_{dc}	$0.707I_{dc}$	$0.707I_{dc}$	I_{dc}
I max. per tube	I_{dc}	I_{dc}	I_{dc}	—
Sec. kva.	$1.57E_{dc}\ I_{dc}$	$1.57E_{dc}\ I_{dc}$	$1.11E_{dc}\ I_{dc}$	—
Pri. kva.	$1.57E_{dc}\ I_{dc}$	$1.1E_{dc}\ I_{dc}$	$1.11E_{dc}\ I_{dc}$	—
Ripple freq.	f.	2f.	2f.	2f
Ripple voltage rms.	—	$0.847E_{dc}$	$0.471E_{dc}$	—

E_{ac}=Transformer Secondary Voltage.

The current in a choke input rectifier, with infinite inductance, is constant in magnitude and the current pulses in each tube are of rectangular shape. The current in each half of the transformer secondary flows only every other half cycle and therefore the volt ampere capacity of the secondary is 1.57 times the product of the DC volt amperes. The current in the primary is an alternating current of rectangular wave shape and its volt ampere capacity is 1.11 times the DC volt ampere output of the rectifier. In practical rectifier circuits, chokes of infinite inductance are not available, but chokes having inductances from 15 to 30 henries at their rated current, are sufficiently large to approach the ideal condition. Decreasing the size of the input choke, decreases the AC voltage drop in the choke and applies a higher voltage to the first filter condenser of the system, thereby storing additional energy in the filter and increasing the DC output voltage. Use is made of this affect in systems having a variable load such as Class A.B. or Class B. amplifiers to reduce the voltage regulation of the system. The decrease in inductance is obtained by operating the choke on the knee of the magnetization curve so that the inductance of the choke decreases with an increase in current. Inductances of this type are called swinging chokes.

The regulation of the choke input rectifier depends only on the tube drop, which is given in Figure 4, and the IR drop in the choke, provided the choke inductance remains constant. This regulation may be made quite small by the use of mercury vapor tubes and chokes of small DC resistance.

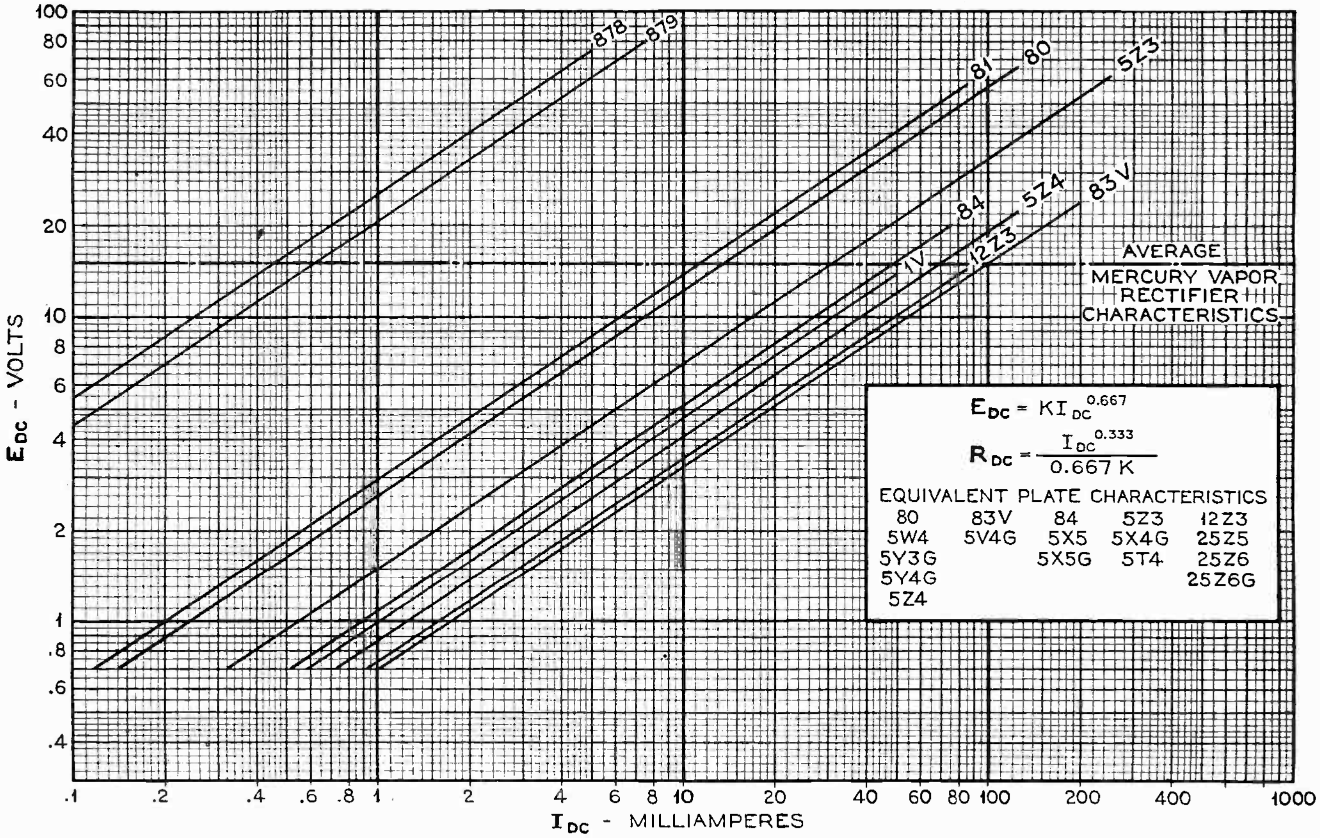
CONDENSER INPUT FILTER RECTIFIERS

The use of a condenser across the filter input increases the available DC output voltage as the condenser acts as a reservoir of energy during the conduction period and discharges into the load when the tube is not conducting. The circuit and the output voltage waves are shown in Figure 2. The output voltage wave is made up of two parts; part one, a portion of the sine-wave, during the charging period and part two, the discharge curve which is an exponential function. The mathematical analyses of this type of wave is quite complicated and it is simpler and quicker to use empirical methods for the determination of circuit conditions for this type of circuit. Manufacturers of rectifier tubes include as part of their tube specifications, a series of curves, showing the DC voltage at the filter input terminals for each type of rectifier tube and for various types of filter loads. In addition, these curves may be replotted, as shown in Figure 3, as a function of current and input capacity. The curves of Figure 3 are plotted for a DC voltage output of 100 volts with current as abcissa and the peak AC voltage as ordinates. Since the charging time of the first condenser is limited to a very short part of the cycle, the time depending on the size of the condenser and the resistance across the condenser, the current during that period may reach high peak values. As the voltage drop in the tube is not constant but varies with the tube current, the available output voltage can only be obtained experimentally. The curves of Figure 3 are plotted for zero tube drop and must be corrected for the tube used and the tube current to obtain the AC voltage required to deliver 100 volts DC. The correction is made by finding the DC voltage drop, in the tube used, from the curves of Figure 4 multiplying by 1.5708, the ratio of the peak value to the average value of a half sine-wave, and adding this voltage drop to the ordinate of curve 3. This value, when divided by 1.41 gives the RMS plate voltage to deliver 100 volts DC into the filter. To obtain any other DC voltage, the AC voltage must be multiplied by the ratio of the desired DC voltage to 100 volts.

The harmonic voltages in the full wave condenser input rectifier are of double the frequency of the AC applied voltage, the magnitude depending on the size of the input condenser and the load across it. These values are given in Figure 5. As in Figure 3, the effect of the tube drop is omitted. The tube drop tends to decrease the ripple voltage so that the curves of Figure 5 give the worst conditions.

The voltage across the first condenser is equal to the peak AC plate voltage less the tube drop. When there is no load on the power supply as is the case with the tubes of a receiver out of tne socket or during the warming up period of the set, the peak voltage across the condenser is substantially equal to the peak AC voltage applied to the tube. As the load on the set increases, the peak voltage on the first condenser decreases by the amount of the tube drop. The peak value of the tube drop may be as high as 100 volts for tubes having a large voltage drop and used in filter circuits with a large input condenser. The tube currents depend on the ratio of the discharge time to the charging time and for circuits having a large load, that is, a low resistance across the first condenser and a large input condenser, the peak value of the tube current may be many times the RMS value or the average DC value. The regulation of this

AVERAGE PLATE CHARACTERISTICS OF RECTIFIERS



$$E_{DC} = KI_{DC}^{0.667}$$

$$R_{DC} = \frac{I_{DC}^{0.333}}{0.667\,K}$$

EQUIVALENT PLATE CHARACTERISTICS

80	83V	84	5Z3	12Z3
5W4	5V4G	5X5	5X4G	25Z5
5Y3G		5X5G	5T4	25Z6
5Y4G				25Z6G
5Z4				

FIG. 4

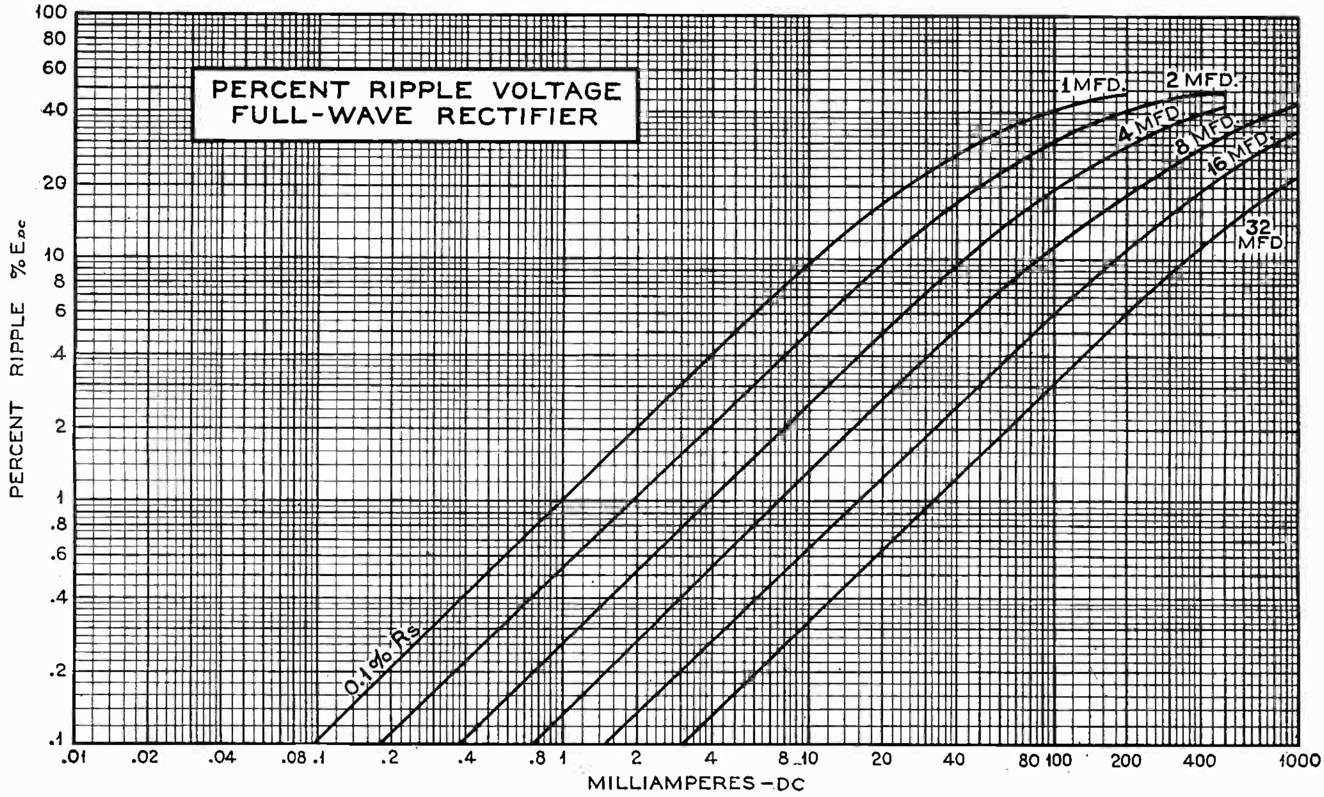


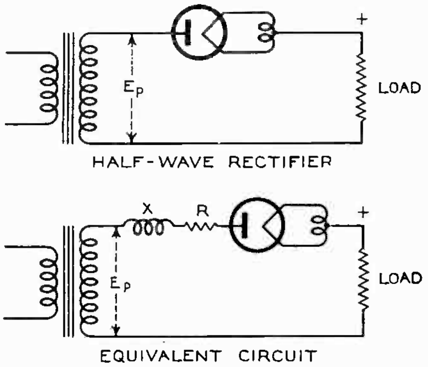
FIG. 5

type of rectifier, as explained above, cannot be computed but can be obtained from the graphs given.

To reduce the duty on the filter condensers of the system, use may be made of the fact that wet electrolytic condensers have a leakage characteristic which increases very rapidly with the applied voltage. Condensers of this type are called regulating condensers and by their use, the peak voltages that occur during the warming up period of the set or at no load, may be kept down to within the rated voltages of the condensers.

HALF WAVE RECTIFIER

The half wave rectifier utilizes half of the cycle of the AC applied voltage, the tube conducting current during half of the cycle. Because of this fact, the choke input type of filter is rarely used with the half wave rectifier. In order to maintain the output voltage at reasonable values, a large input condenser



$X = X_S + X'_P$
X'_P = PRI. REACTANCE REFERRED TO SEC.
R = EQUIVALENT RECTIFIER RESISTANCE

FIG. 6

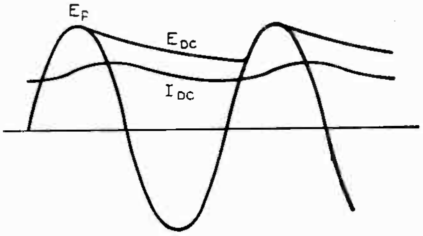


FIG. 7

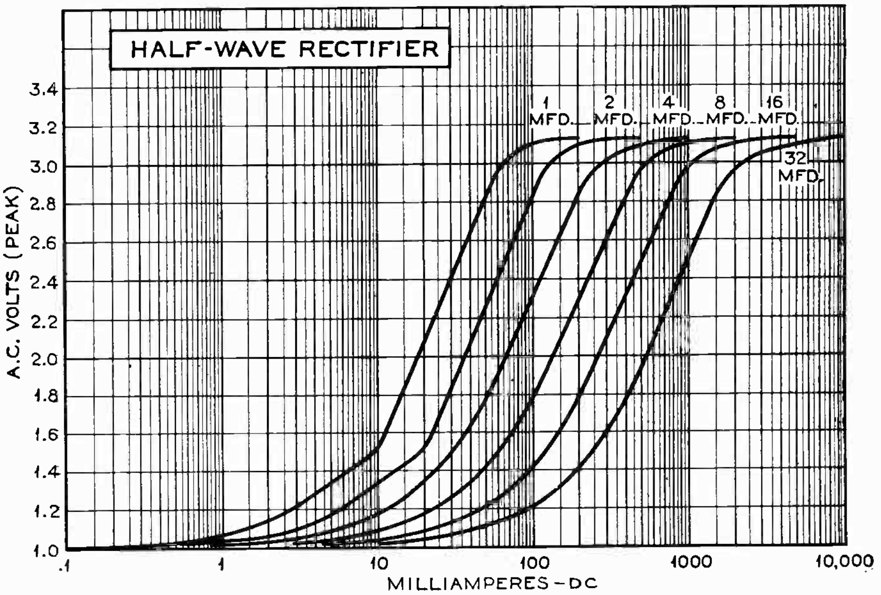


FIG. 8

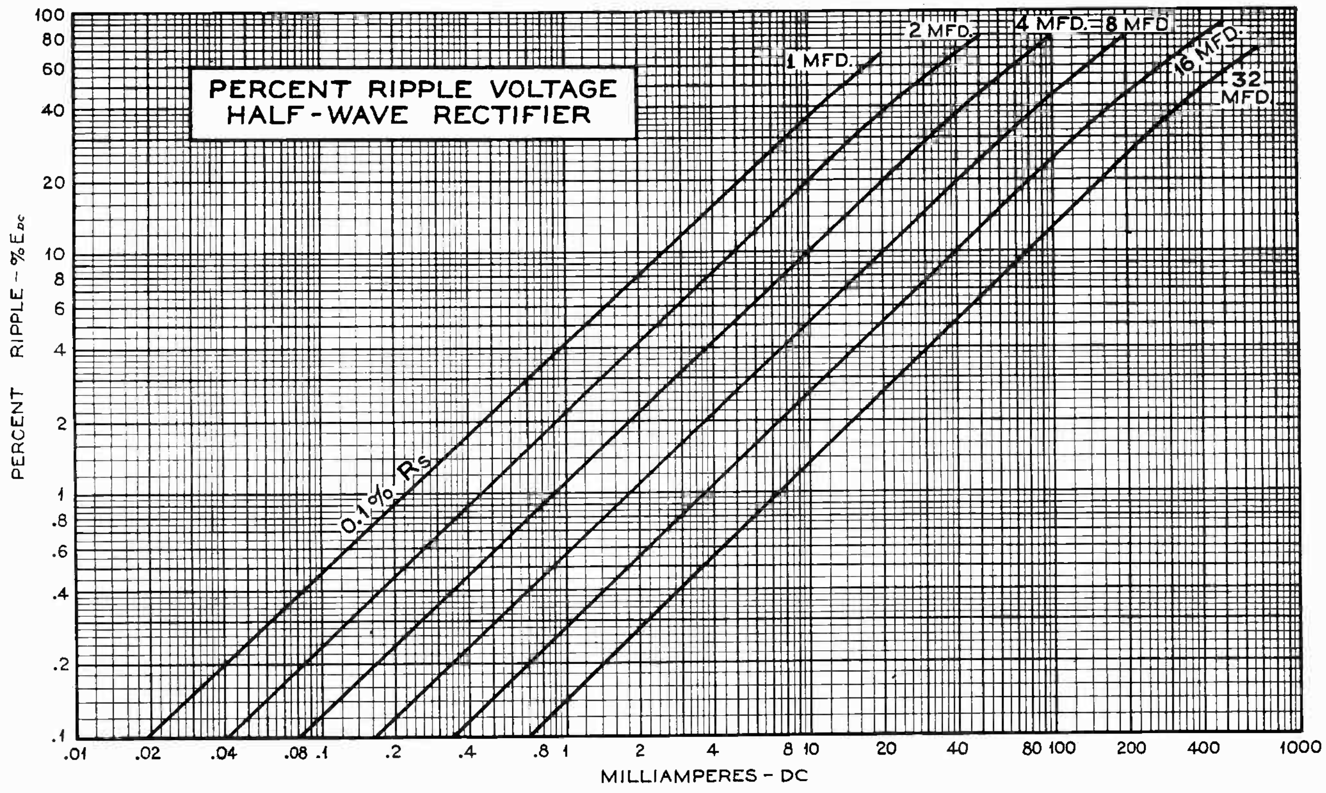


FIG. 9

must be used. The ratio of discharge time to the charging time of the half wave rectifier is very large, about twice as great as for the full wave condenser and the discharge curve being of exponential form, departs markedly from the approximately straight line curve that exists in the full wave rectifier. Because of this fact the determination of the DC output voltage of the half wave rectifier can be obtained only from empirical data, the maximum DC output voltage at no load being 1.41 times the RMS applied voltage. Figure 7 gives the current and voltage curves in the half wave rectifier and the curves of Figure 8 give the peak AC input voltage, neglecting tube drop, required to deliver 100 volts DC into various types of filter circuits. The ripple voltage of the half wave rectifier has a frequency equal to the frequency of the applied AC voltage and this maximum value is determined by the capacity of the input condenser and the load across it, Figure 9 gives the percent RMS ripple voltage based on the DC output voltage. These curves are drawn for 0.1% series resistance in the tube.

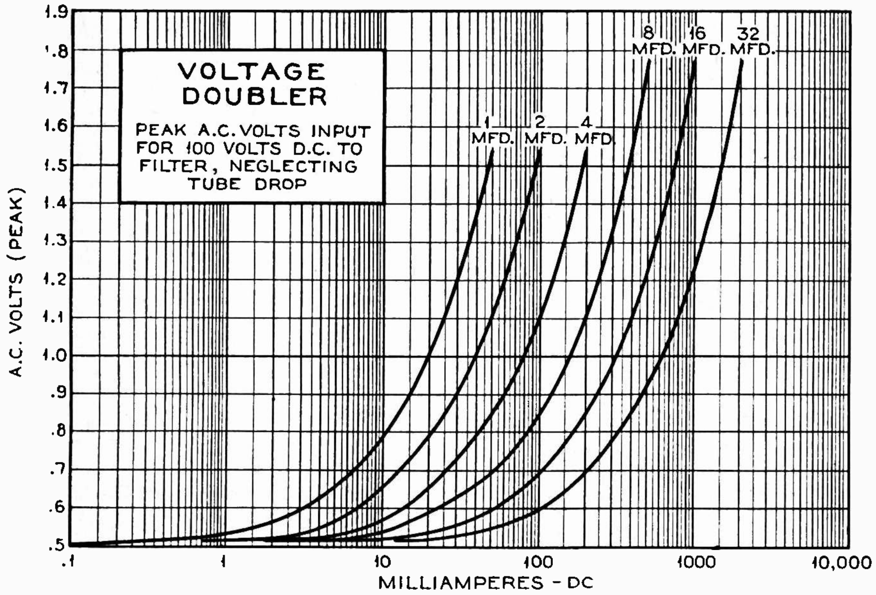
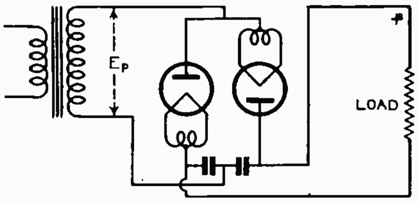
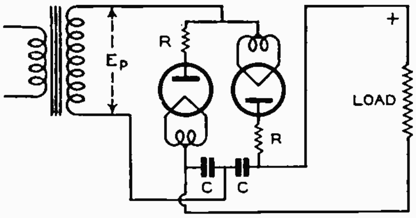


FIG. 10



VOLTAGE DOUBLER CIRCUIT

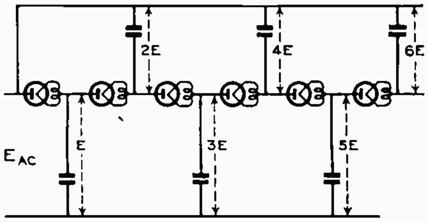


EQUIVALENT CIRCUIT

FIG. 11A

VOLTAGE DOUBLING RECTIFIER

An adaptation of the half wave rectifier is the voltage doubling rectifier, in which the AC voltage charges a condenser on alternate half cycles so that the condenser discharges in series with the rectifier tube. By this means the maximum DC output voltage at no load is equal to twice the peak AC voltage applied. Since part of the output voltage is obtained by the discharge of a condenser, the greater the size of the condenser, the smaller will be the voltage drop of the system and the higher will be the DC output voltage, approaching two times the peak AC voltage for infinite capacities or zero load. The curves of Figure 10 give the peak AC voltage required to deliver 100 volts DC to the filter, the tube drop being neglected as in the previous curves.

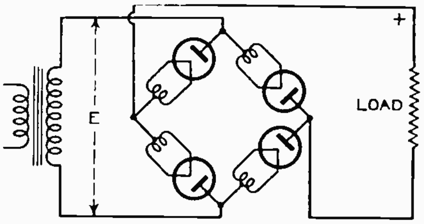


VOLTAGE MULTIPLYING CIRCUIT

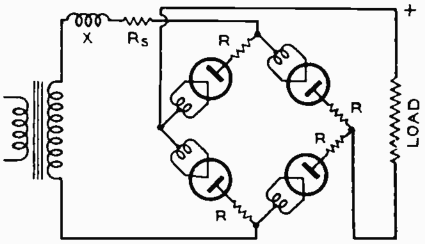
FIG. 11B

The ripple voltage of the voltage doubling circuit is of twice the frequency of the AC applied voltage and the magnitude is determined by the input capacity of the filter and the load across it. The curves of Figure 9 give the ripple voltage for the voltage doubling circuit. The regulation of the voltage doubling circuit is not as good as the regulation of the full wave rectifier as the voltage output of the system depends on the capacity of the input condensers used.

The principle of the voltage doubler may be extended so that a tripler, quadrupler or any multiple of voltage input may be obtained. The diagram of Figure 11B shows a circuit for a voltage multiplication of N times.



BRIDGE RECTIFIER CIRCUIT



EQUIVALENT CIRCUIT

R_S = EQUIVALENT TRANSFORMER RESISTANCE REFERRED TO SECONDARY.

X - EQUIVALENT TRANSFORMER REACTANCE REFERRED TO SECONDARY.

FIG. 12

BRIDGE TYPE RECTIFIER

The bridge type rectifier is used where a center tapped plate transformer is not available or where the peak inverse voltage of the tube in a full wave circuit exceeds the tube rating. The bridge type rectifier uses two tubes in series for rectifying each half cycle and therefore requires a total of 4 tubes for full wave rectification. In addition, three separate filament transformers or windings are required. The operation of the bridge type circuit is identical to the operation of the full wave rectifier except that two tubes are always in series and therefore the tube drop is twice as great as the tube drop in the full wave rectifier. Figure 12 shows the circuits of the bridge rectifier circuit.

REGULATION

Regulation of a power supply unit must be considered from two points of view, the regulation under steady state loads and the regulation under suddenly applied loads. Receivers using Class A output systems normally operate at constant load, the only variation in load being caused by the variation in the strength of the input signal which determines the bias voltages on the grids of R. F. and I. F. stages and therefore the plate currents. This load variation is relatively small and has but slight effect on the output voltage of the rectifier system.

Receivers using Class A-B or Class B output stages are subject to sudden drains on the plate supply on modulation peaks of the received signal. These load variations may be large enough to produce peak loads two or more times the normal load on the rectifier. The rectifier must be capable of supplying these peak loads without too great a voltage drop, or serious distortion will result. The large variation in voltage that occurs in a power supply system having poor regulation imposes a severe strain on the filter condensers at light loads or when the set is warming up. This latter condition may be minimized by using a rectifier tube whose heating time is the same as the heating time of the set tubes.

The poor regulation of a power supply can be attributed to any one or more of the following factors:

1. Poor Voltage regulation of the plate supply transformer.
2. High voltage drop in the rectifier tube.
3. Filter input condensers too small for given load.
4. Chokes having too high resistance.
5. Using output condensers having capacities too small for change in load.

These conditions are dependent on the type of rectifier circuit and filter circuit used, the choke input rectifier inherently having better regulation characteristics than the condenser input rectifier.

The size of the filter output condenser does not affect the steady state regulation of the power supply, but its value is of great importance in the dynamic regulation of the power supply. The dynamic regulation of a power supply differs from the steady state regulation in that the size of the choke and filter output condenser are of prime importance.

For a constant voltage supply or where the rate of change of load is more than the rate of change of current or voltage of the filter input, the dynamic regulation can be reduced to a minimum by making the capacity of the filter output condenser as large as possible. Doing this not only improves the dynamic regulation but also increases the ripple attenuation of the filter. The minimum size filter output condenser that can be used is theoretically given by

$$C = \frac{L}{R^2} \text{ MFD.}$$

L = inductance of series choke in henries

R = average load resistance.

The series resistance of the choke must be small compared to the load resistance, but as this is a condition for good steady state regulation, it is easily met.

Regulation or the drop in voltage at the filter output terminals with an increase in load causes the filter output terminals to look like an impedance when viewed from the load. By this is meant that the power supply can be considered as a perfect power supply without regulation and a series resistor. Aside from the variation in voltage and its attendant disturbances in the system, the power supply system having a high percentage of dynamic regulation causes coupling between circuits. Any current fluctuations in a connected circuit will produce a voltage across the power supply terminals equal to the product of the power supply impedance and the current variation. This voltage is also impressed across terminals of any other circuits connected to the same power supply. If there is any other coupling between the circuits, the common impedance may cause an unstable condition and produce oscillation. A high mutual impedance in the power supply is the usual cause of "motor boating" in high gain amplifiers.

To reduce the tendency to "motor boating" the power supply regulation must be reduced to a minimum. This can be done by proper design and the liberal use of condensers in the filter output circuit and the use of low resistance filter chokes and tubes having a small voltage drop. The use of a bleeder resistance at the filter output terminals will help in reducing the percentage static regulation but will have little effect on the dynamic regulation.

The best results are obtained by using voltage controlled rectifier systems in which the percent regulation can be kept down to less than ½ of 1%.

To improve the dynamic characteristic of the rectifier, the voltage regulator must be controlled by the output voltage and must have a time constant low enough to be able to follow the fastest variation in voltage or current produced by the load. In the average circuit, the frequency at which the system becomes unstable is quite low, so that extremely small time constants are not required. A time constant for an automatically regulated power supply of 0.1 seconds is normally low enough. Special applications may require other values. These can be determined from the nature of the load.

(Part II will be published in the October-November issue of the Research Worker.)

EXACT-DUPLICATE REPLACEMENTS

from

A to Z

That's precisely the idea of AEROVOX Exact-Duplicate Replacement Condensers. You can find a matched replacement for any set from A to Z and anything between, in the AEROVOX replacement line.

And don't confuse these units with so-called universal replacements. If you insist, AEROVOX too offers general-utility units which will do the job after a fashion, just as an ox-cart wheel will take the place of a Ford wheel—if absolutely necessary.

But AEROVOX Exact-Duplicate Replacements are absolutely matched. They fit right, work right, look right. And that's the way to do a real servicing job.

Get Your Copy . . . .

Latest general catalog contains 8 pages on exact-duplicate replacements. Look up any set and you'll find the required replacement. Meanwhile, your local live-wire jobber stocks AEROVOX replacements for your convenience.

AEROVOX CORPORATION

70 WASHINGTON STREET, BROOKLYN, N. Y.

Sales Offices in All Principal Cities