# HALF WAVE AND DOUBLER POWER SUPPLY SYSTEMS

## Introduction

Transformerless sets of the A.C.-D.C. and Voltage Doubler types are of special interest to the service engineer due to the frequency with which they appear on the repair bench. This fact is not so much an indictment of their design as it is an indication of their popularity. Due to both low price and convenience of size this general type of receiver outranks all other types in number in use.

The underlying reasons for the frequent failure of the power circuit components of these types of receivers have been of considerable mystery not only to the service man but also to many receiver design engineers. Rectifier tube and condenser failures were the rule not many seasons past and seemingly without "rime or reason" replacement tubes and condensers of reputable manufacture repeatedly failed shortly after their service installation. It was not unusual to find both a defective or "dead" rectifier tube and a shorted or open filter condenser in the same receiver. Tube and condenser companies were individually placing the blame on the manufacturer of the other component, since it was impossible to tell which component had failed first. Fortunately such a condition no longer exists. Co-operative study of the problem by tube and condenser manufacturers has resulted in a satisfactory explanation of the causes of component failure and a number of precautionary design principles are now being incorporated in current receivers.

Until quite recently the "transformerless" type of receiver design was confined to the smallest and least expensive models. A number of interesting advances in both the condenser and tube art have recently influenced design and more pretentious models are being offered in larger table cabinets and small consoles with voltage doubler types of power supply circuits. In some quarters the introduction of these types of voltage doubler receivers has been questioned as an attempt to mislead the customer since the receivers do not employ a power transformer. However, it should be evident that any effort to provide the public with a given level of performance at a lower cost is in the public interest if it is accomplished by the application of sound engineering principles and the employment of high quality components.

The introduction of the dual rectifier in one envelope (type 25Z5) in 1933 caused a mild flurry of doubler set development and a number of receivers have appeared from time to time with a doubler circuit. The apathetic attitude toward this type of circuit was caused by the lack of suitable output tubes and high capacitance filter condensers necessary to realize its advantages.

The revival of interest in this type of power supply circuit has been occasioned by the following factors:

**A. The availability of compact high capacitance dry electrolytic condensers.**

Both the high power output type of A.C.-D.C. sets and voltage doubler receivers require higher capacitance condensers than other types of filter circuits. As will be shown later the A.C. ripple current which the condenser must pass is likewise higher than for conventional transformer type filter circuits. Formerly both cost and size prohibited the use of high capacitance units. The introduction of type FP* (Mallory Fabricated Plate) condensers early in 1938, brought to the radio industry a unit which provided the high capacitance required in a compact and inexpensive construction.

*Registered Trade Mark

**B. The availability of vacuum tubes designed for economical series heater operation and high efficiency at relatively low plate voltages.**

Since the voltage doubler and high output half wave rectifier provide plate supply power without requiring a power transformer, it is necessary to operate the tube heaters in series connection with the power line. When the 6.3 volt series of tubes requiring 300 milliamperes were the only tubes available a high value of series resistance in the form of a line cord resistor or high "wattage" resistor was required to drop the voltage to the required value. This resulted in the waste of a considerable amount of power as heat. Several series of vacuum tubes with higher heater voltage ratings at lower series current have appeared which have stimulated the design of series heater receivers. Not only has the heater current been cut in half but the power is now used in the tubes to produce useful electron emission rather than wasted in a dropping resistor as heat.

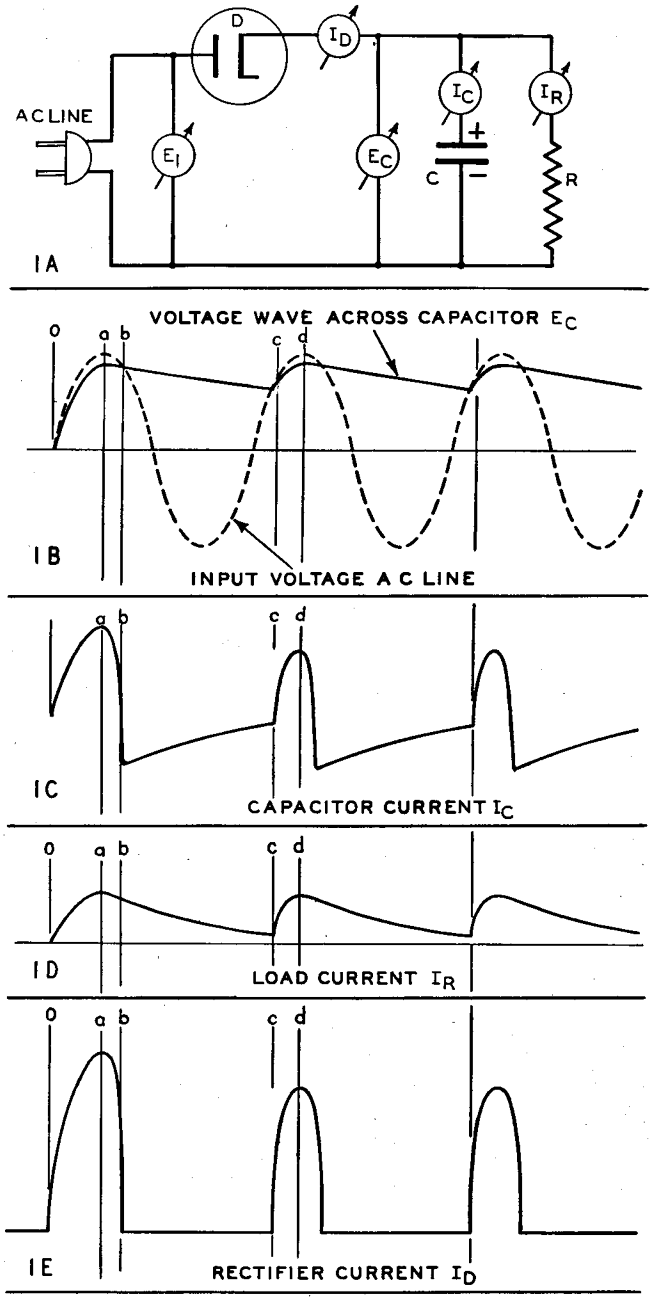
# Half Wave Rectifier Operating Characteristics

The voltage doubler and other voltage addition systems depend upon the successive valve action of half wave rectifiers. Since possible service failures of these systems are common in both cause and effect to those encountered in the half wave rectifier, the characteristics of the half wave system will be described in detail.

While the subject of the theory of half wave rectification has received some analysis in standard radio textbooks, such discussions as are available either treat the subject in a general descriptive manner or present mathematical formulas whose applications to the practical case are involved and tedious. In such cases the assumption is made that the resistance of the rectifier tube and supply line are negligible compared with the load resistance. This is not the case under some conditions of use and it is felt that a presentation of the subject illustrated by characteristic curves of measurements made on a typical circuit will be of value. The available rectifier tubes for A.C.-D.C. set operation are sufficiently identical in operating characteristics to allow a single group of curves to be presented.

In Fig. 1A is shown a simplified diagram of a half wave rectifier with condenser input. When an alternating voltage is applied to this circuit the diode rectifier is conductive during that portion of the cycle over which its plate is positive with respect to the cathode. Assuming the condenser to have no initial charge, as at time of 0 of Fig. 1B, the current flowing in each of the two branch circuits C and R is the same as it would be if they were entirely separate until the condenser is charged to the peak voltage of the supply as at time (a). During this initial charging period the shape of the current wave flowing in the resistor is essentially sinusoidal and in phase with the input alternating voltage as shown in Fig. 1D from time 0 to (a). During this same time interval charging current is flowing into the condenser as shown in Fig. 1C from time 0 to (a). The current through the rectifier is the sum of these two currents and is shown in Fig. 1E. When the peak has been reached the capacitor will start to discharge through the load resistor but the resistor also continues to pass current from the line through the rectifier. As soon as the voltage drop in the load resistor due to the current discharge from the capacitor exceeds the instantaneous value of the input supply voltage, the anode of the rectifier becomes negative with respect to its cathode and it ceases to conduct. This occurs at time (b) of Fig. 1E. The capacitor continues to discharge through the load resistor with the current decaying exponentially as shown from time (b) to

FIGURE I VOLTAGE AND CURRENT WAVE SHAPES IN HALF WAVE RECTIFIER WITH CONDENSER INPUT.



(c). During this time the voltage drops as shown from (a) to (c) in Fig. 1B. Since with the usual choice of circuit constants the capacitor is not completely discharged when the supply voltage again becomes positive, the start of charging current is delayed until the instantaneous supply voltage exceeds the capacitor terminal voltage. This occurs at point (c) of Figure 1B.

It will be observed that the wave shapes of both the current and voltage waves are far from sinusoidal and that the peak current through the rectifier tube may be many times the average or D.C. load current. The actual magnitude of these ripple currents and voltages are determined by the value of the input filter condenser, the size of the load resistor, and the supply line frequency.

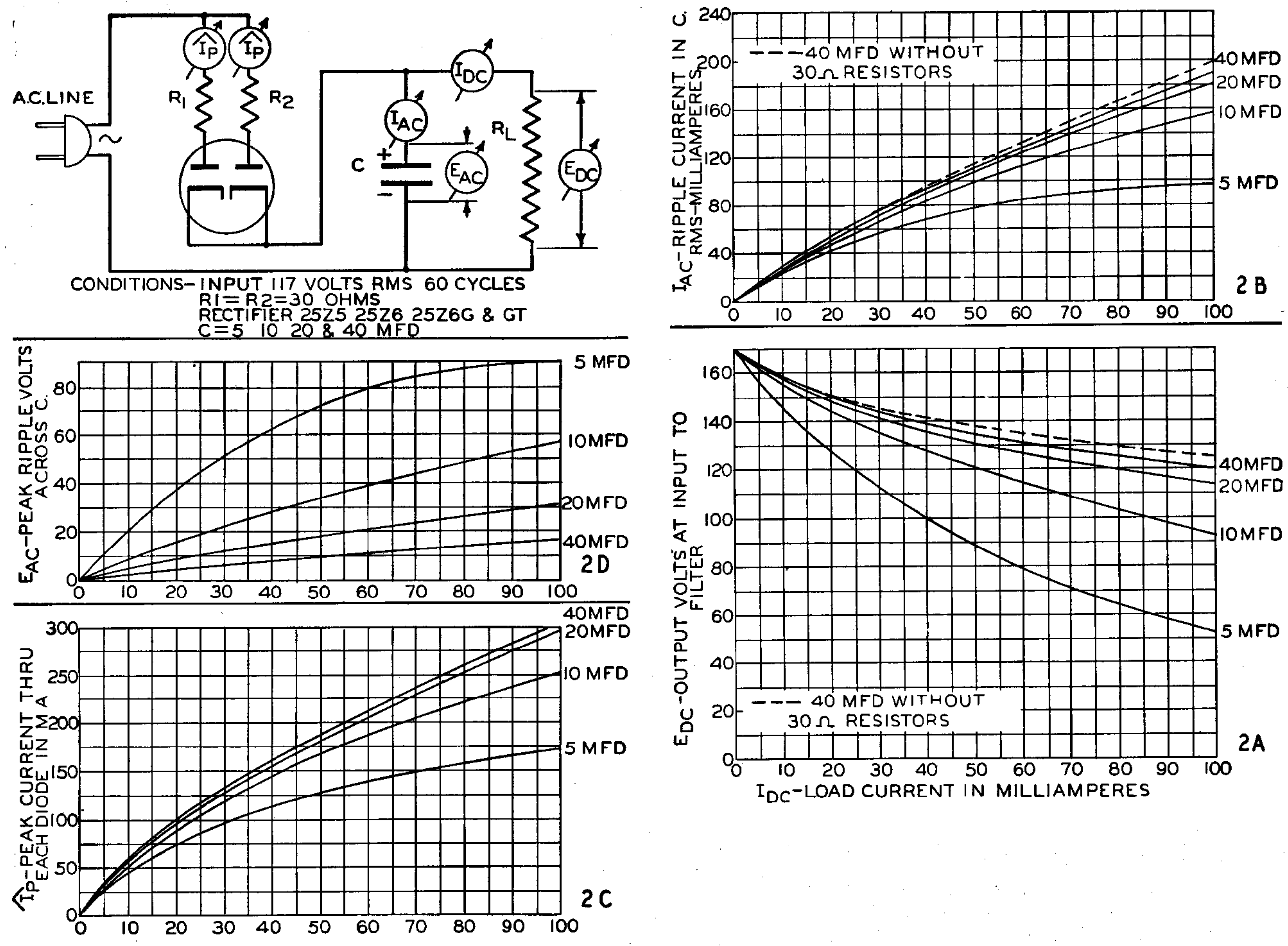
Fig. 2 illustrates a series of measurements made with typical operating conditions. It will be noted that a line voltage of 117 has been chosen as standard since this value is representative of the average line voltage encountered in actual use. A series resistor of 30 ohms has been connected in the lead to each anode. The use of these resistors as a protective measure will be discussed later. Similarly the capacitor values of 5, 10, 20 and 40 microfarads are consistent with the current practice rather than the 4, 8, 16 and 32 series still retained in the tube data books.

Since the various ripple voltages and currents are seen from Fig. 2 to vary through wide limits with load current and with variation of input capacitance it is of importance to consider the limiting factors of performance and safety of operation of the tube and the condenser.

## A. R.M.S. Ripple Current in the Initial Filter Condenser

The RMS ripple current flowing into the input filter condenser as measured by a thermocouple type of current measuring instrument is shown in the series of curves of Fig. 2B. There are two effects of this ripple current flowing in the condenser which must be considered to determine whether the operating conditions are safe for any particular capacitor, namely heating effect and tendency to reduce the effective capacitance by the formation of a film on the cathode plate of the capacitor.

FIGURE 2 HALF WAVE RECTIFIER CHARACTERISTICS



1. *Heating Effect of Ripple Current*

Electrolytic types of filter capacitors exhibit a series resistance characteristic at power line frequencies which, although of negligible effect on the filtering efficiency cannot be disregarded from the standpoint of heating effect. The RMS ripple current flowing through the series resistance of the capacitor causes a temperature rise which augments the usually high ambient temperature in sets of the A.C.-D.C. type. Such sets are generally housed in small enclosed cabinets having restricted ventilation capabilities. The ability of the condenser to radiate the heat depends upon its construction and also upon its position on the chassis with respect to other hot components such as rectifier and output tubes, location of ventilating louvres and presence of convection drafts.

It is generally conceded that a condenser in a metal can construction will radiate its internal heat more efficiently than a cardboard tube unit, and it is also evident that the input unit in a common cathode concentric wound type of construction should be on the outside of the roll and thus closest to the container.

If the temperature of the condenser is allowed to exceed approximately 90° Centigrade, the capacitor may become permanently damaged by a "run-away" characteristic in which the internal temperature of the capacitor is augmented by increased direct current leakage. This has been a frequent cause of capacitor failure in cases in which a receiver has been operated for long periods of time with restricted ventilation. It is for this reason that compact receivers should never be placed in locations such as in bookcases, etc., where free circulation of air will not occur.

Until quite recently, the lack of standardization of size and construction of capacitors for A.C.-D.C. and voltage doubler service has made it difficult to predict whether a given capacitor would give satisfactory service. Determination of this characteristic could only be made by measuring the ripple current heating by means of a thermocouple imbedded in a sample condenser, the condenser being life tested under conditions of similar ambient temperature. Fortunately this situation has been remedied by the introduction of standardized compact units as typified by the (Mallory) FP construction. This unit, with its fabricated plate design, hermetic sealing, and metal can construction has proved by extended life tests its ability to withstand both high ambient temperature operating conditions and high superimposed current ripple. For the condenser section on the outside of the roll of the FP condenser in applications discussed in this book it is permissible to allow 10 milliamperes RMS current ripple per microfarad in a 60-cycle half wave or doubler application with a 60° Centigrade ambient temperature. For the 25-cycle ripple condition, it is permissible to allow 8 milliamperes RMS ripple current per microfarad of input filter capacitance.

Condenser manufacturers have published permissible ripple current ratings for their particular units. It should be noted that most of these ratings are specified for the 120-cycle rating of the full wave type of circuit. In cases of high ripple (200 MA or more) the manufacturer should be consulted for recommendation of a particular type of construction.

With the foregoing in mind it is instructive to examine Fig. 2B with respect to the conditions of operation of the capacitor. It will be noted that the 5-mfd. curve exceeds the above recommended current for all values of D.C. load current beyond 25 MA. The 10-mfd. curve exceeds the limit for all values of load current beyond 50 MA. The curves for higher values, i.e., 20 and 40 mfd., exhibit no limitation within the limits of the curves. From the standpoint of ripple current alone it would appear that a very high value of input condenser should be specified. It will also be noted that a high value of input capacitor results in better regulation curves as shown in Fig. 2A. The upper practical limit of capacitor size is dictated usually by a balance of economic factors and performance requirements. Another factor enters the picture in the effect of the size of the input capacitor on the operating conditions of the rectifier tube. This will be discussed later under the subjects of peak rectifier current and rectifier-condenser failures.

2. *Effect of Ripple Current on Cathode Film Formation*

The electrolytic condensers employed are of the polarized type in which only the anode or positive plate has been formed or provided with the insulating film. The superimposed A.C. ripple tends to form a film on the cathode similar to the anode film during the portions of the cycle when current flows from the capacitor. This cathode film interposes a capacitance in series with the anode film capacitance and thus tends to reduce the effective total capacitance of the unit with continued application of high ripple current. In the older type of large smooth or plain plate condensers the capacitance of this cathode film was so high, due to the large areas of plate required per unit of capacitance, that the total effective capacitance was reduced very little as the result of cathode formation on high ripple. As the size of the capacitor is reduced by the employment of either etched or fabricated anode construction (a fabricated plate anode has approximately 1/10th the area of plain plate for the same capacity) the effect of cathode film formation on effective capacitance becomes very apparent especially if the cathode plate is a piece of plain foil. For this reason FP condensers specified for A.C.-D.C. or voltage doubler service are made with cathode plates of etched foil to obtain an effectively large cathode area and thus a higher cathode film capacitance for a given ripple current. This construction has proved a satisfactory answer to the problem.

## B. Peak Ripple Current Through the Rectifier

Fig. 2C shows the variation of the peak current through each rectifier with size of input filter condenser and D.C. load current. In the circuit shown the total peak rectifier current for the tube which consists of two diodes in one envelope would be twice the values shown on the curves. A fact not usually considered is that the peak value of current through the tube can be many times the average

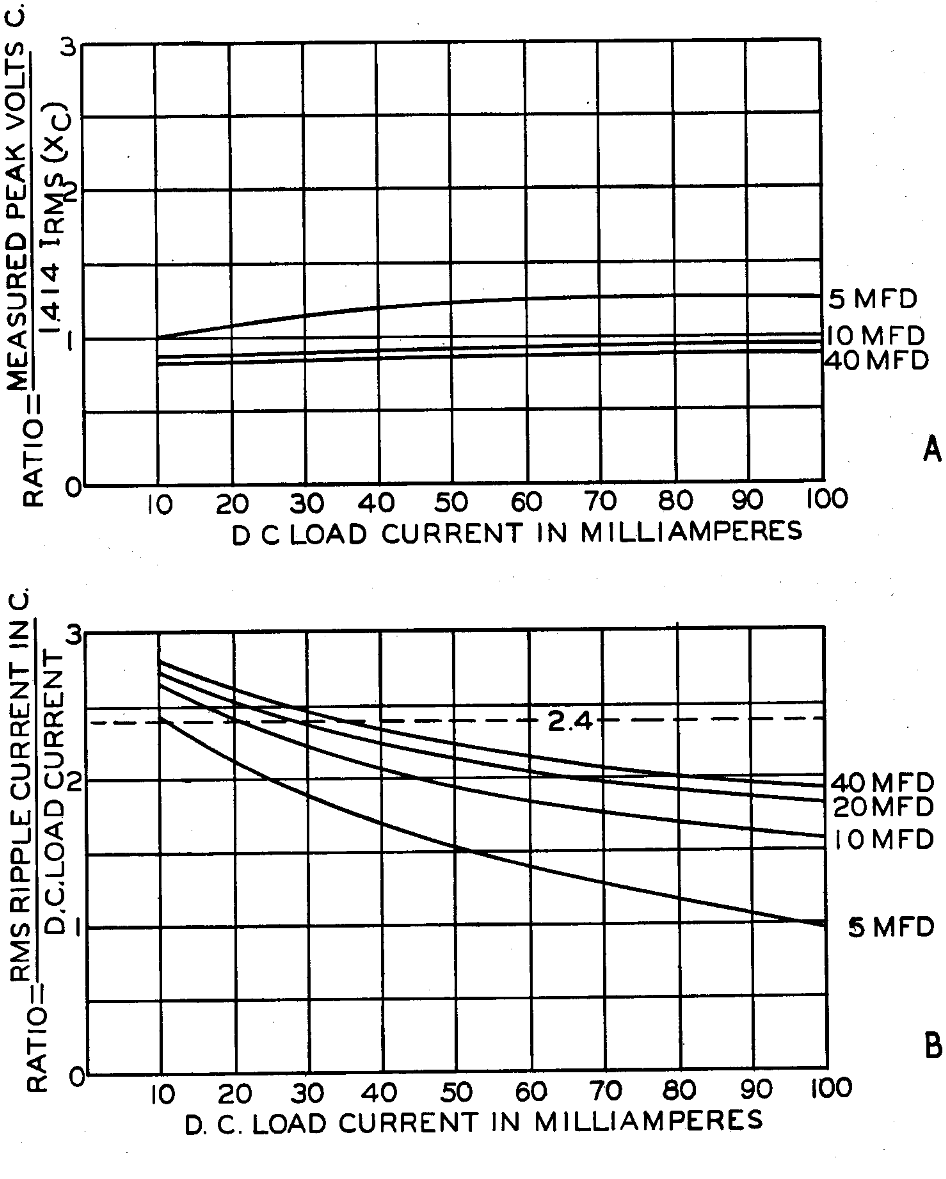
D.C. current flowing through the filter. The reason for this is evident from Fig. 1E in which it is seen that plate current flows through the rectifier for only a portion of the cycle and during this short time pulse enough energy must flow to restore the loss of charge of the filter condenser due to the load current. For each type of rectifier tube there is a maximum plate current rating. For the type 25Z5 or 25Z6 this rating is 500 milliamperes. If this rating is exceeded in normal continuous operation short rectifier life may result. This condition places a practical limit on the size of input condenser which may be safely used unless a series resistor is employed in the plate circuit of the rectifier tube to limit the peak plate current to maximum recommended value. The use of such a series resistor, while occasioning the loss of a few volts of plate potential, provides a protection to both tube and condenser which, it is predicted, will assure long life to A.C.-D.C. and voltage doubler sets. The incorporation of a 30 to 50 ohm resistor in older receivers will prevent premature failure of rectifier tubes or filter condensers and is to be recommended.

## C. Peak Ripple Voltage Across Input Filter Condenser

The ripple or hum voltage across the filter condenser is of a wave shape similar to that shown in Fig. 1B. The magnitude of this voltage in a practical case is shown in the curves of Fig. 2D. It will be seen that the peak ripple voltage shows more variation with increasing capacitance than does the other characteristics shown in Fig. 2. Since the voltage wave form is dependent to a great extent upon the values of input capacitance and load current or resistance, it would at first appear that there would be no method of correlating the peak voltage with any of the other characteristics. In order to determine whether the condenser had a safe margin with respect to voltage, a vacuum tube voltmeter reading of the peak voltage would seem to be necessary. Fortunately it is possible for the practical case to arrive at a figure for peak voltage from a knowledge of the D.C. load current and the RMS ripple current flowing in the first condenser. Fig. 3A shows that for the case of high capacitance input the peak voltage is within 10 percent of the value which would be estimated on the assumption that both the ripple current and ripple voltage are of sine wave form. The practical significance of this fact is of value when considered in the light of the curves shown in Fig. 3B. From these curves it is evident that if the D.C. load current is multiplied by the figure 2.4, an approximation of the RMS A.C. ripple current will be obtained. This figure will give a conservative margin of safety since practical applications involve load currents of more than thirty milliamperes D.C. Thus it is possible to arrive at an estimate of all of the working conditions in a half wave rectifier circuit from a knowledge of the D.C. output voltage and current, or more simply the D.C. current alone.

Since the electrolytic condensers used for this service are normally of the 150-volt rating which are formed at 200 volts D.C., peak voltages will not be dangerous unless they closely approach this latter figure. In normal applications on 60-cycle supply with half wave rectifier systems, it is unusual for the D.C. voltage plus the peak

FIGURE 3 RATIOS OF CONDENSER VOLTAGE AND CURRENTS TO D.C.LOAD HALFWAVE



ripple voltage to approach the formation voltage of the anode film. This may be seen from Figs. 2A and 2D which when added give the peak voltage to which the input capacitor is subjected. In 25-cycle operation, on the other hand, there may exist conditions in which the peak ripple plus the D.C. voltage may equal or exceed the formation voltage of the anode film of the 150-volt unit. Such applications require the employment of a higher voltage rating. This arises from the fact that the reactance of the condenser is higher at the lower frequency. The peak conditions occurring in voltage doubler circuits will be considered later.

# Voltage Doubler Power Supply Systems

A number of receivers have appeared recently in which the power systems employ several half wave rectifiers connected in such a manner as to add their rectified output to produce a D.C. voltage greater than the peak line voltage. This general type of power system has been given the name of voltage doubler although it produces twice line peak voltages only for the conditions of very high capacitor values and negligibly small load currents. A more appropriate name might be voltage addition power systems.

In analyzing these circuits it is evident that there are two general types in use of which a number of variations have appeared. The general classes might be given the names: (A) Symmetrical or Balanced Type and (B) Series or Common Line Type.

Recently these types have also been referred to as the full wave and half wave doublers respectively. These designations probably arise from the fact that the former exhibits a ripple frequency of twice the line frequency across the entire filter input while the latter impresses an input ripple of line frequency.

**Examples of recent models employing voltage doubler power supply systems follow:**

**Type (B) Zenith:** Model 6R485, Chassis No. 5672-P, Tube Complement 50Z7G-Rectifier, 12A8G, 35L6G, 12K7G, 12Q7G.

Model 6R481, Chassis No. 5675. Identical to Model 6R485, **without** automatic tuning feature.

**Type (A) Galvin (Motorola) Model 61F,** Tube Complement—25Z5, 25B6G, 25B6G, 6D6, 6A7, 6Q7GT.

**Type (A) Farnsworth Television and Radio Corporation**

*Models:* ATL-50, ATL-51, ATL-52, ACL-55, ACL-56, AKL-58, AKL-59.

*Chassis:* C2-1, C2-2, C2-1, C2-3, C2-3, C2-4, C2-4 respectively.

All of these models and chassis numbers embody the following Tube Complement: 25Z6GT, 25L6GT, 6SK7, 6SK7, 6A8GT, 6SQ7, 6H6.

**Type (A) Crosley Radio Corporation:** Model 719. Tube Complement: 6A8, 6SK7, 6P5, 6SF5, 25L6, 25Z6, 25Z6. Late in the season, Crosley added two models, No. 739 and No. 7739, which use the same Tube Complement as Model 719, but employing the series or half-wave doubler (Type B).

**Type (B) General Electric:** Models HJ905 and HJ908. Tube Complement: one each 12SA7, 12SK7, two each 12J5GT, one each 12SF5, or 12SF5GT, 25C6G, 6AB5 or 6N5, two each 25Z6G, or 25Z6GT.

General Electric Models H736 and H708. Tube Complement: 6SA7GT, 6SK7GT, 6Q7GT, 6J5GT, 25C6G, two No. 25Z6GT.

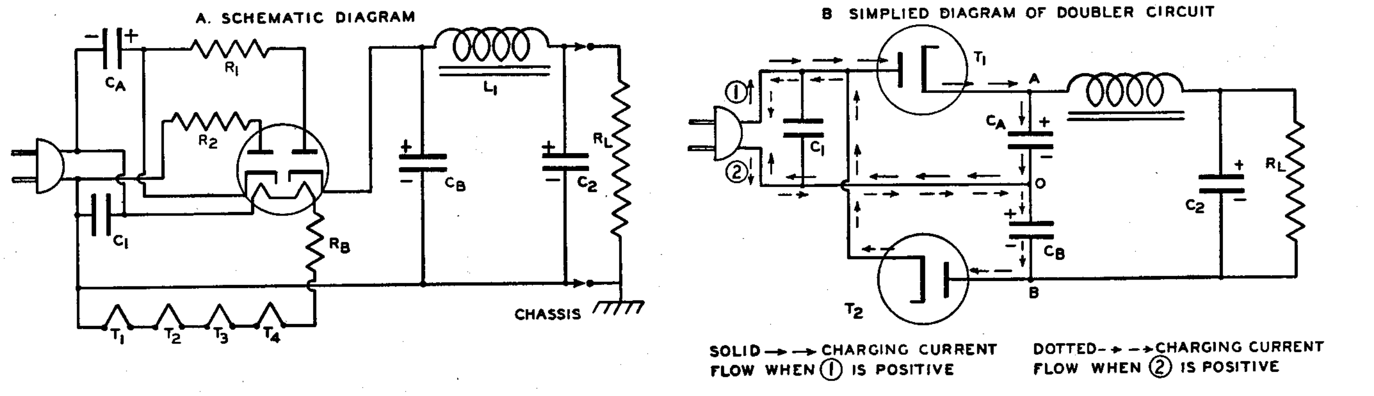
# The Symmetrical or Full Wave Type of Voltage Doubler

This type of circuit shown in Figs. 4A and 4B will be recognized as the most common and is the one usually illustrated in tube data books. Fig. 4A is drawn in schematic form as it would occur in a receiver circuit diagram. Peak current limiting resistors $R_1$ and $R_2$ have previously been discussed in connection with the half wave rectifier. Filaments $T_1$ through $T_4$ represent the heaters of the other tubes of the receiver. Resistor $R_3$ is the line dropping resistor previously mentioned. To follow the voltage doubling action this schematic diagram has been simplified in Fig. 4B with only the portion of the circuit essential to its action retained.

The circuit action may be explained as follows: When the line voltage polarity is such that point 1 is at a positive potential with respect to point 2 a current will flow in the direction of the solid arrows through rectifier tube $T_1$, thus charging condenser $C_A$ so that point A is positive with respect to point O. During this half period no current will flow through the rectifier tube $T_2$ since its plate is then negative with respect to its cathode. During the next half cycle, current will flow only through $T_2$ since point 2 is then positive with respect to point 1 and charging current will flow as shown by the dotted arrows charging condenser $C_B$ negatively with respect to point O. The potential difference between points A and B (if the condensers did not discharge) would be twice the line peak voltage. Actually one condenser is discharging through the load while the other is being charged, in much the same manner as the input condenser discharged in Fig. 1B during the alternate half cycles. Thus if the dotted sine curve of Fig. 5 represents the line potential of points 1 and 2, the curves A and B will represent the potentials of A and B respectively with regard to O. The potential difference between A and B is therefore obtained by adding the curves as shown by curve E (Fig. 5) which represents the voltage input to the filter. It will be seen that although the condensers are charged for only a portion of the half cycle and thus the ripple frequency occurring across the individual condensers is of line frequency, the voltage fluctuations occurring across the entire circuit leading to the filter is double the line frequency. In this regard the symmetrical type of doubler is similar to a full wave rectifier in that the hum frequency is twice the line frequency. If capacitors $C_A$ and $C_B$ are not approximately equal in capacitance the ripple voltage across one of them will overbalance that across the other and a hum component of line frequency will be evident.

It has usually been assumed that the two condensers of a doubler circuit of this type will be identical in capacitance value and such is usually

FIGURE 4 SYMMETRICAL OR BALANCED TYPE OF VOLTAGE DOUBLER


A. SCHEMATIC DIAGRAM

B SIMPLIED DIAGRAM OF DOUBLER CIRCUIT

SOLID → → CHARGING CURRENT FLOW WHEN ① IS POSITIVE

DOTTED- → - →CHARGING CURRENT FLOW WHEN ② IS POSITIVE

the case. At least one circuit has appeared, however, in which condenser CB was made twice the capacitance of CA.

## Typical Operating Characteristics of the Symmetrical Doubler

In Fig. 6 are shown a series of measurements of a typical voltage doubler circuit of this type. The data was obtained with an average tube and type FP condensers of 150-volt D.C. working rating as CA and CB. It will be noted that the curves are in general quite similar to the half wave rectifier characteristics shown in Fig. 2 except for the higher output voltages obtained. It is of interest to observe that the ripple currents in the individual condensers bear a slightly lower ratio to the D.C. load current than in the half wave case and that the "rule of thumb" ratio of 2.4 is generously safe.

The peak voltage values of Fig. 6D should be added to half the D.C. voltage values of Fig. 6A to obtain the maximum voltage to which the individual condenser are subjected for any given load condition. It is evident that for the conditions shown the 150-volt type of unit which will accommodate a value approaching 200-volt peak is safe even for the case of the 5-mfd. units. However, the use of 5-mfd. units would not be safe from the standpoint of ripple current.

The type 25Z5 tube is rated for a maximum D.C. load current of 75 MA for doubler service and although the curves of Fig. 6 have been extended to 100 MA it has become the practice to employ two rectifier tubes with their elements in parallel if the load current requirements exceed 75 MA.

The peak diode current can become quite high for high values of input capacitance as shown in Fig. 6C. Conditions of operation should be so chosen as to keep this value below 450 MA peak per plate for the type 25Z5 or 25Z6 tube. The use of the protective series resistors assists in keeping this current within safe limits.

## Operating Conditions of Capacitors in Symmetrical Doubler Circuits

Assuming the capacitors of Fig. 4 to be of equal size it is evident that the conditions under which the individual units operate are similar to the half wave rectifier application as explained under operating characteristics. Since the voltage across the individual condensers are added in series, the voltage rating of these con-

FIGURE 5 ADDITION OF POTENTIALS IN SYMMETRICAL DOUBLER SHOWING RIPPLE FREQUENCY OF DOUBLE SUPPLY FREQUENCY

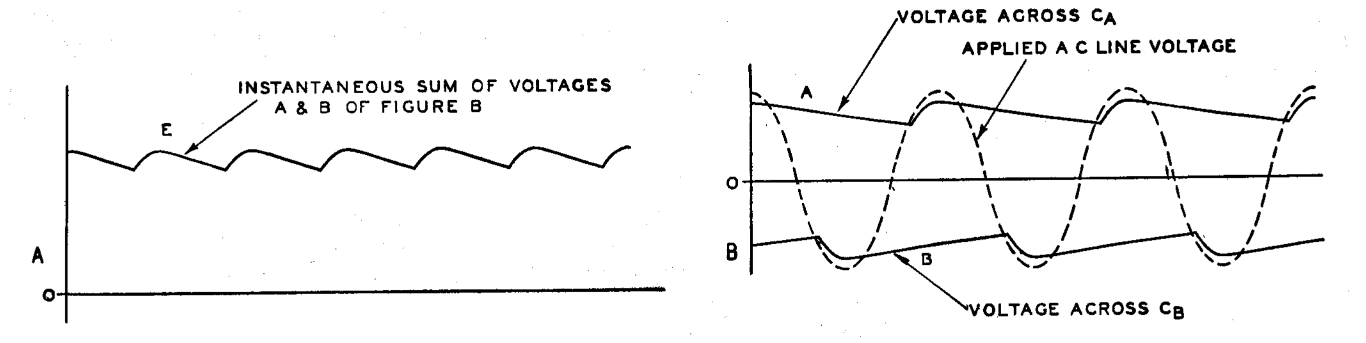
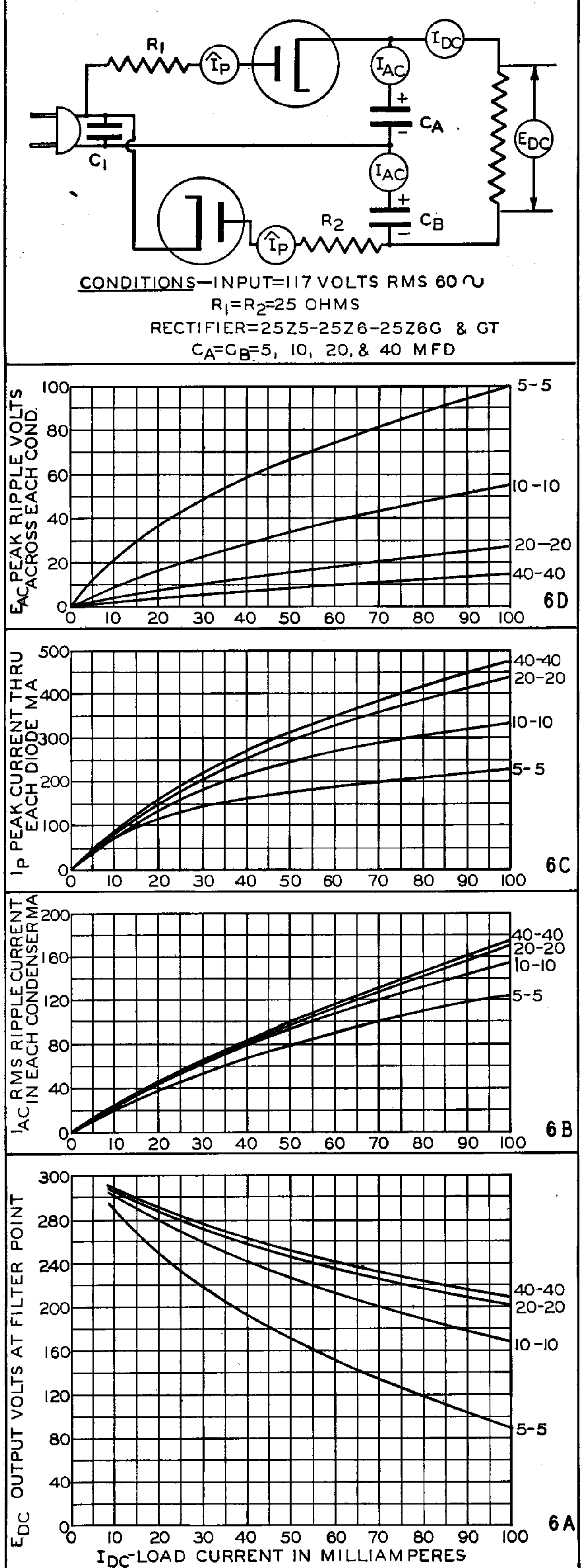


FIGURE 6 SYMMETRICAL DOUBLER
TYPICAL CHARACTERISTICS



CONDITIONS—INPUT=117 VOLTS RMS 60 ∿
$R_1=R_2=25$ OHMS
RECTIFIER=25Z5-25Z6-25Z6G & GT
$C_A=C_B=5$, 10, 20, & 40 MFD

densers need be no higher than for the half wave rectifier applications, 150-volt working condensers are usually specified for this type of circuit. Such condensers are safely rated for all except unusual conditions of extremely high ripple peaks as might occur with low capacitance values and 25-cycle supply lines.

It will be noted that condenser $C_B$ has its cathode connected to the chassis and thus if it is of metal can construction the unit may be directly mounted on the receiver chassis. Condenser $C_A$, on the other hand, must have its can insulated from the chassis and be suitably covered to prevent accidental contact of any grounded parts with the can of the condenser. One side of the power line is connected to the junction of these two condensers designated as point O in Fig. 4B. Since either side of the power line circuit may be grounded depending on the direction in which the attachment plug is inserted in the power outlet, it is evident that care must be taken in the design of transformerless sets such as the A.C.-D.C. and doubler types from the standpoint of shock and fire hazard.

The output condenser of the filter ($C_2$ of Fig. 4), must of course be rated at a value determined by the full output of the doubler less the filter drop and is usually a 250-volt rated unit.

## Considerations of Circuit Returns and Power Line Grounding in the Symmetrical Doubler

Of importance from the performance standpoint is the effect of circuit returns and power line grounding conditions on hum pick-up in the audio circuits and hum modulation of the oscillator. Either the metal chassis or a negative bus wire is made the return point for the RF, IF and audio grid circuits as well as their respective cathode or cathode bias circuits. The heaters of all these tubes are connected in series with a suitable voltage dropping resistor across the power line. In half wave circuits such as are shown in Figs. 1 and 2 the power line can readily be connected directly to the **return** side of the grid circuits (negative side of filter output), if suitable protective measures are taken to reduce shock and fire hazard. In these circuits the succession of heaters starting from the chassis is usually as follows: Second detector at ground on chassis, then first detector, if of the converter type, or oscillator if of the separate tube type, then in succession the other heaters in order of the audio and radio gain until the output tube and the rectifier are found at the other end of the series string. By this method the D.C. and A.C. differences of potential between the heaters and their respective cathodes are kept low for the tubes most likely to introduce either audio or carrier modulation hum.

In the symmetrical doubler circuit of Fig. 4A it will be seen that there exists a D.C. voltage difference of half the B supply voltage between the chassis and the first heater of the series string $T_1$ and that upon this D.C. potential difference is superimposed the ripple voltage of $C_B$. Fortunately modern tubes have very low cathode to heater leakage as well as improved heater constructions which keeps this source of hum at a minimum. As mentioned above certain recent receiver models employing this type of doubler circuit have departed from the usual symmetry of capacitance and have made $C_B$ twice the capacitance of $C_A$. This reduces the RF impedance between chassis and power line, as well as reducing the ripple voltage between heater and cathode of the first tube in the series string.

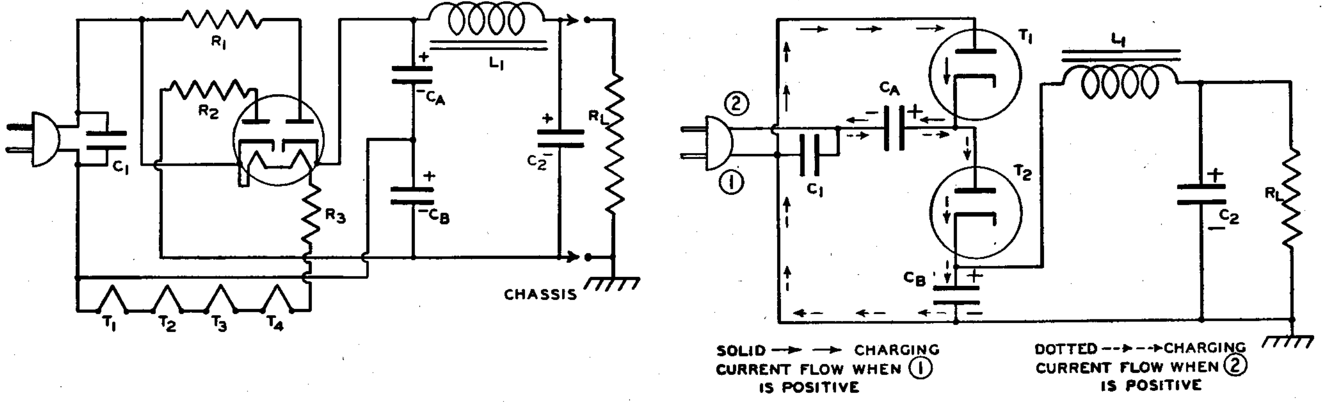
## Common Line or Series Line Feed Type of Doubler Circuit

Another general type of voltage doubler circuit has been variously called the common line, series line feed type, or half wave doubler, is shown in Figs. 7A and 7B. This circuit operates in a somewhat different manner from the one just described and might be designated as a voltage addition or multiplier circuit rather than a doubler circuit. It was proposed prior to 1933 and has found occasional application since that time. It will be noted that this circuit allows one side of the power line to be connected directly to the negative side of the filter output and thus overcomes the difficulty of a high voltage difference between heater and cathode of the high gain tubes at the chassis end of the heater series string. The circuit is shown in schematic form in Fig. 7A and in simplified form as Fig. 7B. Only the portions of the circuit essential to an explanation of its action have been retained in Fig. 7B.

The operation of the circuit may be explained as follows: Assuming point 1 to be positive with respect to point 2 during the initial half cycle, charging current will flow in the direction shown by the solid arrows through rectifier tube $T_1$, until capacitor $C_A$ assumes a charge equal to the instantaneous potential of the line. During the next half cycle as point 2 becomes positive with respect to point 1 the charge of condenser $C_A$ will add its potential to that of the line and current will flow through rectifier tube $T_2$, charging capacitor $C_B$ to a potential equal to the sum of the charge in $C_A$ plus the line peak. The path of this action is shown by the dotted arrows. This action would result in a charge of condenser $C_B$ of twice the peak line potential if it were not for the fact that this condenser begins discharging through the load the instant that current starts flowing through rectifier tube $T_2$. A cursory analysis of this circuit would indicate that since current seems to flow in both directions through capacitor $C_A$, as shown by the solid and dotted arrows, a non-polarized type of electrolytic condenser would be required. This is not the case and it is possible to use a standard polarized type in this position. After the steady operating condition is reached the net charge, which capacitor $C_A$ receives during the half cycle when $T_1$ is conductive, balances its discharge on the succeeding half cycle, since $C_A$ acts as a reservoir to supply the loss of charge of $C_B$ by current through the load. It will be seen that the polarity of $C_A$ never reverses and thus a polarized or common type of electrolytic condenser may be used.

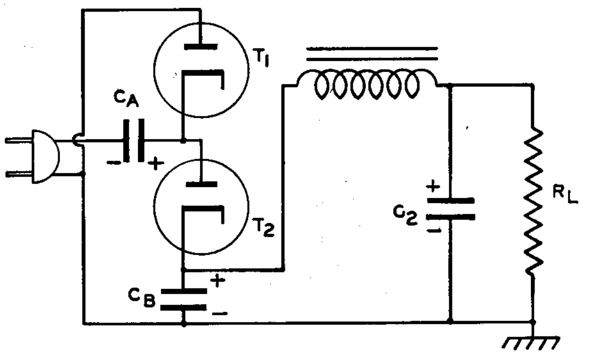
Fig. 8 shows the general nature of the voltage and current wave shapes in this type of doubler circuit. These are seen to be quite dissimilar to those encountered in the half wave rectifier and symmetrical or full wave doubler circuits and a word or two of explanation may be in order. The shape of the pulses for the first two cycles are somewhat conjectural since it is difficult to observe them on the cathode

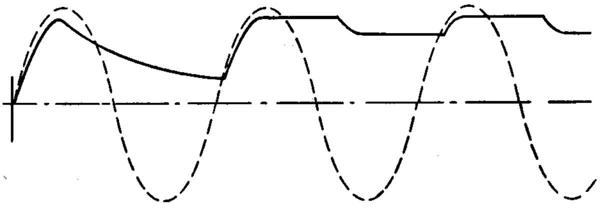
FIGURE 7 COMMON LINE OR SERIES LINE FEED TYPE OF DOUBLER CIRCUIT


A SCHEMATIC DIAGRAM

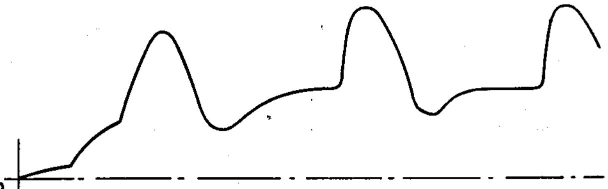
B SIMPLIFIED DIAGRAM OF DOUBLER CIRCUIT

FIGURE 8 VOLTAGE AND CURRENT WAVE SHAPES IN COMMON LINE TYPE VOLTAGE DOUBLER

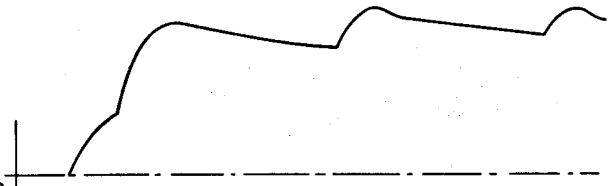




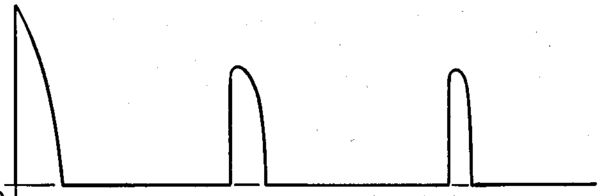
A VOLTAGE ACROSS $C_A$



B VOLTAGE SUPPLY TO $T_2 + C_B$

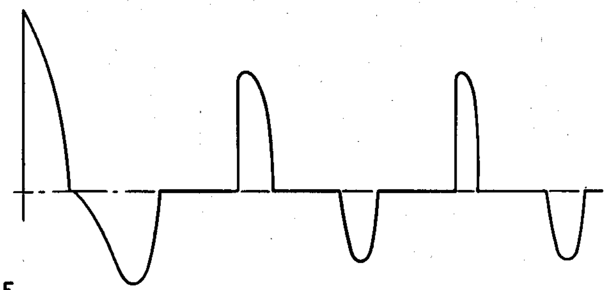


C VOLTAGE ACROSS $C_B$



D CURRENT THROUGH $T_1$

E CURRENT THROUGH $T_2$



F CURRENT THROUGH $C_A$

ray oscillograph without elaborate transient sweep devices. After the steady slate operating conditions have been reached, the charging current pulses into condenser CA (through $T_1$) are of very short duration since it is only necessary to restore the loss of voltage occasioned by the transfer of its charge to CB during the portions of the succeeding half cycles when $T_2$ is conductive. The discharge pulses from CA are of longer duration since current not only flows into condenser CB but also into the load resistor during this time period. A condition of equilibrium is reached when the area of the charge pulse is equal to the area of the discharge pulse and then, due to the difference in time duration of the pulses, the current wave may be quite assymetrical as shown in Fig. 8F.

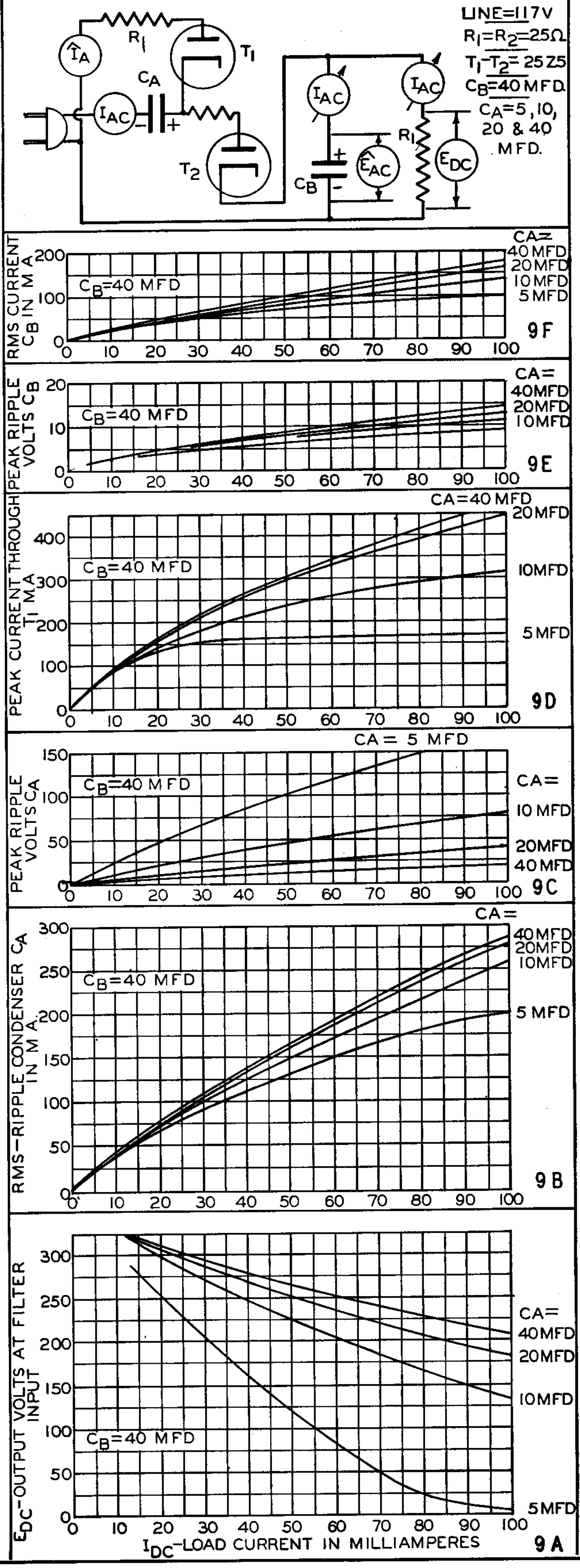
## Typical Operating Characteristics of the Series Line or Half Wave Doubler

Unlike the circuits previously discussed, this doubler has quite dissimilar functions for the two capacitors CA and CB. CA acts as a reservoir of energy and adds its charge to the line during the succeeding cycle. It contributes little to the filtering action and therefore we need only concern ourselves with its effect on output and regulation. CB is similar in its function to the input filter condenser of the half wave A.C.-D.C. circuit of Figs. 1 and 2 except for the higher working voltages encountered. Unlike the symmetrical doubler, the voltage ratings of CA and CB need be similar since CA is never subjected to an instantaneous voltage greater than line peak plus the ripple voltage shown in Fig. 9C. The average or D.C. voltage on CA approaches line peak only for the conditions of low D.C. load currents and high values of capacitance in both units. For these reasons it is evident that CA may, for typical operating conditions at 60 cycles, be specified as a 150-volt rating, especially if its capacitance is high, i.e., 30 or 40 mfd. Capacitor CB, on the other hand, is operating with the full D.C. output voltage of Fig. 9A plus the peak ripple shown in Fig. 9E. It must therefore carry a working voltage rating of 250 or 300 volts, depending on load current and voltage.

In the series of curves shown in Figs. 9A, B, C, D, E, and F, the value of capacitor CB has been fixed at 40 mfd. as being a representative value from the standpoints of regulation and ripple voltage (hum). As previously stated, it will be observed that the value of the line series condenser CA has only a minor effect on the ripple voltage and RMS current conditions of CB. The ripple current in CB again does not exceed the "rule of thumb" value of 2.4 times the D.C. load value discussed for the half wave rectifier case and consequently this estimate of working conditions provides a generous safety factor.

The conditions of operation of the line series condenser as shown in Figs. 9B, C and D distinguishes this general type of circuit from those previously discussed. It will be noted that the RMS ripple current through this unit as shown in Fig. 9B is much higher in proportion to the D.C. load current than for either of the other types of circuits. The ripple current for low values of load current is seen to approach a value of 3.2 times the D.C. current. This value has been chosen as a convenient figure which again provides a generous safety factor when considering load currents of practical usefulness such as 50 MA or more. It will be noted that low values of capacitance should not be specified for condenser CA wherein the current exceeds the value of 10 milliamperes per microfarad previously cited as safe for the type FP capacitor. Other considerations, such as regulation and output voltage, which would influence the choice of this capacitance value, would also result in a capacitor value which would lie in a safe operating region as far as ripple voltage and current are concerned. An upper limit of capacitance is determined only by the effect of capacitance on peak ripple current through the rectifier as shown in Fig. 9D. In this instance the D.C. current limit of 75 MA is reached before the peak ripple limit of 450 milliamperes. As previously stated it has become standard practice to employ two rectifier tubes in parallel for the higher D.C. load current conditions.

FIGURE 9 COMMON LINE OR HALF WAVE DOUBLER TYPICAL CHARACTERISTICS



# Series Line Feed or Half Wave Doubler with Common Cathode Type Condenser

An interesting variation of the type of doubler just discussed is the circuit of Figs. 10A and B. This arrangement of circuit components makes it possible to combine all of the filter capacitors in one common cathode type unit. The resulting saving of both space and economy of construction are obvious. In this case the metal can of a condenser of the FP type can be mounted directly on the chassis and it is not necessary to provide insulation of the condenser can as in the case of the high side condenser of the doublers previously discussed. Since both $C_A$ and $C_B$ carry ripple currents of the magnitudes shown in Figs. 9B and 9F, the ability of the particular type of condenser construction to adequately radiate the heat occasioned by the flow of this ripple current through the series resistance of the condensers, should be considered in the choice of a suitable unit. When these units both having ratings of 40 mfd. and the D.C. load current does not exceed 75 MA, it is possible to combine them with the output filter unit in a single condenser of the type FP construction.

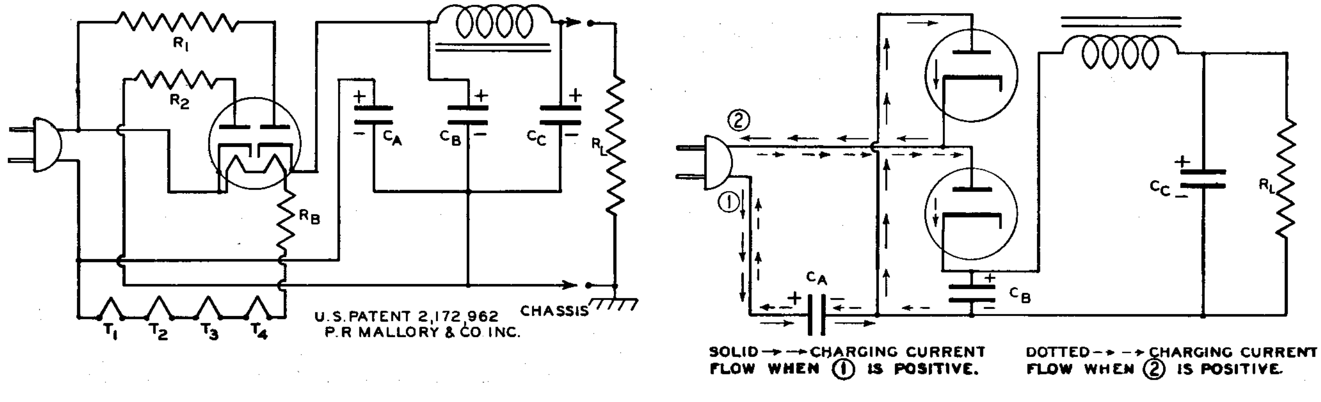
It will be noted that this circuit interposes between the heater and cathode of the first tube in the series string the terminal voltage of condenser $C_A$. Since there is superimposed upon the average voltage a peak ripple as shown in Fig. 9C it is obvious that the value of $C_A$ should be made as high as is practicable not only to keep this ripple at a minimum but also to provide a low impedance path between the chassis and the power line for both radio and audio frequency currents.

## Voltage Multiplier Circuit

An interesting extension of the principles involved in the half wave type doubler circuits of Figs. 7 and 10 is shown in Fig. 11. In this case the principle does not stop with a doubling of the voltage but is extended to cover any desired multiple of the line voltage. Condenser $C_1$ operates in the same manner as condenser $C_A$ of Figs. 7, 8, and 9, and delivers its charge plus the line peak voltage of the succeeding cycle to condenser $C_2$. This condenser adds its contribution of double voltage to the line voltage on the next half cycle when diodes $D_1$ and $D_3$ are conductive. This action continues in chain fashion through condensers and diodes 3, 4, 5, and 6 in turn. It might at first appear as though the chain of rectifiers when conductive would short circuit the charging action. This is not true because, once the series of condensers are charged, current from the individual rectifiers flows for only that portion of the cycle necessary to restore the loss of charge from the condensers due to current through the load. Thus, after the steady state conditions are reached, condenser $C_1$ is charged almost to line peak, condenser $C_2$ almost to twice line peak, etc. It is obvious that condensers $C_1$, $C_3$, $C_5$, and $C_N$, may be combined in one common cathode unit with proper attention given to the required voltage ratings of the individual sections. Similarly condensers $C_2$, $C_4$, and $C_6$ may be combined in another or second common cathode type single unit.

This circuit has been included here more for its interest as an extension of the principles discussed than as a suggested practical power supply system. Those familiar with the technique of the art of constructing surge generators for lightning research will recognize similarity of this circuit with the individual charge and series discharge methods employed to produce very high voltages. A practical limitation of a chain circuit of this type is the fact that if the tubes have their heaters connected in a series string across the power line there will exist dangerously high potential differences between heaters and cathodes of the rectifier at the high voltage end of the system. This difficulty of course might be obviated by the use of heater supply transformers but this would destroy the simplicity of this system.

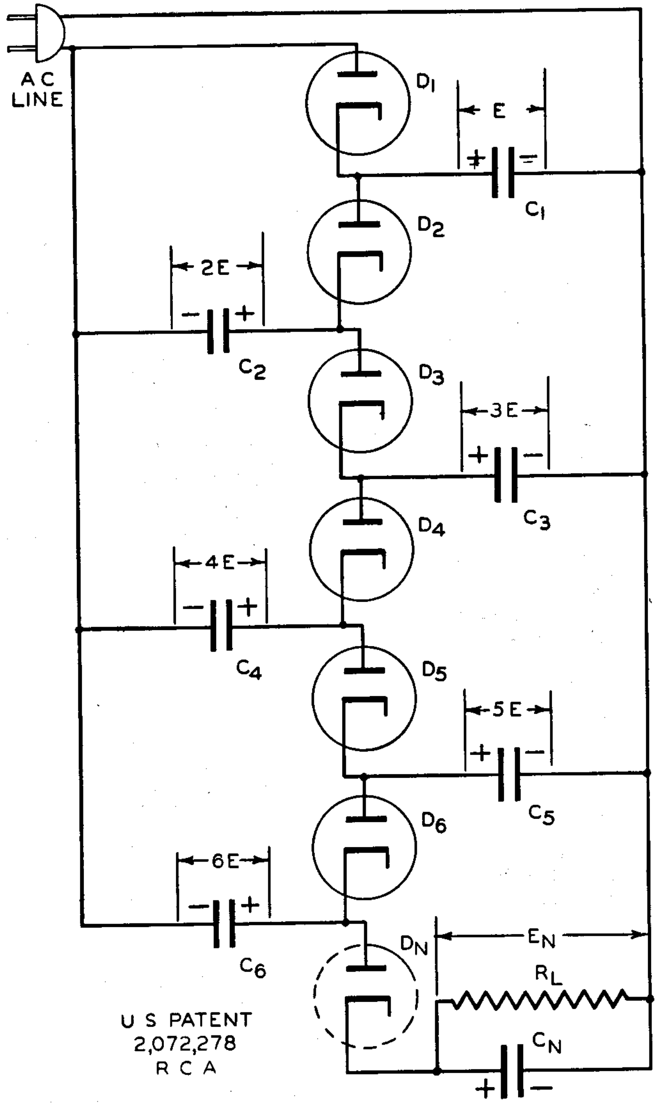
FIGURE 10 SERIES LINE FEED DOUBLER WITH COMMON CATHODE CONDENSER



A SCHEMATIC DIAGRAM

B SIMPLIFIED DIAGRAM OF DOUBLER CIRCUIT

FIGURE 11 VOLTAGE MULTIPLIER CIRCUIT



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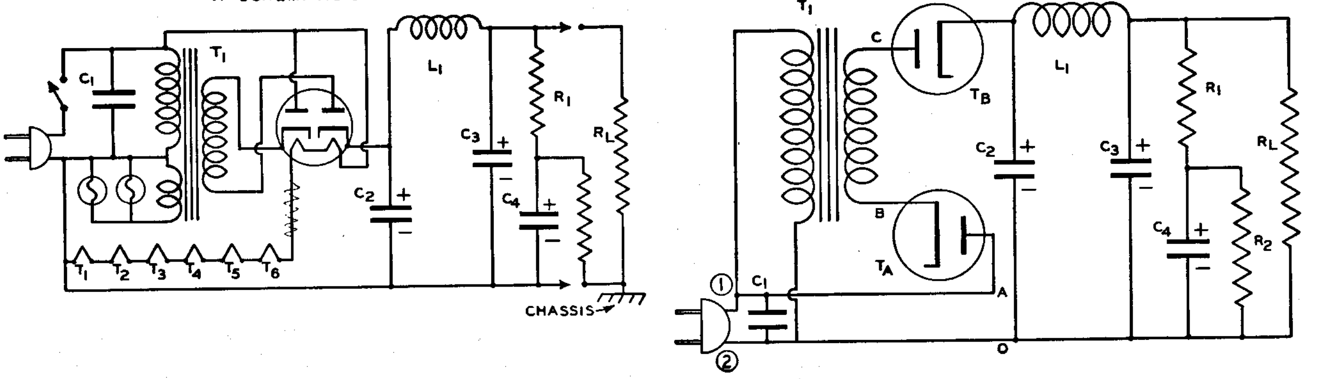
## Voltage Addition and Other Series Connected Heater Power Systems

While the intention of this chapter was simply a study of transformerless power circuits, it may be of interest to indicate a recent trend in the use of the principles discussed, in combination with greatly simplified transformer constructions.

The introduction of high voltage heater type rectifier and output tubes as well as the availability of a complete line of tubes with 150 MA heaters makes it possible to pick receiver complements which do not require an excessive amount of series dropping resistance to operate directly across the power line. Since the insulation and consequently the voltage breakdown between heaters and cathodes has been successfully increased especially in rectifier and power tubes to a value which will withstand B potentials of several hundred volts, it is now possible to construct an economical power system in which the heater power has been removed from the secondary of the transformer and placed on the line side. In addition to this it is only necessary to provide for a portion of the B power from the transformer since by the voltage addition principle the power line may be used with one rectifier tube to supply a portion of the B voltage. A system of this type is shown in Fig. 12. Fig. 12A shows a schematic diagram with all the usual components and connections. Fig. 12B shows this same sys-

FIGURE 12 VOLTAGE ADDITION CIRCUIT


A SCHEMATIC DIAGRAM

B SIMPLIFIED "B" SYSTEM

tem simplified to include only the portion concerned in the derivation of the B voltage.

The operation is as follows: For the half cycle for which input terminal 1 is positive with respect to terminal 2, there appears a voltage of line peak between points O and A in series with a voltage between points B and C, determined by the turns ratio of transformer $T_1$. Since at this instant both rectifiers $T_A$ and $T_B$ are conductive, filter condenser $C_2$ receives a charge determined by the sum of the peak voltages. Assuming these voltages to be equal it is obvious that the power requirements of the transformer need be only half the B supply power. In this manner a receiver of fairly high power output can be built with a transformer no larger than the usual audio frequency interstage or output transformer. Naturally such a system must comply with the requirements of A.C.-D.C. receivers as regards both shock, and fire hazards.

In Canada there have recently appeared a number of receivers which have been called H.V.H. sets. The initials refer to "high voltage heaters" which are connected in series across the power line. The B supply system in this case has been made of the conventional center tapped secondary full wave type and the simplification from an economy standpoint results from the absence of any low voltage windings on this transformer. In this case there is no conductive connection between the power line and the chassis or circuit wiring. The Hydro Electric Power Commission of Canada has approved such receivers as complying with the Canadian safety code. With the introduction of tubes operating with 117-volt heaters, power systems similar to those discussed may well represent a trend in the ever-present urge to provide the public with more radio entertainment at less investment.

# Component Failures in Transformerless Power Systems

As mentioned in the introduction, the number of service failures of A.C.-D.C. receiver components exceeds all other types. Most of these failures occur in receivers manufactured some seasons ago before a thorough understanding of all of the operating conditions was widespread among design engineers. With no intention of condemning either the design or the production of the older receivers, it would be of value to outline the various causes of component failures with suggested remedies to obviate their recurrence. Since the phenomena involved apply to all of the systems discussed no particular reference will be made to any one type of power supply system unless a particular feature is pertinent.

## Heater Circuit Failures

As has been previously pointed out, the heaters of the various tubes of receivers of this type are connected in series and in turn connected to the power line with a suitable voltage dropping resistor. With the introduction of higher voltage ratings of the heaters of these series operated tubes, it is possible to design a receiver in which the sum of the heater voltages equals the line voltage, so that a series dropping resistor is unnecessary. Since this removes one component from the receiver, there is a natural temptation to design in this direction. However, when this is done a series of phenomena are likely to occur in service which may result in one of two types of tube failures. The cold resistance of the heater circuit is considerably less than the final hot resistance, especially if the heaters are of tungsten wire. The ratio of hot to cold resistance may be as high as 7 to 1. Thus when the receiver is turned on a sudden rush of current occurs which may cause violent mechanical movements of the heater within the cathode sleeve. Since certain heaters of widely different voltage rating may possess different thermal lag characteristics, a disproportionate voltage distribution may occur during the heating period. This situation is further complicated by the fact that for certain types of tubes the heater is an alloy rather than a tungsten wire and possesses a different temperature coefficient. Another factor of importance concerns itself with the method of heater construction. Both folded and reversed coil heaters are in general use and the tubes of the same type made by different manufacturers may be of dissimilar construction from this standpoint.

The sudden high current surge on starting may cause such a violent mechanical movement of the heater within the cathode sleeve that short circuit to the cathode or open circuit may occur. If this happens in a tube near the grounded or chassis end of the filament string, the result is merely a defective tube. If it occurs in the rectifier or output tube at the high end of the string, it may place 117 volts A.C. directly across the initial filter condenser in the case of an A.C.-D.C. set or across one of the doubler condensers if the symmetrical type of doubler is involved. The subsequent failure of both tube and condenser may be diagnosed by the service man as a condenser fault rather than a heater failure in the tube.

The condition which is described can be aggravated by the fact that localized heating of the cathode surface may result in the event that the power has been turned off for a short interval of time and the cathode has not cooled down uniformly. Under these conditions there is a possibility that a localized hot spot on the cathode may result in cumulative overheating, since all of the current will be comprised of the emission from the single spot and will, of course, cause a terrific concentration of heat. This condition will, naturally, be aggravated by the presence of any gas in the tube, since the heavy positive ions will bombard this same cathode spot and in such a chain of events back emission may occur from the overheated anode adjacent to this cathode hot spot.

For these reasons some tube and receiver manufacturers have determined a minimum value of series resistance of low temperature coefficient to be used in any series filament string to restrict the high starting surge. This minimum resistance should be in the neighborhood of 50 ohms or more.

A companion type of trouble, which while not so serious from an economic angle, is nevertheless very aggravating, is the frequent failure of dial or panel lights. In the earlier receivers these lights were either placed directly in series with the heaters or were tapped across a portion of the voltage dropping resistor. Under these conditions the lamp received a serious overload during the starting cycle or if protected from this surge had an operating voltage too low for satisfactory illumination. Within the past few years this situation has been remedied to some extent by the use of ballast tubes having a resistance-temperature characteristic to protect the dial lamp. The most recent development in method of dial light connection in A.C.-D.C. receivers is the type 35Z5 tube which has a tap on the heater across which the dial lamp is connected. The circuit is so arranged that the pilot lamp is also in the plate current circuit and part of its current therefore is derived from the B supply system. Since the plate current does not reach its final value until the starting surge has been completed, it is possible to protect the lamp from over-voltage during starting and still provide sufficient illumination in the final steady state condition.

## Failure of Rectifiers and Condensers During Starting Transient Conditions

The elusive nature of rectifier tubes and condenser failures in A.C.-D.C. sets has been due almost entirely to the set of conditions which can occur during the first few cycles after the receiver is turned "on." Some years ago one of the larger tube companies in an attempt to determine a rational explanation for tube and condenser failures in a certain receiver, conducted a number of tests in which the set was turned on manually, allowed to operate until final temperatures were reached and then turned off. This cycle was repeated until a failure occurred. It was found that the failures occurred once in every 720 operations on the average and that upon mathematical analysis this figure corresponded to the random chance of turning on an A.C. circuit at the positive peak.

Another company in investigating the reason for frequent tube and condenser failures in one of their larger A.C.-D.C. sets found that an unusual set of field conditions was responsible. This particular receiver employed excellent filtering and therefore had an exceptionally low hum level. In demonstrating this the dealer would turn down the volume control to allow the prospective customer to listen to the hum. If the control were inadvertently turned too far and the receiver turned off, the B supply system would be drained of its charge but the cathode type tubes would still be hot when the receiver was turned on again. Under these conditions the rectifier tube was forced to supply an instantaneous peak current greatly in excess of any normal operating condition since the input condenser had been drained of its charge. It was found that the transient current under these conditions was sufficiently high to fuse the cathode tab in the rectifier tube. This tab will normally carry a current as high as two amperes without fusing.

With conditions of this nature occurring in the field it is natural that tube and capacitor manufacturers would individually place the blame upon the other party especially in view of the lack of any accurate data. Tube companies were hesitant or unwilling to allow the use of extremely high filter condenser values since the peak current and transient charging current through the rectifier tube was correspondingly high. On the other hand the condenser manufacturer was equally insistent that the capacitor value be sufficiently high to guarantee reasonable life expectancy under the high RMS ripple current conditions.

A satisfactory remedy has been found in the use of a series resistor in the supply system. This resistor will limit the instantaneous initial current which the rectifier may be called upon to supply and if the steady-state peak current does not exceed the value which the tube companies have found to be satisfactory there is little reason to anticipate a greater proportion of tube failures in the transformerless type of set than in those employing a power transformer.

It is suggested that service men who have encountered frequent rectifier tube failures in existing sets install a resistor of approximately 50 ohms in series with each plate of the rectifier tube. The loss of plate voltage occasioned by the introduction of this resistor should not be serious enough to be noticeable and can usually be more than compensated by the substitution of a higher value of input filter condenser, especially if the capacitor must be replaced during the service repair.

## Shock and Fire Hazard

The transformerless type of circuits discussed in this chapter all employ some type of direct or conductive connection between the chassis and the power line. In most circuits one side of the power line is either directly connected to the chassis or is connected through a fairly large capacitance. The standard practice in most communities in the United States requires that one side of the house wiring circuits be connected to ground at the electric power meter. It is readily seen that if the receiver plug is so inserted in the outlet that the chassis is connected to the ungrounded side, the full power line voltage can occur between the chassis and any other actual ground such as a water pipe, radiator system, or grounded conduit or outlet face plate. This is the reason for the insistence on the part of both the Fire Underwriters Laboratory of the United States and the Hydro-Electric Power Commission of Ontario, that in these cases no exposed metal part of the chassis be accessible for accidental contact by the user. Such condensers as may be necessary to provide adequate radio frequency grounding or by-pass of the power line must be low in value to limit the 60-cycle current which might flow as a shock current.

Another wise precaution of these regulatory commissions is that every component which has any direct connection with the power line must be enclosed completely in metal so as not to present a fire hazard in the event of accidental short circuit or breakdown of any of the parts which would occasion a power arc.