Electronic Gadgeteering and the War

As our nation rapidly adjusts itself to an all-out war effort, we tighten our belt another notch or two, cut down our appetite for so many things we crave, and accept the cold fact that more and still more items must come under rigid priority regulation. Civilian requirements simply must give way to military demands. Thus recent War Production Board pronouncements now rule out the general availability of capacitors other than on priority or, again, for essential replacement in existing radio sets.

Meanwhile, we have been publishing material for some time past on electronic gadgeteering, or, if you prefer, industrial "electroneering." This series has met with wide-spread interest and acceptance. Many of our readers have gone in for electronic gadgeteering.

Despite the fact that many components are no longer generally available for electronic gadgeteering purposes, it is our belief that many readers have a supply or at least a junk box of capacitors and other components on hand, with which they can put together various electronic assemblies. Also, there are those who work in essential war industries where electronic gadgeteering may be applied to good advantage and in which cases favorable priority ratings may facilitate the procurement of necessary capacitors and other components.

Of course our series on electronic gadgeteering was mainly in the nature of laying down broad principles, rather than dealing with specific applications. Also, this series was definitely intended to stimulate thinking along such lines, and to encourage the reader to develop his own versions and usages. Even while this war is on and commands our utmost efforts, it is well to be nurturing ideas and techniques and plans for the peace to follow, when we shall once more return to peacetime pursuits and when every possible employment opportunity will have to be created to take care of our vast army of demobilized fighters and wartime workers seeking a place in our nation's economy.

So please bear with us even when the components required are not available for civilian usage. Remember that we are studying and developing broad principles and possibilities, laying the foundation for an electronic era, and that the recent series, "Industrial Applications of Electronic Devices," was intended to stimulate original thinking and experimentation for both the present Battle for Production and for the future to come.

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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. 14, NO. 2 — FEBRUARY, 1942 — 50c per year in U.S.A. 60c per year in Canada

Transformerless Power Supplies

PART I

By the Engineering Department, Aerovox Corporation

TRANSFORMERLESS power supply units are not new in principle. The so-called "line rectifier" and voltage doubler first attracted somewhat widespread attention among radio set builders in 1933 when the 25Z5, first of the high-voltage heater-cathode dual rectifiers, appeared. The gradual increase in distribution and application of the several types of transformerless power supplies has been concurrent with growth of the midget a.c.-d.c. radio receiver.

Aside from the well-known radio application, transformerless power supplies are applicable to test instruments and other electrical apparatus in which space is limited or magnetic fields, such as might arise from transformers, undesirable. New attention is centered upon this type of power unit at this writing because the war emergency has made it increasingly difficult to obtain certain transformers.

All of the high-voltage-heater tubes designed expressly for use in transformerless power supplies are of small size. The same is true of modern high-capacitance electrolytic filter capacitors. For certain applications, the transformerless unit is desirable over other types for inclusion in a small space with other apparatus.

Transformerless units can deliver d.c. power at high voltages or at the line voltage. The voltage multiplier circuits, while providing the potential step-up, do not possess the voltage regulation provided by transformer circuits. However, the current output and regulation may be improved by methods which will be discussed later in the text. One of the leading virtues of the simple transformerless circuit—the line rectifier—is its ability to operate from either an a.c. or d.c. line.

The usefulness of the transformerless rectifier circuit in certain applications has been slowly recognized. An understanding of the operation of the transformerless voltage multiplier circuits is not possessed by sufficient radio men who are called upon to work with this equipment.

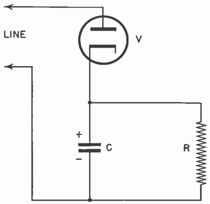
This article will describe the various transformerless power supply circuits which have been adapted to radio receivers, electrical test instruments, photoelectric and electronic equipment, and small radio transmitters. Sufficient information will be given to impart to the reader an understanding of the circuit operation and to enable him to set up any one of these circuits with the best components for desired operation.

HALF-WAVE CIRCUIT

The simplest transformerless power supply is the half-wave line rectifier shown in Figure 1. This is the so-called a.c.-d.c. power unit. The general design and operating principles of half-wave rectifiers apply in full to this circuit.

Operation of the circuit is well understood. The diode-type tube, V, conducts only on positive half-cycles of line voltage, and during those intervals the filter capacitor, C, is charged to a voltage equal to the peak line voltage less the small drop through the tube. On negative half-cycles, the plate of the tube is negative with respect to its cathode and it cannot conduct further. The capacitor cannot discharge back through the tube and into the line, so it discharges through the load resistance, R.

For the usual values of filter capacitance and load resistance, the capacitor will not get rid of its entire charge before the tube plate again becomes positive and charging current again flows. Consequently, it is seen that the charging current on each succeeding positive half-cycle will find the capacitor still partially charged, and no charging current will flow into the capacitor until the instantaneous line voltage is



HALF-WAVE RECTIFIER
FIG. 1

sufficient to exceed the voltage across the capacitor.

The tube passes current into both the input filter capacitor and the resistor. Total current through the rectifier is the sum of the charging current flowing into the capacitor and the load-circuit current. For a given tube, this total must not exceed a certain value stated by the tube manufacturer. The tube table included in this article shows the peak plate current which may safely be handled by the various tubes designed for transformerless power supplies.

From a study of the capacitor and resistor current magnitudes, it may be seen that the average d.c. load current is always only a fraction of the peak plate current flowing through the rectifier. If the filter capacitance permits a rectifier current higher than the manufacturer's rated peak value to flow through a tube, small safety resistors must be installed in each plate lead to limit the total current to a safe value. The value of these tube-protecting resistors may be obtained from the manufacturer's data. However they are generally of the order of 30 to 50 ohms and do not introduce too great a voltage drop in the circuit.

Since the half-wave line rectifier utilizes only alternate half-cycles of line voltage, the ripple frequency present in the rectifier output will be identical with the low line frequency. This means that the half-wave transformerless circuit is not as easily filtered as full-wave rectifiers. The supply frequency, input filter capacitance, and load resistance determine the ripple voltage and ripple current magnitudes.

Choke input is rarely ever used with the half-wave transformerless power supply; capacitor input has been found to be superior in this circuit. The half-wave unit gives best results when high-capacitance capacitors are used. The 40-mfd. electrolytic capacitor has been designed principally for this application. A large input capacitance is necessary to maintain the output voltage at a reasonable level. High-resistance filter chokes are not recommended for use in the half-wave circuit, since the output voltage is already low—somewhat less than the effective value of the line voltage—and in most cases cannot be drastically reduced.

VOLTAGE DOUBLER CIRCUITS

The transformerless voltage multiplier circuits make it possible to obtain a high d.c. voltage without a step-up transformer. Explained briefly, this is accomplished by alternately charging two or more capacitors to the peak line voltage, or very nearly so, and allowing them to discharge in series so that the total voltage will be the sum of the voltages appearing across individual capacitors. This action is achieved automatically by two or more diode-type rectifier tubes which perform the switching operation electronically.

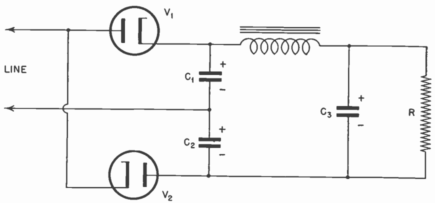
The most familiar transformerless voltage multiplier circuit is the *voltage doubler*. The doubler is employed widely in a.c.-operated midget radio receivers to obtain plate voltages approximately equal to twice the line voltage. Figures 2 and 3 shows voltage-doubler circuits.

The circuit of Figure 2 is a full-wave arrangement, also termed the symmetrical doubler circuit. This circuit operates in the following manner: When the plate of the diode V_1 is positive, current flows through that tube and charges the capacitor C_1 to a voltage equal to the peak value of the line voltage less the small drop through V_1. The polarity of the charged capacitor is then as indicated in the diagram. During this half-cycle of line voltage, the plate of V_2 is negative and that tube can pass no current.

When the line polarity reverses, however, current will flow from the lower side of the line, which is now positive, through the circuit containing V_2 and C_2 and back to the upper side of the line. C_2 is then charged to a voltage equal to the peak line voltage less the drop in V_2, and its polarity is as indicated in the diagram.

Note that the two sides of the capacitors that are joined together are of opposite polarity, which means that if the capacitors did not discharge into the load circuit the voltage now appearing across C_1 and C_2 in series would be equal to *twice* the peak line voltage less the small drops through the two tubes. Hence, the term *voltage doubler*.

C_1 really discharges through the load resistance R while C_2 is charging.



CAPACITOR PEAK VOLTAGES
C_1, C_2, LINE VOLTAGE X 1.41 C_3, LINE VOLTAGE X 2.82
FULL-WAVE DOUBLER
FIG. 2

AEROVOX
BUILT BETTER
CONDENSERS AND RESISTORS

CHARACTERISTICS OF TRANSFORMERLESS POWER-SUPPLY TUBES

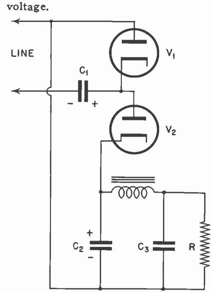
TYPE	HEATER VOLTAGE	HEATER CURRENT	MAX. PEAK INVERSE VOLTAGE	PEAK PLATE CURRENT (Per plate) D.C. MA.	MAX. D.C. HEATER-CATHODE VOLTAGE	MAX. A.C. PLATE VOLTAGE (Per plate) RMS	MAX. OUTPUT CURRENT D.C. MA.	STYLE
12Z3	12.6	0.3	700	330	350	235	55	HALF-WAVE
25Y5 25Z5 25Z6 25Z6-G 25Z6-GT	25	0.3	700	450	350	235	75 Per plate	FULL-WAVE
35Z3-LT	35	0.15	700	600	350	250	100	HALF-WAVE
35Z4-GT	35	0.15	720	600	350	250	100	HALF-WAVE
35Z5-GT	35	0.15	700	600	350	235	100	HALF-WAVE
45Z3	45	0.075	350	390	175	117	65	HALF-WAVE
45Z5-GT	45	0.15	700	600	350	250	100	HALF-WAVE
50Y6-GT	50	0.15	700	450	350	235	75 Per plate	FULL-WAVE
50Z7-G	50	0.15	700	400	350	235	65 Per plate	FULL-WAVE
117Z6-GT	117	0.075	700	360	350	235	60 Per plate	FULL-WAVE

But the capacitor charge is not entirely dissipated in the load in the short interval before the polarity of the line returns to positive, a residual charge remaining in the capacitor. Consequently, the charging of each capacitor on subsequent positive half-cycles begins only at that instant when the instantaneous line voltage exceeds the capacitor terminal voltage due to the residual charge. The charging then continues until a value is reached equal to the line peak less the tube drop. The capacitor then discharges exponentially through the load, while the other capacitor is charging, until the drop across the load resistance (due to the capacitor discharge) exceeds the instantaneous line voltage.

The voltage presented to the filter is the actual potential difference between the positive terminal of C_1 and the negative terminal of C_2. This value would have a possible maximum, under conditions of no load or extremely light load, of double the line peak. The actual value, however, will depend upon how much current is being drawn by the load resistance.

Due to the separate discharge of C_1 and C_2 on successive half-cycles, both sides of the line-voltage cycle are utilized by this circuit. The voltage pulsations are accordingly at twice the line frequency although the ripple across each individual capacitor is at the line frequency. In this respect, the output of the full-wave voltage doubler resembles that of the full-wave rectifier. The full-wave doubler is therefore much easier to filter than the half-wave transformerless supply.

C_1 and C_2 are usually of the same capacitance for best results, although this is not an imperative requirement for circuit *operation*. These two capacitors are charged by separate diode units in the same manner as in the full-wave rectifier, and the increased output voltage afforded by the doubler circuit is obtained from the two capacitor voltages in series. Hence, the capacitor voltages, due to charging, never exceed the line peak and their voltage rating may be the same as recommended by the capacitor manufacturer for half-wave service at line voltage.



CAPACITOR PEAK VOLTAGES
C_1, LINE VOLTAGE X 1.41
C_2, C_3, LINE VOLTAGE X 2.82
HALF-WAVE DOUBLER
FIG. 3

Figure 3 shows a *half-wave doubler*. Operation of this circuit may be described in the following manner: When the plate of diode V_1 is positive, this tube passes current, charging C_1 with the polarity indicated and to a voltage equal to the peak line voltage less the tube drop.

When the line polarity reverses at the end of the half-cycle, the voltage due to the charge in C_1 will be added to the line voltage. V_2 passes current and C_2 is charged to a voltage equal to the line peak (less the drop through V_2) plus the voltage across C_1. C_2 begins discharging into the load resistance as soon as V_2 begins conducting and consequently does not quite receive the full charge which would be equal to twice the line peak.

The "reservoir" capacitor C_1 is never subjected to higher voltage than the sum of the line peak and ripple voltages. Therefore, its voltage rating may be the same as the low value permissible for half-wave transformerless operation. C_2, on the contrary, receives approximately twice the peak line voltage plus the ripple voltage and must be rated to withstand this total. C_1 may have reversed current flow, depending upon the capacitance and load resistance.

For the same value of load resistance, the half-wave doubler output is lower than that of the full-wave circuit. Likewise, the half-wave doubler, like the simple half-wave rectifier, is more difficult to filter, since in this circuit the ripple frequency corresponds to the low line frequency.