ELECTRON POWER PACK

A Real D. C. Transformer with No Iron-Cored Parts

By DAVID GNESSIN

ALL radio and electronic equipment operates by virtue of the D.C. power furnished by the power-supply stage. Except in the case of dry-cell batteries, banked to provide the necessary voltage, or in the use of the greatly decreasing D.C. power lines, high-voltage D.C. can be provided only by rectifying A.C. or converting battery D.C. into A.C. by mechanical rotary or vibrating methods, then later rectifying in the usual manner.

We are concerned here with providing high-voltage D.C. from a secondary lead-acid or similar cell. To avoid using mechanical means of raising the voltage *(because of its large first cost and wear of moving parts)* we will have to raise it electronically. This brings up interesting considerations.

Direct current is unique. Except during the instant it is switched on or off, its flow through a transformer produces a steady magnetic field, which prevents the energy transfer required to raise the voltage. D.C. voltage may be reduced by dropping it through a suitable resistor, but it cannot be raised by merely passing it through something else. A.C. can be raised, but D.C. cannot.

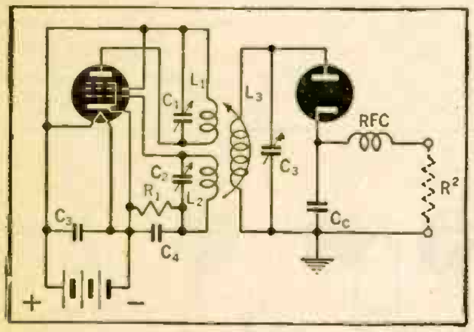

Fig. 1—This pack consists of an oscillator and a rectifier, and may have only one tube.

How, then, is it possible to operate a radio receiver on a farm with only the 32-volt D.C. farm battery, or an automotive radio-transmitter in a boat with its 12-volt marine battery, when the tubes in that equipment require voltages of 90 or more volts (D.C.)?

The answer is: A low-voltage power-oscillator is operated directly from the battery, providing high reactive voltages in its output, rectified to produce high voltage D.C.

Using a dual-purpose tube, such as the 25A7 shown in Fig. 1 (with its two sections separated into two halves of the tube envelope for ease in reading the diagram), with one section acting as oscillator and the other section as diode rectifier, the power-supply stage is made as simple as any other method, with the distinction of having no moving parts, ergo frictionless! With the possible exception of the archaic electrolytic interrupter this method has not been adapted for commercial use up to this time.

(AUTHOR'S NOTE: Probably the only ELECTRONIC means of raising a low D.C. voltage to the high voltage D.C. necessary to operate electronic equipment is the POWER-OSCILLATOR/RECTIFIER method described herein. With not a single moving part it is a radical departure from the conservative methods of providing power-supply from a low D.C. source. Its analysis is described in detail.)

The primary source is a storage battery, shown in the diagram as a 24-volt lead-acid battery. This type was selected to best demonstrate the operation of the 25A7 tube. Batteries of other voltages may of course be used, if their voltage is equal to the filament voltage of the tubes utilized. For example, the 12B8 tube could be used with a 12-volt battery.

The battery supplies both "A" or filament voltage, and "B" or plate voltage, from the same positive and negative terminals. In the description following, the letters "A" or "B" will be utilized to designate filament or plate circuits, respectively, although it will be remembered the voltages are taken from the same battery in each case.

The heart of this power supply is the power-oscillator circuit. This is the left section of the tube shown in Fig. 1. Refer to it frequently when following the description. In this manner, its operation will be made very clear.

If you know what an electron does, and how it can create a magnetic field, follow the description carefully, with frequent glances at the diagram, and you'll have no difficulty in understanding how the circuit works, and why it does what it does.

When the filament is heated, the cathode—connected to the negative end of the B battery, evaporates electrons, which are drawn to the plate because of its positive charge (it is connected to the positive end of the B battery). Electrons go from the plate through L_1 back to the battery.

We can ignore the part played by the screen and suppressor grids. Though they are important, they are not necessary for the purposes of this explanation. The control grid *is* important in the action we are describing. It is connected (through L_2 and the grid-leak condenser combination R_1 and C_4) to the cathode, and hence is at the same voltage. But L_2 is closely coupled to L_1, through which a current is now flowing. As this current increases, a magnetic field is set up around L_1 and also L_2. Now watch what happens! A voltage is induced in L_2, whose windings are in such a direction that this voltage will make the grid end of the coil positive and the cathode end negative. But as the grid becomes more positive, electron flow through the tube increases, which increases the flow in L_1, the magnetic field around it, and consequently drives the grid still more positive!

Obviously the current through the tube cannot just keep on increasing. Several things, such as the limit to the cathode's ability to emit electrons, the increase in grid voltage toward the battery's limit, and the drop in plate voltage due to the increasing current bucking the impedance of coil L_1, put a limit to it. Thus the current through the tube and coil is soon at a maximum, and stops increasing. It cannot remain steady, though. Just as soon as it stops increasing, the voltage on the grid is no longer influenced by it. (Remember that only when a magnetic field around a coil is *increasing* or *decreasing* can it induce a voltage.) So the positive voltage on the grid begins to disappear as it starts to return to its original condition of equi-potential with the cathode.

As soon as the grid starts to become more negative, *less* current can flow through the tube. The magnetic field around the coils starts to *decrease*, and a voltage is induced in L_2 which causes the grid to become *more* negative. This continues till the current drops to zero, when of course there can be no magnetic field around the coils and no action on the grid, which by this time is far negative as compared to the cathode. As the piled-up electrons on the grid start to flow back to the cathode, the grid becomes more positive, and the whole cycle starts over again.

This is a condition of *steady oscillation*. Because the condenser-coil combination L_1-C_1 likes to charge and discharge at a definite frequency (a definite number of times a second), it is easiest for the tube to oscillate at that frequency. That is why we have C_1 as well as L_1. The grid-leak, R_1, is used to keep the grid at an average negative potential when the tube is oscillating. Every time the grid goes positive it gets a few electrons from the cathode—becomes a sort of plate, in other words. As these electrons flow off through R_1, the voltage drop gives the grid sufficient *bias* for best operation. C_1 is simply to let the rapid pulses (of radio-frequency) current around R_1, whose opposition to their flow might be great enough to stop oscillation.

Coil L_3 is also coupled closely to L_1. By means of its condenser C_3, it may be tuned to resonance with the oscillating circuit. Its impedance to the rapid alternating currents

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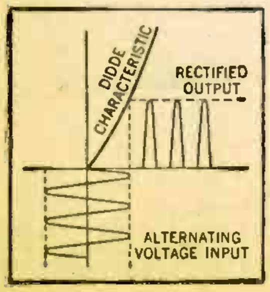
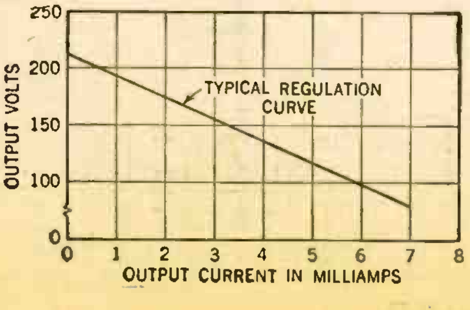


Fig. 2—Oscillator input to rectifier, and output before filtering. Fig. 3 — The voltage supplied drops rapidly as the load is increased.



ELECTRON POWER PACK

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induced in it by L_1 is thereby reduced to a very low value—roughly that of the actual resistance of the wire in the coil, and therefore high voltages are generated in it.

Now that the oscillator has produced alternating current, we can see its real use. Consider the "tank-circuit" L_1 C_1. The coil and condenser are in parallel. The design of these elements is such that at the fundamental oscillating frequency they offer maximum impedance. The A.C. component of voltage in the tank circuit is:

$E = IZ$ where I = circulating A.C. current
Z = impedance of tank circuit

Thus, no matter how low the A.C. current is, with a maximum tank impedance the A.C. voltage (reactive voltage) is likely to be high. In the circuit described this value can go up to 200 volts or more.

The tank coil acts as primary for the transformer L_2 L_3, the secondary of which is connected to the rectifier. From there on the circuit is exactly like a half-wave rectifier operating from a power transformer off a 60-cycle A.C. line. That's all there is to it!

As we draw current from the rectifier circuit (the diode end of our 25A7), which is attached across this coil and condenser combination, the voltage drops. An oscillator built up according to the specifications of this article is therefore unsuitable for such work as operating large power tubes, where heavy currents are needed. It is, however, useful for many small devices.

One of the greatest practical uses of this type of power supply is for applications where very high voltages with low currents are required. A single 6L6 oscillator has been used to supply 6,000 volts to be rectified for a cathode-ray tube, and the G-E "suitcase" electron microscope uses a resonant-type power pack.

CLASS OF OPERATION

To get appreciable power output from a power-oscillator stage, some form of plate-grid feedback must be employed. It must be remembered that frequency stability varies inversely with closeness of feed-back coupling. Thus with close coupling for maximum power transfer, frequency stability will suffer. This is of no consequence in the circuit where the output is immediately rectified to produce D.C. power. Under these conditions the circuit may be referred to as Class "C" power-oscillator.

Some thought should be given to the energy required for the grid circuit. The grid draws both voltage and current. This power cannot come from the preceding stage as it usually does with Class C stages . . . . There is no previous stage! The grid power must come from the plate-circuit power supply. The characteristics curve of such a stage would then show E_g–I_p relations far out in the region of positive grid potential. As such, even as Class C its operation is entirely unlike any other class of tube circuit design.

ENGINEERING ANALYSIS

(This section may be skipped by readers who dislike formulae.)

The D.C. power supplied to the rectifier diode (right section) by the power-oscillator (left section):

(1) $P_1 = I_b \, E_b$
where I_b = Average value of plate current (D.C.)
E_b = Plate voltage (D.C.)

The power output to the tank circuit L_1:

(2) $P_{tank} = E_p \, I_p = I_L{}^2 R_L$
where E_p = A.C. component of plate voltage (R.M.S.)
I_p = A.C. component of plate current (R.M.S.)
I_L = Circulating current in the oscillating circuit
R_L = Total resistance of the tank circuit plus the resistance reflected from the grid (acting as load) and load (L_3 with the associated rectifier circuit)

The power lost at the oscillator plate:

(3) $W_{dis.} = (1) - (2) = P_1 - P_{tank}$

The driving power for the oscillator stage:

British Combine Photo

Despite transport difficulties, the Western members of the United Nations are managing to supply our Eastern ally with some of the communications equipment so important to the successful conduct of modern war. The photo pictures one of these contributions, a car armored to meet battle conditions and completely equipped with the latest Occidental mobile radio direction-finding apparatus, so much needed in this war of communications.

(4) $P_d = E_g\ I_g$

where E_g = A.C. grid voltage (R.M.S.)

I_g = A.C. grid current (R.M.S.)

The power available for output:

(5) $P_o = E_p I_p - (E_g I_g + R_d)$

where R_d = Resistance of the detector circuit acting as load through L_3

Ignoring the inherent and unmeasurable losses in the oscillator and associated circuit, the efficiency of this stage:

$$\text{(6)}\quad \text{Eff} = \frac{P_o}{P_i} = \frac{E_p I_p - (E_g I_g + R_d)}{I_b E_b}$$

This stage is nothing but a half-wave rectifier, known to all students of radio as a means of producing direct current power from an A.C. source. It is called a detector in this case to differentiate it from the usual rectifier operating off the 117-volt primary A.C. lines.

Inspection of the circuit (right half of circuit diagram Fig. 1) will reveal components arranged much like the typical diode detector in a modern superheterodyne. In the radio receiver the detector removes the modulation peaks of the modulated R.F. carrier, thus demodulating the received wave. The removed modulation is passed on to a device which thus actuated produces sound. In the detector shown here, however, the removed peaks occur at the same carrier frequency . . . . There is no modulation. Therefore, the output is a series of peaks occurring at regular intervals and having the *same amplitude*, as shown in Fig. 2. These removed peaks are passed on, not to operate earphones, but to act as pulses of energy like charges of a generator to supply a source of direct current.

No. Wire	*Turns for Max. Milliwatts*
20	12
24	13
27	15
30	18
33	20

Fig. 4

The rectified D.C. output pulses of current charge the load by-pass condenser C_6 to nearly the same voltage as that across the transformer secondary L_3. Since the condenser stores the charge it tends to bias the tube between peaks, permitting the diode to conduct only when the input voltage is greater than the stored D.C., that is, only at peaks. In this respect, the stage operates Class C (if a diode can be considered as Class C). The charge, replenished at each pulse, is drawn from this stage by the load circuit, such as radio receiver, photo-electric cell, or other electronic equipment. The load is represented in the diagram Fig. 1 as a phantom resistor, R_2. The D.C. available for the load is that across the condenser C_6. The choke RFC keeps the high frequency out of the load.

The capacity of the condenser C_6 must be such as to offer minimum reactance to the input frequency, effectively filtering the D.C. output.

The condenser C_5 tunes L_3 to the resonant frequency, thus permitting maximum transfer of power, adding more voltage due to "resonant rise of voltage."

Since the duplex tube in the circuit is to function as rectifier it must be selected with the usual check on maximum peak inverse voltage rating. In the half-wave rectifier design the tube should be able to stand a voltage of 2.83 E_s, where E_s = voltage across L_3. In conservative design, assuming an output of 90 volts D.C., the tube would stand a maximum peak inverse voltage of 254.7 volts. The 25A7, for example, can stand this voltage, and is rated to deliver up to 125 volts D.C. from the rectifier section. If two separate tubes were used instead of a duplex tube, the voltage output might be raised considerably.

With an output of 90 volts D.C., the rectifier would provide about 6 milliamperes output to the load. (See Fig. 3 for rough approximation.) This is sufficient to operate most small electronic equipment, with the possible exception of a power tube to drive a speaker. In this case either a very small P.M. speaker should be used, or headphone operation should be incorporated. In the event that strong speaker operation is required, a 28D7 may be used as power amplifier, operating directly off the 24-32 volt storage battery. This should provide sufficient output. For the design of such a stage see the June issue of *Radio-Craft* under the title, "A 28-Volt Receiver."

The fundamental frequency of operation of the power-oscillator should be from 4 to 10 megacycles, depending on the design of the load coil L_3, which slides inside L_1 L_2. The plate and grid coils are wound on the same form, and are identical. Fig. 4 shows the Load Coil (L_3) table listing the wire gauge (B & S) and the number of turns necessary for maximum power output in milliwatts. With a 1 inch (outside diameter) low loss coil, about an inch or two long, referring to Fig. 4 wind the load coil for your particular application. Cement it with a good h.f. binder or wind it tightly.

Since the load coil slides inside the primary, it is necessary to allow sufficient inside diameter in the primary coil to accommodate the load coil. For the primary use a ceramic coil form about two inches in length with a nominal inside diameter of ½ to ¾ inch. (If a selection is available, select a form which will permit the load coil when wound to be pushed into position to stay there by friction.) The plate and grid coils should be wound in the same direction, ⅛ to ¼ inch apart, using 10 turns of No. 14 wire, closewound, for each winding. This will correspond to a frequency between 4 and 10 megacycles. The exact frequency need not be known, since the only tuning involved is for greatest energy transfer, which once set will not be changed. Condensers C_1, C_2 and C_5 tune their respective coils to the required frequency. This will have to be done with an insulated screwdriver, judging resonance by noting the reading of a voltmeter in the output circuit. Maximum voltage is the best setting.

The optimum value of the grid-leak R_1 should be found experimentally, since it varies for each coil and with the load, generally being between 200 and 5000 ohms.

In designing the power-oscillator it is important to base the data on the highest no-load voltage to be encountered, since the voltage will rise with reduced load. Thus the output voltage varies inversely as the load, as shown in the regulation graph Fig. 3. With a fairly fixed load the output should be essentially constant. The regulation might be somewhat improved with a power-supply filter, but this will reduce the output somewhat.

If a stable load coil is desired without experiment, wind L_3 with 60 turns No. 30 wire. The coil form will be longer than one inch, but will require very little adjustment.

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