# PRACTICAL ELECTRONICS

## PART V—RECTIFIERS HIGH-VACUUM AND GAS-FILLED

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ELECTRON-TUBE rectifiers make direct out of alternating current. Electrons are emitted from the hot cathode in great numbers and flow readily from it to a plate in the tube if that plate is kept at a voltage more positive than that of the cathode. If the plate is negative and the filament positive, a negligible number of electrons are emitted from the cold plate (at ordinary operating voltages). So, if voltage is applied first in one direction, then the other, the tube will seem to have a very low resistance (speaking in terms of Ohm's law) when the negative voltage is on the cathode, and a very high resistance when it is on the plate. See Fig. 1.

It is necessary to know something of the characteristics of the dozens of different types of electron-tube rectifiers, if we are to use the right one in the right place. It is also important that the tube not only be properly selected for the job, but be operated under the right conditions. This is especially true for the gas-filled rectifiers. These tubes are very easily damaged if carelessly operated or abused.

Complete information on ratings and operating conditions may be obtained from receiving tube manuals for smaller types, and from the technical data sheets issued by manufacturers, for the larger industrial tubes.

High-vacuum tubes, such as are used for rectifiers in most radio receivers, are simpler and more rugged. They have four important characteristics which must be considered; peak current, average current, peak inverse voltage and forward voltage. *Peak inverse voltage* (Fig. 2-a) is the amount of back-pressure the tube will stand before "breaking down" and carrying current from plate to cathode. When this occurs the tube ceases to be a rectifier, and there are serious consequences. Such an *arc-back* is likely to release gases from the metal elements of the tube, and make it a poor type of gas-filled rectifier, with characteristics altogether different from the original ones. Several arc-backs may destroy the tube's usefulness entirely.

A tube subjected to high inverse peak voltages may short across between the wires leading through the stem, in glass tubes. In such cases the glass cracks and the vacuum is lost, ruining the tube immediately.

*Peak current* is another rating important to the safety of the tube. It is the limit beyond which even a few minutes' operation will damage or destroy it. If the current through a rectifier is increased much beyond the peak, sparks will be seen jumping from the filament (cathode). Small pieces of the cathode coating are actually being taken bodily along with the emitted electrons. The cathode is—in most rectifiers—coated with a compound which is a much better emitter of electrons than the metal below it. Once this surface is destroyed, the tube becomes useless.

Possibly the most important characteristic in well-designed apparatus is the *average output current.* This may be increased by faults in the apparatus fed by the rectifier, and thus may increase due to defects in such apparatus. If the rated average output current is exceeded, the tube heats because of bombardment of the anode by the countless electrons rushing toward it. The plate (or plates) become red. If excessive current is long continued, gases are given out which ruin the tube. If the current is not so heavy as to make the tube gassy, its life will still be shortened, due to rapid wearing away of the active cathode coating.

Another voltage often given on technical data sheets is the rated *forward voltage* (Fig. 2-b), (which usually appears in tube manuals as "A.C. voltage, RMS"). It is dependent on the peak inverse voltage, and is usually given for convenience. It does not refer to the voltage between plate and cathode inside the tube, which is the really important one to consider. This *internal voltage drop* depends not only on the forward voltage applied, but on the amount of output current—in other words upon the resistance of the *load.* If that is a low-resistance device, naturally more current will flow into it at any given voltage. As the number of electrons leaving the cathode grows denser, the repelling effect on those still struggling to get out into the tube becomes greater. So, as the electron flow from cathode to plate increases, the voltage required to push the electrons across the space within the tube goes up.

A tube cannot be considered an ordinary resistor, in which double the current will result in exactly double the voltage drop, but it does offer increasing opposition to increasing current. This opposition varies with the amount of current flowing through the tube, so that a tube may seem to have several different resistances, if measured with different currents flowing through it. Therefore the voltage drop in a tube can-

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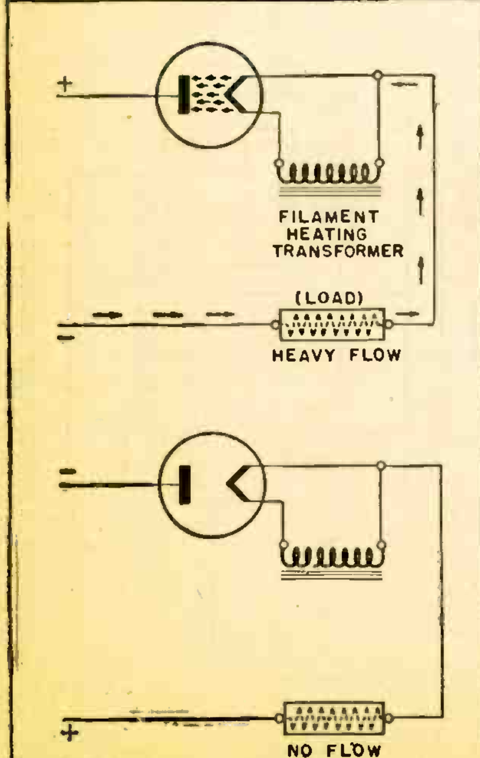

FIG. 1

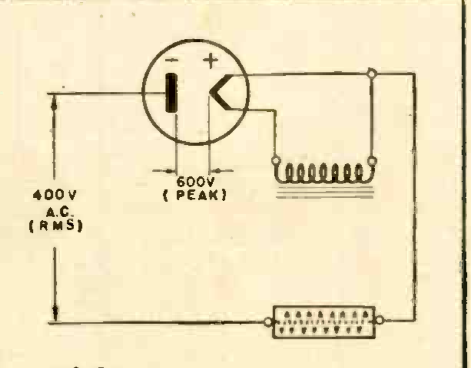

FIG. 2a

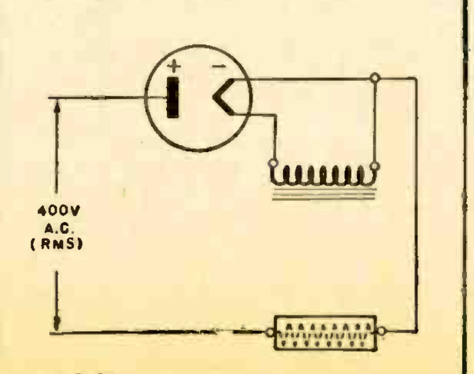

FIG. 2b

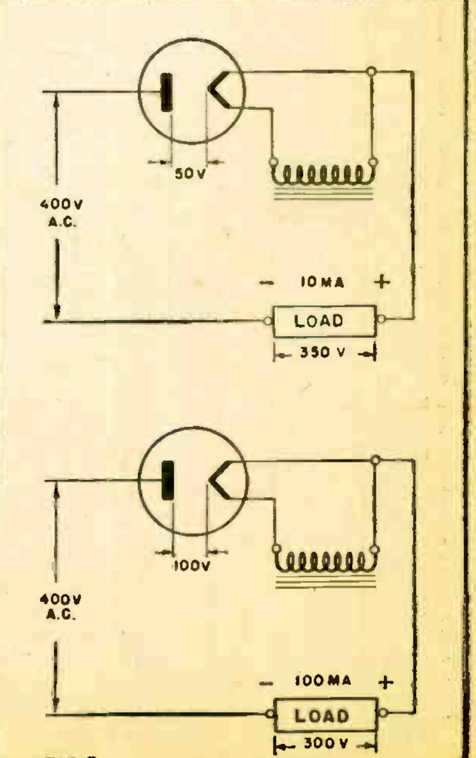

FIG. 3

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not be calculated by simple Ohm's law, but is usually given in graphs on the technical data sheets or in the tube manuals.

In Fig. 3 we have a rectifier with a voltage of 400 applied to it and a load with a resistance of 35,000 ohms. The load draws 10 milliamperes, and the voltage across it is 350. The rest of the drop (50 volts) is inside the tube, between the plate and cathode. If we drop the resistance of the load to 3,000 ohms, the voltage across it drops to 300 and the current rises to 100 milliamperes. In this case, the tube has acted as a fairly *linear* device, voltage rising with current very much as in an ordinary resistor. This might not have been the case had our load been a capacity instead of a resistance. In such a case, we might expect to find about 510 volts D.C. output with our 400 volts A.C. input, and a much sharper drop in voltage with increased current than we should expect from Ohm's law.

This increased voltage drop with increased current is important for two reasons. It acts as a safeguard for the tube should excessive voltages be put on it, or if (because of short-circuits or any other reason) the resistance of the output circuit (load) is unduly decreased. We have in effect an additional resistor in our circuit. This opposes any increase in current, thus preventing that increase from becoming as great as it would otherwise have become. The resistor action of the tube thus often saves it from being destroyed when some part of the apparatus to which it is attached breaks down and subjects it to an overload.

The second important feature of the tube's resistance is that such a tube causes some loss of power in any circuit in which it is inserted. When large amounts of current are to be rectified a high-vacuum tube becomes uneconomical. Transformers must supply enough voltage to make up for the high internal drop in the tube as well as the drop in the load, and large amounts of electricity are wasted in heating up the anode. The gas-filled tube delivers large output currents with little loss. It shows no such increase in resistance with increased current as does its high-vacuum brother (and consequently does not act as a safety device in its own circuit).

Current flow in a gas tube depends—as we have learned—on breaking down, or ionizing, the atoms of gas which compose its atmosphere. This occurs at a definite voltage for each gas, less than 20 volts for gases commonly used in rectifiers. Below that voltage, little or no current flow takes place. When it is reached, the gas ionizes, and the positive ions attract large numbers of electrons away from the cathode. If the load resistance is reduced or the input voltage increased, more atoms are ionized and more current flows, but the voltage between cathode and anode remains the same, within the normal operating ratings of the tube.

Electron-tube rectifiers which must supply heavy currents are almost invariably of the gas-filled type, for the reason that such tubes will supply large amounts of electricity at high efficiency. Because of that very feature they are much less rugged than the high-vacuum type and must be operated with greater care.

Heavy peak currents have a dangerous effect on the gas-filled tube. Should the current rise beyond the rated peak, the voltage drop across the space between cathode and plate will start to increase. As this happens, the ions, attracted by the negative voltage on the cathode, start moving toward it. Meeting with no electrons to neutralize their positive charges, they rush into the cathode and bombard it in an ionic hailstorm. These ions have enough weight, and—speeded up by the increased voltage attracting them—enough velocity to strip the active coating from the cathode surface ruining the tube. *Arc-backs* when the cathode is positive may have the same effect. In that case the electrons, speeded up by the high inverse voltage, do the bombarding.

The cathode may also be stripped if the tube is operated at too low temperatures. Many gas-filled tubes use mercury-vapor as their atmosphere. A few drops of ordinary metallic mercury are put in the tube during manufacture. The mercury is vaporized by the heat of the cathode. If the high voltage is applied while the tube is warming up, we have a situation similar to a voltage overload. The cathode is not able to emit as many electrons as when fully heated, and the atmosphere in the tube is less dense than required to maintain the low voltage drop between cathode and plate. As this internal voltage increases, so does the attraction of the cathode for the

The original walkie-talkie

positive ions, and so does their speed as they rush toward it. An ion is like an automobile—when it strikes an obstacle, its destructive force is proportional to its speed. It is necessary to use two switches for turning on a gas-rectifier power supply, one to light the filaments, (heaters or cathodes) and the other, (often automatically opererated) to turn on the anode voltage when the tube is properly heated and the mercury vaporized.

Operation at too high temperatures also has its dangers. Since the atmosphere in the usual gas tube is created by the evaporation of mercury, as the temperature goes up that atmosphere becomes denser. This reduces the voltage at which *arc-back* will occur. In many cases it causes the tube to act as a cold-cathode rectifier, carrying small currents on the half of the A.C. cycle when the plate is negative.

The inverse peak voltage must also be more carefully watched with gas-filled than with high-vacuum tubes, and the possibility of high-voltage surges in the supply current carefully considered.

Another gas-tube rating which may seem puzzling is the *maximum averaging time.* This is merely the average current rating, with a safeguard added. A tube may have an average current rating of 1 ampere, and be used in the application where it is working only 20% of the time. Yet the same tube might be ruined if 5 amperes were drawn from it for 1 minute and none for the next 4 minutes. The one-minute drain at five times normal current might be quite sufficient to cause damage. In other words, 5 minutes is too long a time over which to take an average. The usual averaging time is 30 seconds, which would mean in this case that the tube could deliver 5 times normal current for 6 seconds if it remained idle for the next 24.

The very weaknesses of gas-filled rectifiers are due to its greatest virtues—large current-delivering ability and low internal loss. It is therefore not surprising to find them used almost universally where a simple rectifier is needed to deliver large currents at modern voltages. Where extremely high voltages are required, efficiency is sacrificed, and high-vacuum tubes used. Where output currents and voltages have to be controlled, more complicated gas rectifiers, such as the Thyratron and the already-mentioned Ignitron, are used. They will be described in the next lesson.

## SYSTEM AND SERVICING

OUR millions of people depend entirely upon the radio serviceman for the maintenance of their most extensive source of entertainment and news, the broadcast receiver. With all the priorities and shortages the serviceman is left at somewhat of a loss. This should present itself as a challenge, however. and the serviceman should have at his disposal the necessary initiative to cope with the remote conditions under which he is forced to work. Due to these difficult situations, the radio repair man is no longer a serviceman. he is viewed as a radio maintenance technician, because he may sometimes have to redesign or reconstruct in order to affect a repair.

When we consider that now many servicemen are beginners in the field, their difficulties are greatly increased. The new serviceman must turn his efforts in two directions—to understand thoroughly the schematics of modern receivers, and the functions of the single circuits of which these receivers consist. With this knowledge he will be able to proceed to the first important step in servicing—*locating* the circuit, stage and part in which the defect is concealed.

The next thing is to learn to use the most effective of the methods of locating trouble: point to point testing; substitution; circuit analysis; or the use of signal tracers and the cathode-ray oscilloscope. All these have been covered in *Radio-Craft* articles.

Out of these four methods available, the serviceman should use the method or methods which most rapidly and accurately aid him in localizing the trouble. With a small amount of study and practice, he is sure to find many *additional uses* for his available equipment, heretofore not realized. He develops a mania for knowing the ins and outs of his test equipment. He should also be readily familiar with the *theory* behind the circuits with which he is working, or else his test equipment is practically useless. This statement cannot be overemphasized.

After the serviceman is aware of the methods available to him, the next step is to correlate the procedure to follow. These procedures vary widely with situations and equipment, but four major steps are to be followed for the maintenance of electronic equipment:

(1) Check the power supply and its adjacent equipment.
(2) Localize the trouble within the set.
(3) Determine the cause of the trouble.
(4) Determine and effect the remedy.

These steps are self-explanatory, and should not require too much discussion or portrayal.

Keep a notebook handy at the test bench in which three columns may be tabulated. First, the model number of the set serviced should be entered for identification; second, the symptoms which prevailed; and third, the replacement or adjustment which was necessary to effect a repair. It is quite true that there are many commercially published "Trouble Shooter Manuals," but nonetheless, all the symptoms and troubles one set alone would have, could not be covered in a large volume of manuals. For this reason, the servicing notes kept at the bench will repay the effort made in collecting them.—*J. M. K.*