Fundamentals of Radio Servicing

Part IX–The diode vacuum tube

By JOHN T. FRYE

HAVING spied on the busy electron while it skipped through conductors, resistors, coils, capacitors, and transformers, you may feel that you are an authority on the behavior of the little cuss; but until you have observed one doing its stuff inside a vacuum tube, you really have little idea of the power and versatility packed into one of these tiny charges of negative electricity.

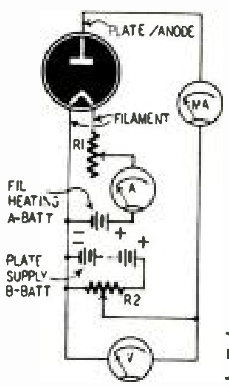
Take a look at the experimental setup diagrammed in Fig. 1. The circle represents a hollow glass sphere in which are contained a couple of loops of resistance wire and a small metal plate mounted near to, but not touching, this wire. Leads are brought out from the plate and from both ends of the "filament" wire, and all the air possible has been pumped from the glass bulb before sealing it.

A low-voltage battery, an ammeter, variable resistor R1, and the filament are connected in series. Another, higher-voltage battery, with its negative terminal connected to the negative terminal of the filament battery, has resistor R2 bridged across it so that any positive voltage from zero (at the extreme left-hand position) to the full battery voltage (at the extreme right-hand position) may be selected by the moving slider. A voltmeter is arranged to read this voltage. The slider connects through a milliammeter to the plate of our "vacuum tube."

With the slider of R2 set at zero positive voltage (extreme left), let us slowly decrease the resistance of R1, permitting more and more current to flow from the battery through the filament. The passage of this current produces heat in the filament wire; and when enough current flows, the wire becomes red hot. Our ammeter reveals how much current is flowing through the filament, but our milliammeter still stands at zero. However, if we move the slider of R2 to the positive end of the battery, the milliammeter indicates pronto that current is passing through it!

Where does this current come from? It must be flowing from the high-voltage battery, but where is the complete circuit? Surely the current cannot pass through the space between the filament and the plate inside the glass sphere, for we have always thought of a vacuum as being a perfect insulator; yet, there is no other logical explanation of what that milliammeter pointer is saying. The current *must* be bridging the gap inside the bulb, but how?

Remember that back in Chapter I we found there are always a number of free electrons wandering aimlessly



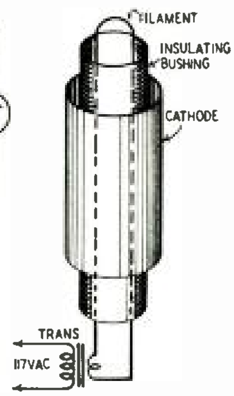


Fig. 1 (left)—Test setup illustrates diode action. Fig. 2 (right)—Cathode is cylinder surrounding the filament.

around through any conducting material? By applying voltage, we can control the direction and speed of this movement of electrons to a certain degree; but even with no e.m.f. applied, the restless little jiggers are constantly hopping around from one atom to another.

When they come to the surface of the conductor, however, they bump into a force, somewhat resembling the surface tension of water, that keeps them from passing through. While they possess some *kinetic energy* (kinetic energy is power acquired through motion; it is the reason a soft hand can slap so hard), they do not have enough to shoot through this surface barrier. They must have help if they are to escape into "the wild blue yonder."

Providing heat is the easiest way to supply this help. When the temperature of a body is raised, free electrons begin to feel freer and friskier by the second. They start to accelerate and to shoot madly about like a bunch of water bugs playing tag, and sooner or later one

These are a few of the common diodes—all sizes and ratings are manufactured.

of them takes a long running jump and pops right through the surface of the body into the air or vacuum surrounding it. As the temperature goes still higher, more and more of these heat-propelled electrons make the grade until finally the heated object is surrounded by a veritable cloud of fugitive particles that it has *emitted*.

Please note that it makes no difference *how* the emitting body is heated. It could be done with a blowtorch, a gas flame, the focused rays of the sun, etc., but inasmuch as the emitting material must be heated inside a vacuum in our radio tubes, the heating effect of an electric current has proved to be the most practical.

Sometimes the filament itself is the emitting body (or cathode), as is the case in Fig. 1; but in other instances the emission is from an *indirectly heated cathode*, as is shown in Fig. 2. Here the filament is heated by current from an alternating-current transformer, and this heat passes through a bushing made of electrically insulating but heat-conducting material and raises the temperature of the sleevelike cathode to the proper temperature for emission. Tubes are therefore loosely divided into "filament" and (indirectly heated) "cathode" types.

When an electron is emitted, its negative charge is subtracted from the total charge of the emitting body; therefore the body becomes unbalanced in a positive direction, tending to attract the negative electron back into itself if some other stronger force is not exerted on that negative particle. That is where the plate in our vacuum tube enters the picture. If the plate is positively charged with respect to the emitting filament, it tends to attract to itself the electrons that have escaped into the vacuum; and when there is a constant parade of electrons from the filament or cathode of a vacuum tube to the plate, we have a *plate current*.

These electrons pass from the plate to the positive terminal of the battery through the milliammeter, causing it to deflect. Incidentally, when only 10 ma is flowing, 6.28 times 10^{18} electrons are being emitted by the filament and attracted to the plate every second (*not* 6.28 times 1018, as the printer erroneously reported in Part I of this series). However, the electrons flow from the negative terminal of the battery into the filament at the same rate at which they return to the positive terminal *via* the plate; so no electrons are really lost or gained.

Now that the mystery of how current can flow through a vacuum has been cleared up, let us do a little more experimenting with the apparatus shown in Fig. 1. Suppose R1 is adjusted until our filament just begins to glow a dull red and that R2 is then manipulated so that the voltage applied to the plate starts at zero and advances in 10-volt steps. At each step, let us carefully note the values of the plate voltage and the plate current.

Next, let us increase the current through the filament until the filament is a bright cherry red, and then let us repeat our step-by-step increasing of the plate voltage, again carefully noting the changes in the readings of the voltmeter and the milliammeter. Finally, let us combine the results of these two observations in one graph, Fig. 3.

From this graph we can see that as the plate voltage increases, the plate current for the low-filament-current condition also increases, rapidly at first and then leveling off until a further increase in plate voltage produces practically no increase in plate current. The same thing is true after we have increased the filament current, but now the leveling-off point occurs at a higher value of plate current. For low plate voltages, the plate current is practically the same for high or low values of filament current.

The total number of electrons emitted from the filament depends upon its temperature, which in turn depends upon the current passing through it. The total number of electrons attracted to the plate depends upon, first, how many are emitted by the filament and, second, what percentage of these the attraction of the plate voltage can win over from the attraction of the filament itself. The higher the plate voltage, the higher is this percentage.

When our filament glowed a dull red, a limited amount of electrons were released. When the plate voltage was low, only a small number of these could be attracted to the plate instead of returning to the filament; but as the voltage, and consequently the attraction, of the plate went up, more and more of the available electrons succumbed to its Siren call until finally it was getting *all* of them. Beyond this point, an increase in plate voltage obviously could not increase the plate current.

When we increased the filament current and raised the temparture of the filament, we increased the number of electrons emitted. Under these conditions, it was necessary to raise the plate voltage still higher before it was attracting the total increased output of the filament. It is apparent that for every value of filament current there is a certain value of plate voltage which will attract *all* the emitted electrons and beyond which no further increase will result in more plate current. This maximum current is called the *saturation current* of the tube, and it is important that the tube be so designed that this saturation condition is never reached with the normal values of filament current and plate voltage that are applied.

Why the vacuum?

Perhaps you are wondering why there is a "vacuum" in vacuum tubes. Emission *will* take place in the open air, but there are two good reasons for placing our tube elements inside a vacuum. In the first place, if the filament were heated red-hot in the open air, it would oxidize quickly and be destroyed. In the second place, if the space between the filament and the plate were not emptied, the poor little electron would have a tough time trying to shoulder its way through the bulky atoms of air and gas which have a mass some 1,800 time that of its own.

The two-element tube that we have been studying is a fundamental type, as we shall note in the next chapter, yet this *diode*, as it is called, is used in some form or other in nearly every radio and television set on the market today. Moreover, it is subject to practically all the ills suffered by its more complicated brethern.

If the filament breaks, we have no way of raising the temperature to the emitting point; and "open" filaments are one of the most common causes of tube failure. It is equally obvious that if any two elements, such as the filament and plate, actually touch each other, the tube cannot function normally. This "shorted element" route is one by which many tubes reach the junk pile.

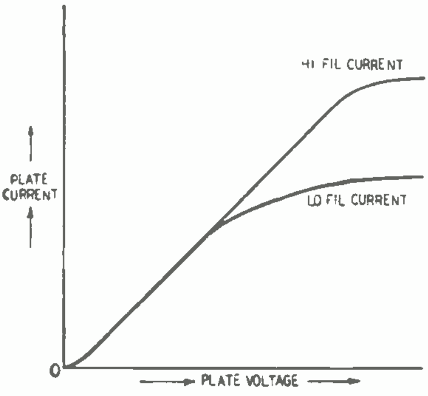


Fig. 3—Hotter cathode emits more.

As was pointed out before, the operation of the tube depends upon the elements being housed in a good vacuum, and anything that impairs this vacuum will ruin the operation of the tube. Occasionally minute amounts of gas remain in the tube or escape from some of the elements after sealing; then the tube becomes "gassy." Gassy tubes cause many headaches in the radio repair business, for they are not always as easy to detect as other defective types.

Even under normal conditions, the electron emission of a filament or cathode will fall off after a while, and this deterioration will be speeded up if the tube is subjected to overloads. Such reduced emission results in the "weak" tubes indicated by a tube tester.

Poor connections between the leads and the tube elements can result in "noisy" tubes that make a rasping, staticlike sound in the speaker; and if the various elements are not held rigidly in place, the tube will often make a ringing sound come from the speaker when the tube is touched or bumped. Such tubes, because they behave like a microphone, are called "microphonic."