AN AMATEUR WHO BECAME AN EXPERT

Fifteen years ago Mr. Donle was a typical radio fan in Providence, Rhode Island. His interest in experimental work in both ionization and in pure electron vacuum tubes led to numerous inventions; he is now chief engineer of the Connecticut Telephone and Electric Company, in charge of its radio research activities; the "Donle tube" is his latest contribution to science.

The Most Sensitive Tube IN THE WORLD

A remarkable device that operates with a plate of liquid sodium instead of solid nickel and that picks up signals on a stream of ions instead of electrons; described by its inventor—

HAROLD P. DONLE

A NUMBER of years ago we completed a survey of the field of radio receiving. The purpose of this study was to determine the relative opportunities for improvement in the several subdivisions of receiving apparatus. The conclusion reached was that a great margin for advance existed in the process of detection. The phenomena of rectification were not completely understood apparently, and the efficiency of conversion shown by even the best detectors seemed to be quite small.

Since that time a substantial portion of our research and development work has been directed toward improving detector operation.

Having found a number of inherent limitations in the grid type detector tube, and realizing the dangers of interference-

production by oscillating regenerators, we set as our goal the development of a new detecting structure that would have so great efficiency that regeneration would be unnecessary. This was a large problem, and its solution has required a great deal of time and effort; even a summary of all the work done would make a long story.

In the course of this development we have produced several distinct types of detectors. Many of these had decidedly interesting (and, indeed, valuable) characteristics but in some cases the device possessed some weak feature that tended to neutralize its good qualities. As may be imagined, the research work has been extensive. Thousands of operative tubes have been built and studied; to analyze the performance of each has required a complete set of operational characteristics for every tube; even the labor of taking tens of thousands of observations for these curves was no light task. Our latest development, the intensifier tube, which was recently described before the Institute of Radio Engineers, incorporates many of the features worked out during the research just outlined.

In this very tube we have a non-amplifying vacuum tube detector of remarkable sensitiveness and stability. When using this tube in a properly designed two-circuit receiver, we invariably reproduce radio signals more strongly and more clearly than we can produce with a standard regenerator with a grid-tube. The high sensitiveness secured is largely due to the arrangement of electrodes used, in conjunction with ionization of an alkali metal such as sodium.

The new electrode arrangement that is utilized is not in itself sufficient to account for all the results; the structure works inefficiently in the absence of ionization, for ions are responsible for the accumulated charge on the "collector" electrode. Responses to signals are obtained in this tube by a breaking up of this charge when radio frequency impulses are impressed on the detector; the result is a relatively great change in the steady value of the current in the collector-filament circuit.

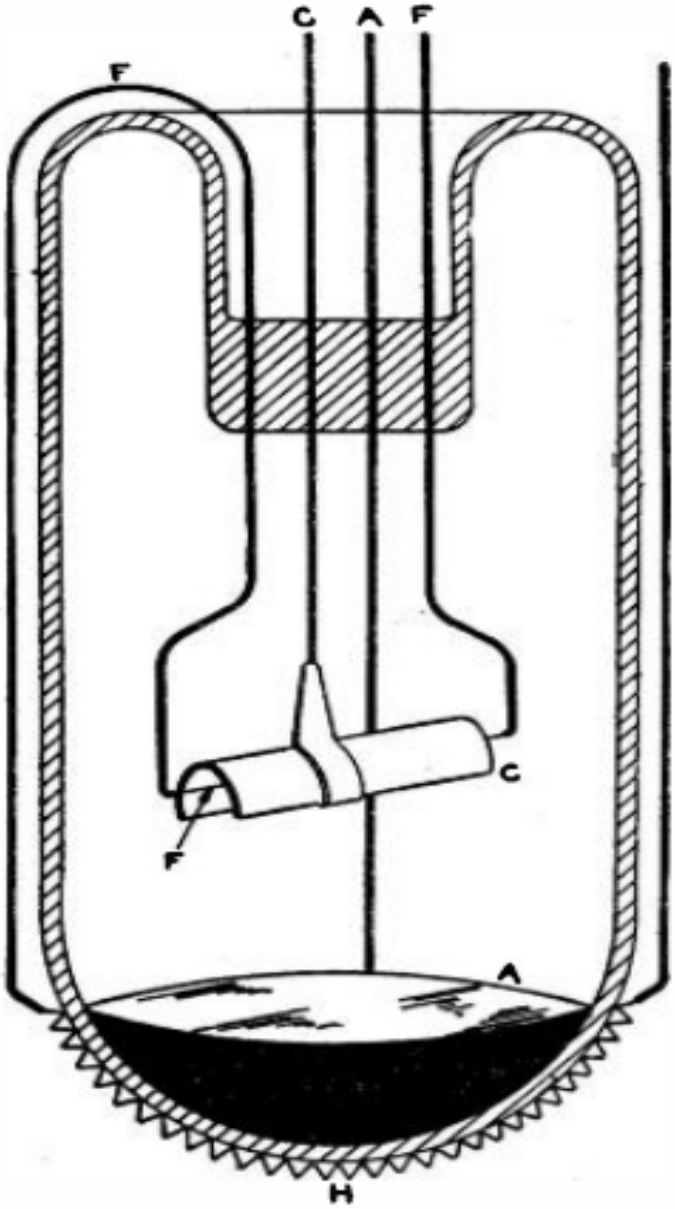
When a regenerator is adjusted for maximum sensitiveness, just short of self-oscillation, the circuits have a low effective resistance which results in a "tailing out" of speech or music and prevents clean-cut reproduction. This effect cannot be had with the intensifier, for its circuit and mode of operation are non-regenerative. Similarly, the intensifier cannot produce interference with reception by others; it is not capable of adjustment so as to radiate energy at the working wavelengths. This helpful characteristic, which allows the user to tune at will without fear of disturbing other people, caused Dr. Chaffee to christen the device "The Golden-Rule Tube."

Figure 1 shows a conventionalized cross-section of this new tube. A glass bulb contains the straight filament F, the collector electrode C (which is a trough-shaped piece of sheet metal supported above the filament) and the main anode A at the bottom of the tube. This anode is, in this particular form of tube, a button of metallic sodium. Connections to the electrodes are provided by way of the three wires that are shown; the second filament lead is brought out through an external heating coil H mounted outside of the tube proper.

The filament current passing through this heater serves to maintain the sodium anode at the correct operating temperature. The four terminals are brought out to the prongs of a standard detector base.

A useful circuit for taking advantage of the intensifier's characteristics is shown in Figure 2. The left-hand portion of the diagram is simply a form of the well-known two-circuit tuner. The detector connection is somewhat unusual, however. Current for heating the filament and the anode is drawn from a 6-volt storage battery, in the tubes now available, and is controlled by a rheostat R. The average current value is

about 1.6 amperes. The anode circuit contains the telephones and a dry battery of any convenient potential between 10 and 30 volts; no adjustment of the anode potential is necessary, for the battery may vary widely without much effect on signal strength. No by-pass condenser is needed across the telephones (or transformer primary, if an amplifier is used)



THE PARTS OF THE TUBE

FIGURE 1; *F is the filament, connected in series with the heater element H, which heats the anode A, causing it to give off ions that fly over to the collector plate C. All of these elements except the heater are enclosed in the inner glass shell.*

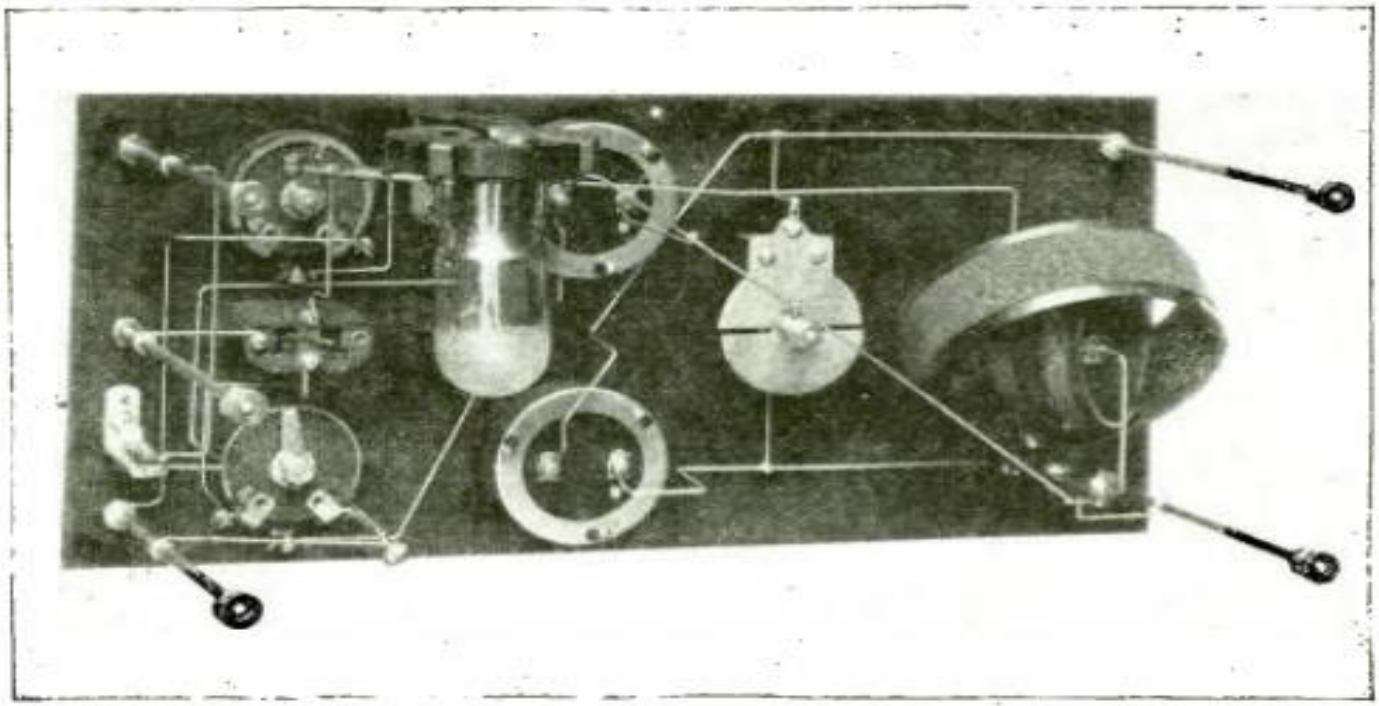
for no radio frequency currents appear in the anode circuit. The anode current is about 150 to 200 microamperes.

The most interesting thing is, however, the connection and behavior of the collector circuit. No stopping condenser or leak resistance is used, and the tube will not work properly if there is any such obstruction to prevent flow of current in the circuit from filament to collector.

The steady value of current in this collector circuit is relatively high; if the collector is connected directly to the filament it will measure as much as 1,500 microamperes or some ten times the normal anode current. To control the collector current conveniently a variable opposing or neutralizing potential is introduced by means of a potentiometer across the filament battery. The larger this neutralizing e.m.f. the smaller the collector current; the normal adjustment is in the neighborhood of 1.4 volts, giving a current of 600 to 800 microamperes or about four times the current in the anode-telephone circuit.

Another interesting feature is that this large collector-circuit current does not flow unless the anode circuit is closed. If we break the telephone connection, the anode current is of course interrupted. But the collector current at once falls to something like half its normal value. This unusual feature is one of the characteristics that identify the new phenomena used in this intensifier tube.

If microammeters are placed in both the collector and anode circuits, the steady value of current in each will be seen to drop as soon as radio signals are applied. The change of current on receiving signals is much greater than with grid tubes, and gives us not only a convenient way of measuring directly on a meter the intensity of quite weak radio waves but also an easy method of operating a telegraph relay on a telephone call-bell by radio. For instance, ordinary daylight signals received at Meriden (on a small aerial) from WOR at Newark, a hun-



AN INSIDE VIEW OF THE NEW RECEIVER

Notice that the tube is mounted in an inverted position. The arrangement of the various instruments and the wiring is clearly shown. All the connections to the set are made from the rear.

dred miles away, cause a drop in collector current of about 50 microamperes; it is simple to arrange a relay to be operated by such a current change.

The large effect which signals produce on the collector current makes it feasible to place the telephones directly in the input circuit. In this case, the anode circuit includes nothing but its battery and the collector becomes both input and output electrode. The collector circuit is one of low impedance, however, and the usual telephones are not suited to it. Their resistance also interferes to some extent with tube operation, so that it is better as a practical matter to place the telephones in the anode circuit. Nevertheless, for a given resistance in the collector circuit signal responses are as loud with the telephones in the input as in the anode circuit.

One other operating feature should be mentioned—selectivity.

Although with the intensifier we have no way of reducing circuit resistance by regeneration, the extraordinary sensitiveness of the device permits us to use exceedingly loose coupling in the receiving tuner. As is well known, this produces not only a high degree of selectivity but also gives great freedom from impulsive interference produced by static or nearby spark stations. Further, the intensifier has a valuable frequency-selecting power of its own; adjustment of filament current and collector potential permits discrimination between neighboring wavelengths by increasing the sensitiveness of the tube to any particular desired wave frequency within its range. As built for broadcasting reception the tubes may be adjusted to give maximum response to 360 or to 400 meters and at the same time to be poor detectors of interfering signals on 600-meter or longer wavelengths. The net result of these several possibilities is to give a practical and easily secured selectivity that is much higher than is ordinarily required.

Experimenters whose only experience with detectors utilizing ionization phenomena has been confined to grid tubes containing gas are likely to believe that any ionization effect must be of unstable

or transient character. A little work with one of the intensifiers will quickly demonstrate that it is the gas and not the ionization that causes the fugitive, rapidly changing adjustments of the old tubes. By using ionization of a metal vapor, and particularly of an alkali metal, we are able to produce in quantity detector tubes which have definite characteristics and the operation of which is uniform throughout the period of use. Control of the ionizing anode temperature gives us complete control of tube operation, and in order to keep an intensifying detector adjusted to maximum sensitiveness for hours at a time it is merely necessary to set the filament rheostat at a value that will maintain the requisite heating and to adjust the collector potentiometer at the best point for the particular signal strength and frequency, and leave them there.

As may well be imagined, we have had our own troubles in producing a tube of this kind. The operation is so radically new that we not only had to develop the device itself but also new methods and apparatus for testing it. The usual schemes used for investigation of grid tubes are of little value to us; for example, the absence of amplification and the presence of a relatively large direct current in the input circuit are not taken care of in the ordinary methods of measurement.

The experimental work has been well worth while, however, for we now have a dependable detector of higher sensitiveness than has ever been reached, yet one which cannot produce interference. Continuation of the investigation is showing further possibilities of increased sensitiveness, and present-day indications are that filament current consumption can be reduced to a point that will permit of dry-cell operation without loss in stability, selectivity or responsiveness of the new tube to radio signals.

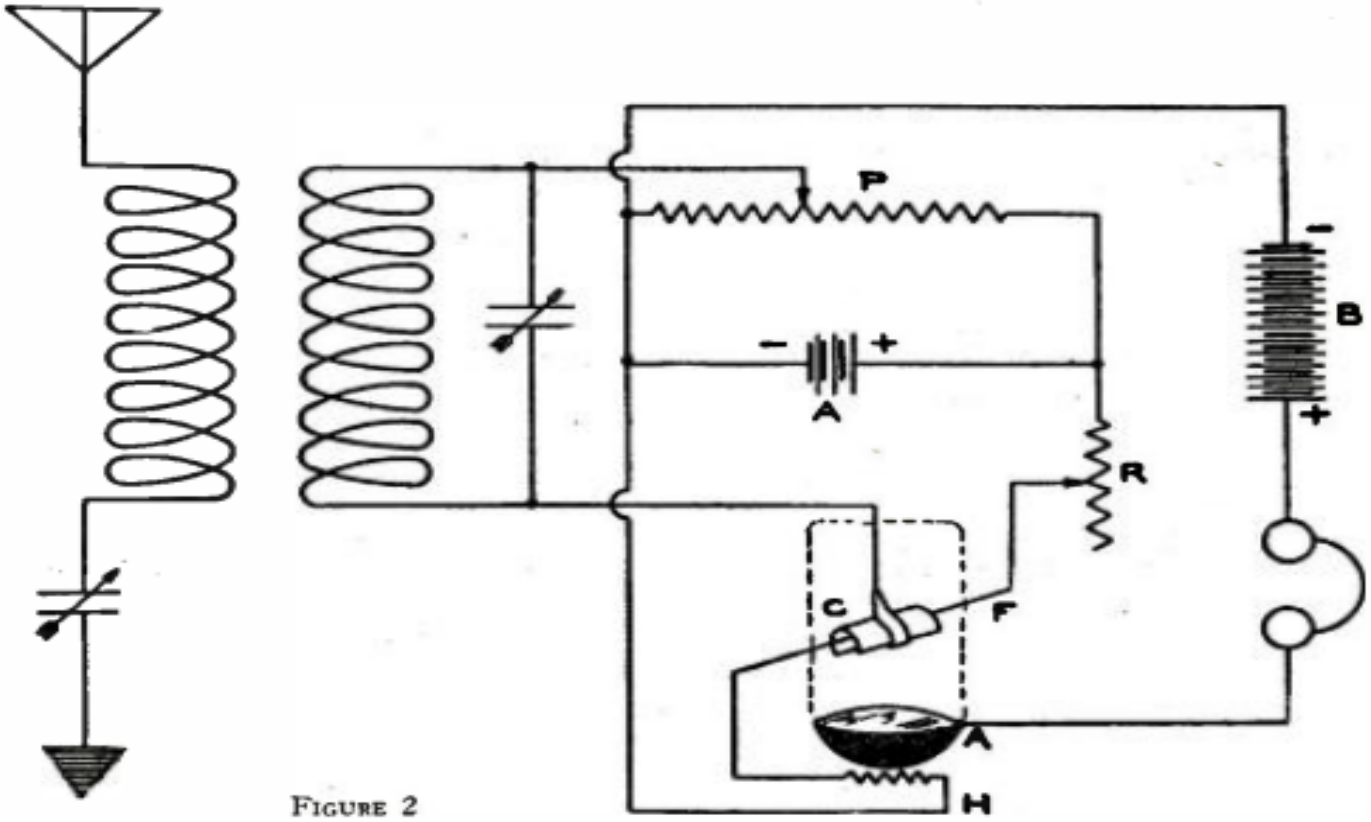


FIGURE 2

The electrical connections for the set that makes use of the intensifying properties of the new tube. This circuit has proven of exceptional sensitivity in detecting radio signals.