A NEW NON-INTERFERING DETECTOR*

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One of the least efficient elements of modern radio is, despite the large amount of development since coherer days, the detecting system. Our best detectors are insensitive things when compared to galvanometers or telephones, and there appears room for considerable advance in increasing detector effectiveness. The present paper describes a radically new way of securing dependable detectors having high sensitiveness, which, it is hoped, will be considered to mark a step forward.

The ordinary three-element tube as a simple detector is not nearly sensitive enough to satisfy the present demands. Many attempts have been made to increase this sensitivity by including within the tube a gaseous atmosphere and while extremely effective detectors have been thus produced, they have required very delicate adjustment and in the majority of cases were not stable and required constant attention. Furthermore, it has been found practically impossible to reproduce in quantity tubes of uniformly maximum sensitivity.

The three-element electron tube and regenerative circuit is largely used at present for reception of radio signals. While it gives excellent results and certainly far exceeds in response any other method disclosed to date, nevertheless it has certain disadvantages and its widespread use has created a situation which is bound to retard the popular use of radio.

By using the three-element detector in a regenerative circuit greatly increased sensitivity is secured, but if regeneration is carried far enough to give worth-while response, there is produced considerable signal distortion. Furthermore, adjustments are critical, the slightest variation in capacity destroying the operating adjustment. What is still more important, the radiation

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from many regenerative circuits, particularly in the hands of inexperienced operators, creates an alarming amount of interference which if continued will seriously hamper reception of the present broadcasting programs.

There seems to be a definite need for a receiving tube which under no condition can radiate any energy from the antenna to produce interference, which can be easily adjusted, which is not affected by the body capacity while the circuit is being tuned, and yet which secures all this at no sacrifice of sensitivity and loudness of response.

For several years we have conducted experiments on many different forms of detectors, and particularly upon detectors employing ionization of metallic atoms. This was a most promising field of development since such ionization was found to be readily controlled and stable. As one of the results of this work we have developed the present tube which is the logical result of experimental work which we have done along these lines. This new tube has none of the disadvantages of regenerative and gaseous detector systems above mentioned. Its method of operation seems to involve many interesting phenomena, which are radically different from those occurring in other tubes.

The construction of one form of this tube is illustrated diagrammatically in Figure 1 where *F* is the filament, *A* is the anode, which may be of metallic sodium in the bottom of the tube, and *H* is the heater which is a short length of resistance wire cemented to the outside of the glass directly underneath the anode. This heater maintains the anode at proper operating temperature. *C* is the "collector" electrode of sheet metal bent

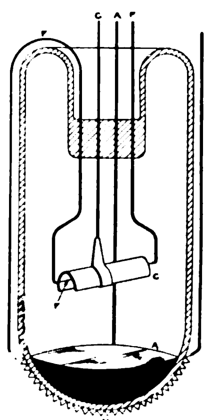

FIGURE 1

into a "U" and positioned above the filament with its open side toward the anode.

Figure 2 shows these various parts before assembly and Figure 3 a finished tube.

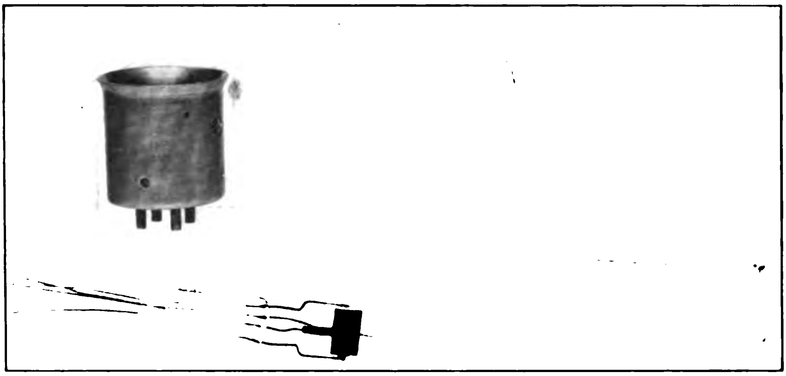

FIGURE 2

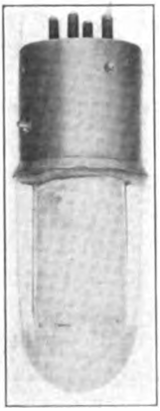

FIGURE 3

In operation the tube may be connected to the circuit, shown in Figure 4, which is simply a two-circuit tuner with one terminal of the secondary connected to the collector electrode of the tube and the other to a contact operating on a resistance connected directly across the filament battery terminals. The remainder of the circuit is as used with any simple detector.

The adjustment of collector potential is the only one necessary for efficient operation other than the usual variation of capacity and coupling of the tuning circuit. The potential of the "B" battery is not at all critical and usually may be varied between ten and thirty volts without much effect on response.

As a detector this tube is remarkably sensitive, its adjustment is simple, and it is absolutely stable in operation. This extreme sensitivity is readily reproducable and permanent.

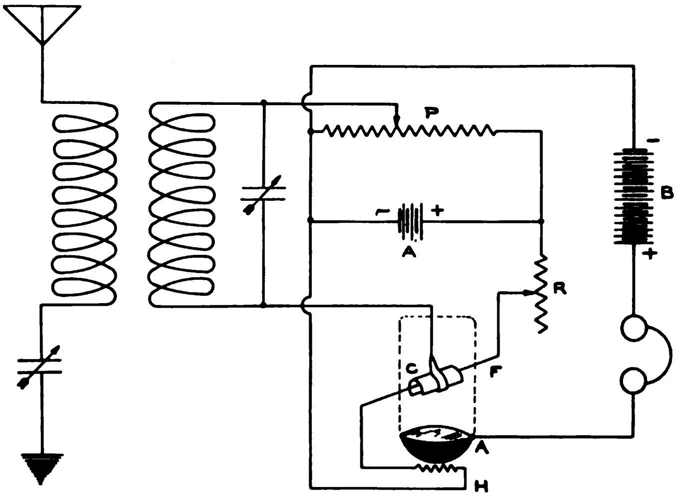

FIGURE 4

The response secured with this tube in a plain circuit equals in magnitude the response from a regenerator, using maximum non-oscillating regeneration. A regenerative circuit under this condition of critical adjustment will give very considerable distortion, which is particularly objectionable when receiving voice or music and which can only be eliminated by a reduction of regeneration and consequent reduction of signal strength.

On the other hand, the new detector creates no noticeable distortion, and, as it does not oscillate over its useful range, it cannot create any interference with other receivers. Furthermore, it is unaffected by small capacity changes, such as those produced by the operator's hand in tuning.

The response of the tube is greatly improved by very weak coupling between the circuits. This is due to its very low input impedance which also makes the proportion of capacity and inductance of secondary circuit for maximum results quite different from those for other tubes. Altho the new detector can be used successfully in an ordinary two-circuit tuner, results will fall short of the maximum unless means are available for selecting the best value of secondary inductance.

In this tube there is an electron flow from the filament to the collector, the magnitude of this current being due in part to the relatively large area of the collector and to its close proximity to the filament. It, therefore, receives an equivalent of large electron flow when it is at the same potential as the negative end of the filament. In order to reduce this flow an opposing potential (which may be taken from the "A" battery) is introduced into the circuit between collector and filament. This potential is called the neutralizing potential and is used as abcissas of curves shown in Figure 5, which show the variation in anode and collector currents I_a and I_c with variation of neutralizing potential E_n, and also the collector current when the anode circuit is open I_c'. The curve labelled $I_c - I_c'$ is the difference between the collector current with the anode circuit completed and opened. This last curve is interesting in that it apparently takes into consideration various phenomena concerned in the operation, and its slope is practically a direct index of the merit of the tube as a detector.

These curves show some of the fundamental characteristics of the tube. The abrupt bend in the collector current at $E_n = -1.8$ is a point at which maximum detection would be expected to take place, according to the usual conception of detection as being due to rectification over a section of the characteristic slope where the rate of change is large. One would also gather from this curve that the effect of a signal impressed would be to increase the average value of the collector and anode currents. Altho some detection takes place on this part of the curve, in magnitude it is not comparable to that secured over the sensitive portion of the slope. The point of maximum sensitivity for these curves is at $E_n = -1.4$ volts, which is at a relatively flat portion of the collector current curve and considerably above the lower bend. Furthermore, a signal impressed on the collector circuit always gives a decrease in collector current regardless of whether the characteristic curve at the sensitive point is concave or convex, many examples of both types having been observed. It should also be noted that this point of maximum sensitivity occurs somewhat above the center of the $I_c - I_c'$ curve. Another point of interest in connection with these curves is the values at operating potentials of collector and anode currents, the collector current usually being two to four times that of the anode. Special attention should be given also to the large changes of current produced by small changes of neutralizing potential.

Figure 6 shows the collector and anode currents at various values of anode potential E_a, but is of little interest in the present discussion except to show the very slight variation in collector current and the slow slope of anode current as a function of anode voltage. Considerable amplification might be expected from a superficial examination of these two anode current curves, Figures 5 and 6. However, the tube is not in fact an amplifier, probably on account of the comparatively high input power required for operation. It nevertheless has a high so-called voltage amplification, which in some cases runs as high as 400.

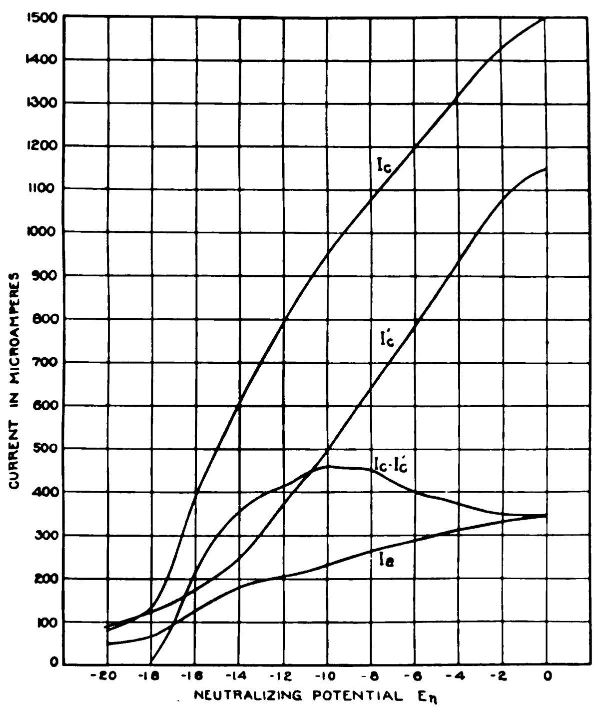

FIGURE 5

To determine some of the predominant features of the new tube in comparison with older types, a special tube was built, having filament and collector structure exactly as in Figure 1. but with the sodium anode replaced by a molybdenum plate, This special tube, like the usual new type, was evacuated to a high degree so as to preclude gas ionization. Since it contained no ionization metal, it operated on the pure electron basis. In

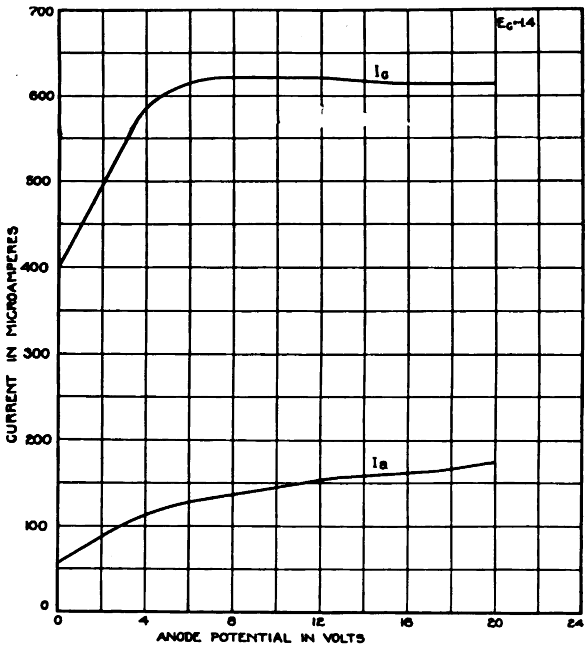

FIGURE 6

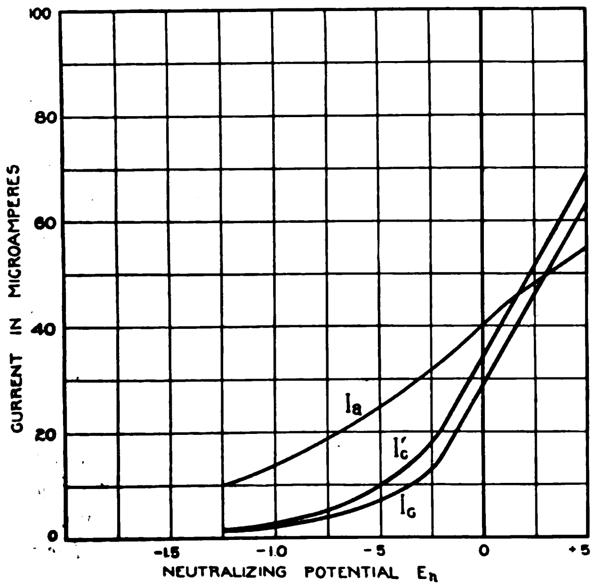

FIGURE 7

the circuit of Figure 4 it showed none of the sensitive response which was had with the sodium tube. Characteristic curves for the special pure electron tube are shown in Figure 7; these were taken under conditions identical with those for curves of Figure 5. The effect of the new ionization phenomena on the form of these curves can be readily seen.

A most interesting point in comparison of these characteristic curves of Figures 5 and 7 is that in Figure 5 the collector current is increased by the completion of the anode circuit, while with Figure 7 the collector current decreases when the anode is connected, this last being similar to the effect on grid current when the anode circuit is opened in the ordinary three electrode tube. As shown in Figure 5, when the operating phenomena of the sodium tube are broken up by too high a neutralizing potential, we also secure the same result, that is, an increase in collector current when the anode is disconnected.

Figure 8 shows the change in collector current of the sodium tube for impressed signals of different wave lengths. The ordinates of this curve show in micro-amperes the actual decrease in collector current caused by a signal of variable frequency, but of constant amplitude. This curve shows that the response for the particular tube on which this data was taken becomes small above the wave length of 1,000 meters, and that below this wave length detection increases rapidly. This might seem to indicate a limited wave length band of operation for this type of tube, but the entire shape and position of this curve depends upon the relative potentials of the tube electrodes and upon their proportions and relative positions. It is possible radically to change this curve by a simple variation of the neutralizing potential. It is also possible by a proper selection of values to secure a serrated form of this curve of which Figure 9 is a typical example.

The possibilities indicated by this curve in the elimination of interference are obvious.

Figure 10 shows the variation in collector current at various values of E_n due to an impressed signal of constant frequency on the collector circuit. Thus it represents the range of the neutralizing potential for a signal, and gives some idea of the ease of adjustment of this variable for maximum signal. This adjustment is obviously broad and allows a relatively wide variation of neutralizing potential for an audible signal, making it simple and easy to locate the point of maximum sensitivity.

It might be of interest to state that the data for this curve was obtained while the tube was functioning on an antenna and that the ordinates represent the change in collector current produced by a signal from WOR (Newark, New Jersey) as received in Meriden, Connecticut, 100 miles (160 km.) away.

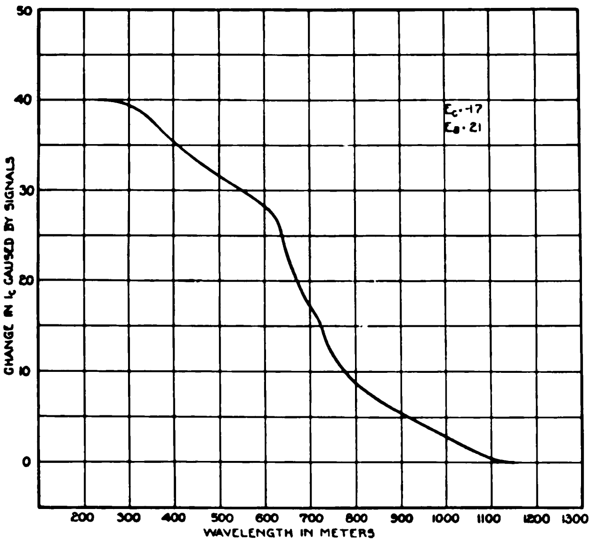

FIGURE 8

The effect shown in Figure 8 of signal frequency on response given by the tube, a most interesting phenomenon, is a consequence of a constant pulsation of collector current, the time period of which is controlled in part by relative electrode potentials and the position of the electrodes. This frequency of pulsation is low compared with the lowest frequency at which the tube is a sensitive detector. Furthermore, this pulsation of collector current at low radio frequencies is in no way affected by a capacity-inductance circuit associated with the tube. For example, if the collector electrode is connected directly to the contact on the potentiometer, with no periodic circuit interposed, the circuit will oscillate at a low radio frequency, the value of which is determined by the various factors set forth as above. Furthermore, when the tube is oscillating at a particular frequency, inserting a closed capacity-inductance circuit in series with the collector will have little effect on the oscillation of the tube.

The fundamental frequency of collector current pulsation for curve of Figure 8 was 74,300 cycles per second and it was possible to detect by use of an amplifier the first and second harmonics, both of which were obviously at frequencies well below the sensitive range.

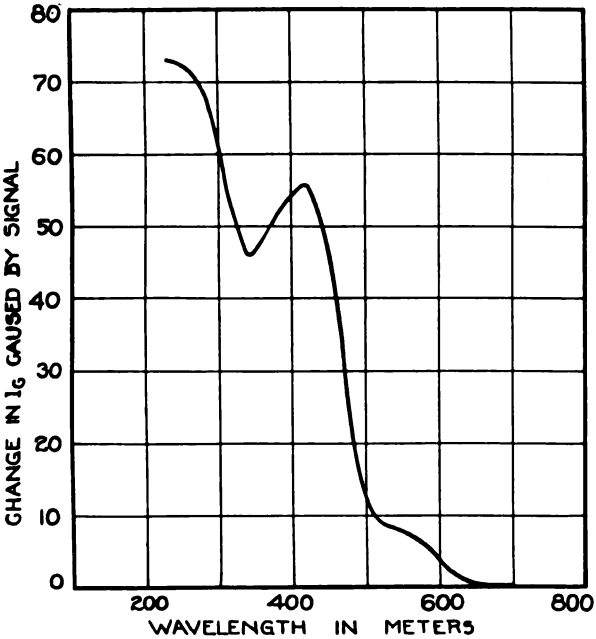

FIGURE 9

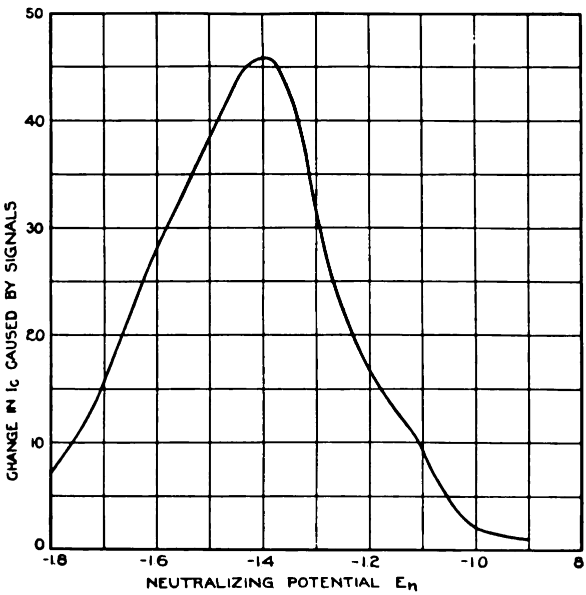

FIGURE 10

Altho the collector current pulsates at low frequencies, the tube is entirely ineffective as a heterodyne receiver due to the almost negligible detection at this frequency. As can be observed by an examination of Figure 8, no appreciable detection takes place until the signal frequency is at least four or five times the fundamental pulsation frequency.

The fact that the collector current pulsates and that this pulsation is not affected by a capacity-inductance circuit demonstrates that there is within the tube a mechanism, necessarily connected with ionization, which causes an alternate build-up and break of current in the collector circuit.

When the alternating potential of a signal is applied to the collector circuit, the pulsation is impeded to a greater or less extent depending upon the amplitude and frequency of this potential. Furthermore, since the pulsation causes a build-up of average collector current, the effect of a signal in this circuit is invariably to reduce the average value of this current.

Since slow changes in the collector circuit current are reflected in the anode circuit, a decrease of the average value of the collector current will result in a like decrease in the anode current, but this occurs without any appreciable amplification. By experiment on large number of tubes the ratio of change of power in collector circuit to resulting power change in anode circuit was found to be approximately unity.

This lack of amplification accompanying the detection effects, makes it feasible to operate the tube with an indicating device, such as a telephone receiver, placed directly in the collector circuit instead of in the anode circuit as shown in Figure 4. This is of interest, altho results are not quite as good as with the normal circuit (Figure 4), due to the fact that in the low impedance circuit, the high resistance of the receivers interferes with proper functioning. The anode circuit impedance is well suited to the standard telephones and transformers on the market.

With the telephones in the collector circuit the device might seem to be more or less the equivalent of a two-element tube, but the contrary is true, however, for with this connection, if the anode circuit is opened, no operation whatever will be secured, thus demonstrating that satisfactory operation depends upon the presence of this new anode circuit.

The action of this tube depends upon ionization produced by electrons emitted from the filament. It is, however, not the purpose of this brief paper to go into detail beyond a description of some of the most interesting characteristics.

The use of an easily vaporized anode metal allows great possibilities in the way of controlling ionization, in part because it becomes possible to secure a very sharp density gradient of atoms available for ionization, and to supply these atoms continuously at the proper rate required for operation, thus leaving unrestricted the mean free path beyond the zones of ionization.

Sodium is a convenient metal of this type, but similar useful effects have already been secured from a variety of differently composed anode materials. The present paper describes only one of the structures used with the sodium anode in this tube, the supply of atoms being regulated by the temperature of the anode and this varied by the external heater. In practice the heater is connected in series with the filament, and the two are thus controlled simultaneously.

At first thought it would seem necessary to allow a considerable time after lighting the tube filament before the anode would become sufficiently hot. That is, however, not the case on account of the following most interesting phenomenon. When the filament is first lighted the anode receives a small amount of heat by direct radiation from the filament and there will be, even at this relatively low temperature, a considerable emission of particles from this anode. This emission will, however, decay with time, and in a period of possibly one hour it will have reached a small fraction of its initial value. However, with the external heater connected in series with the filament, as described above, when the filament is lighted the anode will commence to receive heat from this heater. Its effect in raising the anode temperature will be necessarily slow on account of the interposition of the glass wall of the tube, but the temperature of the anode will be increased by this heater at a rate approximately correct to compensate for the decay of the initial emission, and thus the emission of particles from the anode will become fairly constant within a few seconds after the tube is first lighted. The result of this combination of affairs is that when the tube is lighted it is almost immediately in operative condition, altho in some cases a slight re-adjustment of neutralizing potential is later necessary to maintain a maximum sensitivity.

Ionization controlled in this way is extremely stable and these tubes may be maintained in their most sensitive adjustment for long periods of time. This is an impossibility with a gaseous detector. Also, with this type of ionization, it is possible to manufacture in quantity tubes with little if any variation of sensitivity. The tubes will remain substantially constant in sensitiveness thruout their life.

It is felt that the unique characteristics of this device and its inherent advantages over prior detectors should offer a new avenue of approach to the problem of detection. By replacing, without loss of sensitiveness, many of the regenerators now in use the new tube should further help to eliminate much of the present disagreeable interference.

Research Laboratory of
the Connecticut Telephone and Electric Company,
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November 8, 1922.

SUMMARY: A new detector of high sensitivity is described which to the stimuli of weak impulses gives a response at least equal to a regenerator with the most critical regeneration. This high sensitivity is secured with the use of metallic ionization and a new electrode termed the "collector." Ionization of this type is readily controlled and stable and makes it possible to secure uniform characteristics on production tubes.

Static characteristics are given and show some points of particular interest such as, for example, the high value of current to collector as compared with the anode current. Curves are also given showing the effect of frequency on response, indicating great possibilities in the elimination of interference. The effect of a signal is shown to always decrease the steady value of the collector and anode currents irrespective of the shape of the characteristic curve.

As this detector does not oscillate thruout its sensitive range it obviously cannot radiate any energy and, therefore, interfere with broadcast reception by neighboring receivers.