May 7, 1929. H. P. DONLE 1,712,032

ELECTRON DISCHARGE DEVICE

Filed Dec. 1, 1922

Fig. 1.

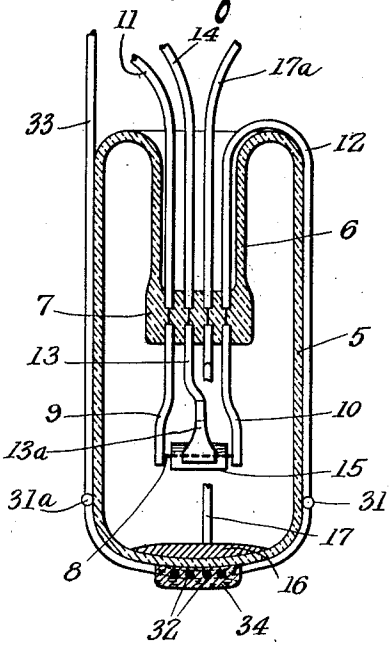


Fig. 2.

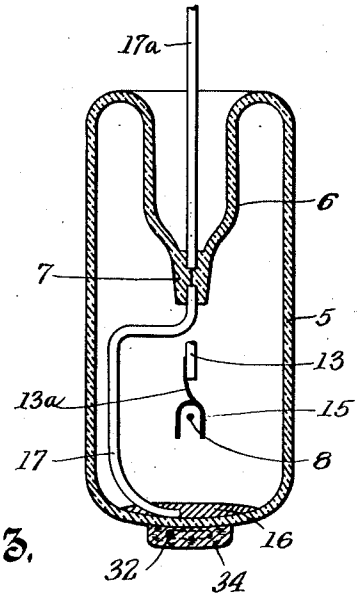


Fig. 3.

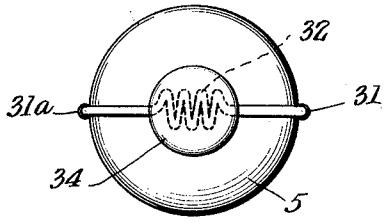
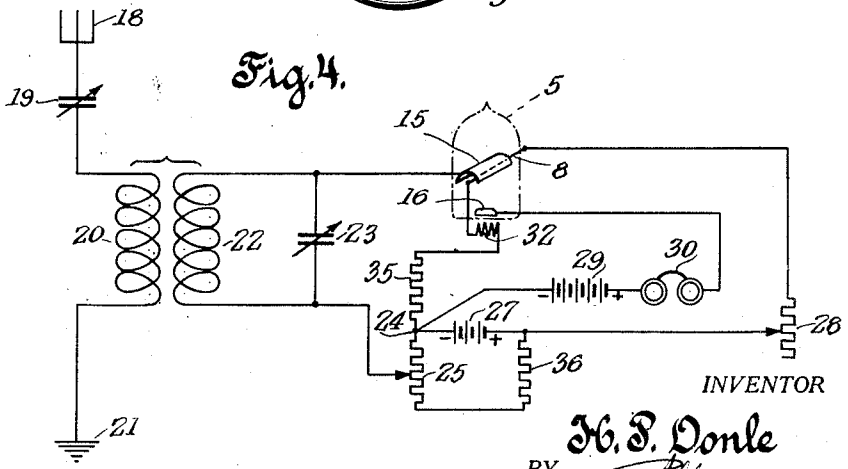


Fig. 4.



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BY

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UNITED STATES PATENT OFFICE.

HAROLD POTTER DONLE, OF MERIDEN, CONNECTICUT, ASSIGNOR, BY MESNE ASSIGNMENTS, TO RADIO CORPORATION OF AMERICA, A CORPORATION OF DELAWARE.

ELECTRON DISCHARGE DEVICE.

Application filed December 1, 1922. Serial No. 604,312.

My invention relates to electrical signal receiving apparatus, and more particularly to instruments utilized in the reception of intelligence by radio telegraphy or telephony.

The primary object of my invention is to provide a detecting and intensifying system of great delicacy in point of responsiveness to weak signal impulses but of sufficient stability and uniformity of operation to permit even untrained users to secure good results. Further objects are to select or discriminate between radio or other high frequency signals having different frequency characteristics, to produce not merely a loud but a faithful and undistorted response to received signal-energy, and to control the action of the entire receiving assembly with a minimum number of adjustments.

I have discovered that by modifying the construction of a vacuum tube and by utilizing this modified tube with circuit arrangements and adjustments differing from those of the prior art, a substantial and exceedingly useful increase in responsiveness may be secured.

Fig. 1 is a longitudinal section and side elevation of one form of vacuum tube which I have found satisfactory.

Fig. 2 is another sectional view taken on a plane at right angles to that of Figure 1.

Fig. 3 is an end view of the lower end of such a tube.

Fig. 4 is a diagram showing a circuit in which the tube may be effectively used.

My new vacuum tube in its preferred form differs from devices heretofore used for somewhat similar purposes; for instance:

1. It contains no interposed or control electrode of the type ordinarily called a grid.

2. Electrons from an incandescent cathode are received by two separate electrodes.

3. The temperature of the main anode is controlled so as to produce a limited quantity of evaporated molecules of the anode material at or near its surface.

4. Provision is made to ionize some of these molecules by electron bombardment at a definite rate.

5. In the operation of the device these ions are in part neutralized and in part re-charged negatively or reionized positively by the filament space charge.

6. The ionization actions are localized, stable and under complete control.

7. Under operating conditions when the anode circuit is opened the collector current decreases.

I thus produce a vacuum tube detector which shows extraordinary delicacy or sensitiveness to the stimuli of received radio impulses, but which, in contrast to prior art tubes depending upon random or un-localized ionization (which erratic phenomena I prevent by means later to be explained) is at all times quantitatively governed by the adjustments of the circuits.

The sensitiveness of my new detector may be as great as or greater than that of a prior art detector tube used in a regenerative circuit, yet in my device there occurs no useful radio frequency amplification. No provision is made to feed back radio frequency currents from indicator to input circuits and the defects of such a process are avoided. Indeed, the possibility of the flow of radio frequency currents in the main anode circuit may be eliminated by the insertion therein of choke coils without reducing the responsiveness of the system to received signals.

The construction and operation of my invention may be more clearly understood by reference to the drawings showing one form of device. In Fig. 1 an evacuated glass envelope 5 provided with a stem 6 and press 7 contains the three electrodes above referred to. The cathode 8 may be of the filamentary form (either linear or spiral), for instance of tantalum, tungsten or any of the materials commonly used for incandescent filaments, and is supported by members 9, 10 which are sealed into the press 7 and electrically connected to the terminals 11, 12. Terminal 12 is carried down the side of the tube and at joint 31 conductively fastened to a length of resistance wire 32 which is bent back and forth in zig-zag form (as shown in Fig. 3) and held against the bottom of the tube by a small quantity of cement or other suitable material 34. This resistance wire constitutes the heater. Its other end is fastened to terminal 33 by the electrically conducting joint 31a.

The press 7 also carries a third sealed in supporting member 13, with appropriate electrical terminal 14. The supporting member 13 has attached to it a metal strip 13a to which is fixed the collector electrode 15.

This electrode is here shown in the form of an inverted and open-ended trough partially surrounding the filamentary cathode 8.

Below the cathode and the collector, at 16 and partially filling the lower end of the glass tube 5, is the main anode which may be a body of metallic sodium. The sealed in wire 17 and the terminal 17^a provide electrical connections with the anode 16.

The vessel 5 is preferably exhausted to a high degree by modern pumping means, the gases occluded within or upon the internal glass and metal portions of the tube being driven off by heating, and the sodium being introduced by melting it from a side tube after the tube 5 has been thoroughly cleaned and evacuated.

Fig. 2 shows the inverted trough collector 15, part of its support 13^a, a section of the filament 8, the anode 16, terminal 17, the glass container 5, the heater 32 and its enclosing cement 34, the view being taken at 90° in a horizontal plane from that of Fig. 1 to show the relative arrangement of the three electrodes.

Fig. 3 shows the arrangement of the heater 32 and the connections thereto, the view being a horizontal cross section of the lower end of the tube.

I have made and successfully used tubes such as those shown in Figs. 1, 2 and 3, in which the cathode consisted of about ¾ inch of 0.004 inch tantalum wire. The collector was of nickel bent from a sheet about ½ inch square with the formed sides approximately parallel. The anode was a layer of pure metallic sodium about ½ inch in diameter and $\frac{1}{16}$ inch thick, and the distance from the anode surface to the cathode was about ¼ inch. The peak of the collector was about $\frac{3}{32}$ inch from the cathode. The heater was formed from about 4 inches of #24 resistance wire, having a resistance of approximately 0.64 ohms.

Fig. 4 shows a circuit which I have found satisfactory for operation of my tube so as to take advantage of its increased sensitiveness. In this diagram the antenna 18 is connected through tuning condenser 19 and primary coil 20 to earth 21. Variably coupled to the primary 20 is a secondary coil 22 having its terminals shunted by a tuning condenser 23 so as to form an adjustable resonant circuit. From one armature of this condenser I provide a direct connection to the collector 15 of the intensifying detector tube 5; the other armature of the condenser 23 is connected to the negative terminal of the filament 8, as at the point 24, by way of a potentiometer 25 which is connected in series with resistance unit 36, the two being shunted directly across the filament battery 27 as shown. By adjusting the movable contact of the potentiometer 25 the collector potential with respect to the negative terminal of the filament may be varied slightly in either the positive or negative direction, so as to control the amount of current flowing through the collector filament circuit 8, 32, 24, 25, 22, 15. The best potential for the collector with respect to the negative end of the filament varies with different tubes, but for the type which I have described may be approximately one volt negative. The current in the collector circuit flows against this potential, which is consequently a neutralizing potential tending to reduce the current which would flow if the collector were connected directly to the negative terminal of the filament. Under some conditions it is advisable to make the collector slightly positive with respect to the negative end of the filament, and in this case the current (always flowing from filament to collector through the circuit) will be in the same direction as the applied potential. When the collector is made negative with respect to the negative end of the filament by means of potentiometer 25, the applied potential is never sufficient to stop completely or to reverse the flow of current through the circuit from filament to collector, and consequently the collector never becomes a cathode.

Current for heating the filametary cathode 8 is supplied from the cathode battery 27 and controlled by the serially connected variable resistance 28. The filament circuit is completed through the heating resistance 32 and the fixed resistor 35.

The main anode circuit runs from the common negative point 24 through the anode battery 29, which may have a variable potential, and the telephones 30 to the anode 16. Obviously the telephones may have substituted for them any other suitable translating or coupling device, e. g., a relay, a loud speaker, or the primary of a transformer leading into an audio frequency amplifying system.

In setting up the circuit of Fig. 4 I use coils and condensers of sizes appropriate to the antenna dimensions and the wave frequencies to be received, so as to bring the resonant adjustments of the two radio frequency circuits well within the ranges of the tuning condensers 19 and 23. For battery 27 I prefer to use three storage cells with a total voltage of about 6, since the filamentary cathode may require from 1.2 to 1.4 amperes of current to raise it to the requisite temperature for sufficient electron emission. The rheostat 28 may conveniently have a resistance of 3 ohms and the fixed resistor 35 of 0.67 ohms, the heater being of 0.64 ohms resistance as described. The collector potentiometer 25 may be of about 100 ohms resistance and the fixed resistor in series with it of about 75 ohms; the collector current under best operating conditions is approximately 550 microamperes with most of the tubes which I have used. I find that the

anode battery 29 may conveniently have an electromotive force of from 10 to 30 volts; since the anode current is ordinarily of about 200 micro-amperes; dry cells are entirely satisfactory for this circuit. The telephones shown at 30 are ordinarily of about 2000 ohms total resistance to direct current.

To operate my receiver I establish the circuit as shown in Fig. 4, heat the filament to normal brilliancy and (while listening in the telephones) tune the primary and secondary circuits to approximate resonance with the frequency of the waves I desire to receive. Having thus obtained signals, I proceed to intensify these by adjusting the collector potential and the filament current to their optimum absolute and relative values, as judged by increased strength of the received signals. Occasionally it is found desirable to readjust the radio frequency circuits to a small extent during this process, but I make no attempt to secure or magnify radio frequency currents in the anode circuit by tuning, the provision of by-pass condensers or otherwise.

A novel and characteristic feature of the intensification phenomena of the preferred form of my device is that when the tube is properly adjusted the act of opening the anode circuit results in a substantial reduction in the current flowing in the collector circuit. For instance, in one tube the adjustment which gave best response required the collector potential to be 1.4 volts negative with respect to the negative end of the filament. At this potential the collector circuit current was 600 microamperes flowing in the circuit from the filament terminal to the collector (i. e. against this 1.4 volts potential). When the anode circuit was opened the collector current fell to 250 microamperes. It is apparent therefore that the collector circuit in this new device performs a very different function from the usual grid or control circuit.

In receiving radio telephone signals on my intensifying detector one is struck by their loudness and clarity and, in contrast to their reception on regenerative devices, the absence of distortion which would be caused either by internal beating, self-oscillations or too great persistence of vibration in the tuned receiving circuits.

Although for general information I have described in detail one form of device and circuit embodying my invention, it is not necessary to use this specific arrangement in order to secure many of its benefits. Many modifications of structure and connections will at once occur to those skilled in the art; for instance, the device of Fig. 1 may be utilized quite effectively in capacity-coupled or in audio transformer radio circuits such as are common in radio reception.

One need not even use exactly the form of tube shown in Fig. 1; for instance, the anode material may be contained in an insulating or conducting cup instead of lying directly upon the glass wall of the tube. I have also secured good effects from specially constructed outside anode tubes embodying some of the principles set forth in my United States Patent #1,291,441, though it is desirable to modify the internal electrodes as described herein. The intensification effects secured by the present invention are greatly reduced or even prevented if the collector electrode projects between the cathode and the main anode, as would be the case if it were attempted to use an interposed grid as the collector. When using an external anode tube the sodium or other ionized material, which is apparently necessary to co-operate in the newly discovered phenomenon of intensification, may be provided by electrolysis of the glass wall through the action of the main anode current. See Patents Nos. 1,477,868 and 1,477,869.

The trough-like design of collector 15 is convenient and preferred but not essential for I have secured good results by using two electrically connected plates, one on either side of the cathode and parallel thereto, placed edgewise with respect to the main anode.

I have found that the temperature of the anode during operation should be kept within limits which depend upon the material used, though within these limits it is not especially critical. If the anode temperature is raised above a certain value, for any particular anode material used, there is likely to be so great an increase in vapor density within the tube, at points remote from the anode, as to set up random or un-localized ionization which may materially reduce the sensitiveness of the system. When sodium is used for the anode of such a tube as I have described, the temperature of the anode becomes sufficiently high to provide requisite particles for ionization within a few seconds after the filament circuit is closed. Heat from the filament is radiated to the anode surface and even at the relatively low temperature thus produced there is a considerable emission of particles from the anode. As time goes on, however, this original emission will decrease, and might become only a small fraction of its initial value. Soon after the filament is turned on, however, heat from the external heater 32 will reach the anode through the glass tube, and, by properly choosing the size of this heater and the current therethrough, the temperature of the anode may be increased at a rate which will very nearly compensate for the decrease in original emission above described. Thus particles for ionization may be provided for an indefinitely long time at an approximately uniform rate. The effect of the heater 32 may be sufficient to liquefy certain anode materials, such as so-

dium, and consequently it is desirable to operate the tube in the position shown in Figs. 1 and 2 so as to retain the anode material in position even though molten.

Sodium is a particularly desirable metal for tubes utilizing this signal intensifying effect, but I do not desire to be limited to main anodes formed of this metal, since I have secured excellent operation from tubes having anodes of other metals, including potassium, and from alloys such as sodium and potassium in equal proportions, also tellurium, lithium and mercury. It does not appear essential to utilize highly electropositive metals although those cited are convenient. The best condition for control of ionization at the anode surface appears to be most easily maintained with the anode heated slightly above its melting point, and hence it is desirable to use anode materials which melt at relatively low and easily attainable temperatures. From my experience with these intensifying tubes it appears that there should be present a controlled quantity of molecules or atoms vaporized preferably from the anode, that the greatest density of these molecules or atoms should preferably be limited to the immediate neighborhood of the anode surface, and that by bombardment of these localized molecules or atoms there should be produced a controlled amount of positive ionization within a zone near the anode surface. Random or unlocalized ionization throughout the tube should be prevented, preferably by complete exhaustion of included gases so as to obviate the possibility of gas ionization in the space and by maintaining the vapor density of the anode material comparatively low within the body of the tube. I prefer to operate the tubes at the lowest feasible temperature consistent with sufficient localized ionization, so as to reduce the vapor pressure of the anode material to such a degree that the chance of forming ions by electron collision with vapor molecules in the evacuated space away from the electrodes is minimized.

Although I have shown the telephone or other indicating instrument associated directly with the main anode circuit, I do not wish to be limited to such connection. The constantly flowing currents in both the anode and the collector circuits are normally reduced upon the arrival of signals, the amount of such reduction being substantially in both circuits and reproducing the signal variations or modulation. It is more convenient to use the telephones, or transformer for audio frequency coupling, in the main anode circuit since the impedance of the anode cicruit is considerably higher than that of the collector circuit and hence is better suited to the accessories available on the market.

The phenomena which underlie the operation of my new device are quite obscure and complicated, although its desirable effects are easily obtained and controlled in the manner I have described. Without desiring to be limited by any statement of theory, I may say that the arrangement acts as though the collector circuit current pulsates continuously with small amplitude at a frequency which depends upon the tube constants and adjustments but is necessarily much lower than the frequency of the signals to which the greatest response is given. This pulsation appears to be a consequence of the production of positive ions at or near the anode surface by bombardment of electrons from the cathode, and the passage of those ions to the vicinity of the cathode and collector where certain of them are neutralized by the electron cloud forming a space charge about the filament. There is experimental evidence that some of the neutralized ions pick up additional electrons from the space charge, thus becoming recharged negatively, that others strike electrons with sufficient velocity to become reionized positively, and that many of the particles ionized at the anode and accelerated toward the cathode finally strike either the cathode or the collector. It also appears that for a time, the percentage of positives and negatives reaching the collector is such that more and more ionization takes place, thus building up the collector current until at some final value the current falls to a lower value. The time of this pulsation may be something like 1/100000 second, and (under operating adjustments) the cycle is continuously repeated. When radio signals of a substantially higher frequency are applied to the collector circuit, the ionization appears to be broken up to an extent dependent upon the intensity of the applied signal, so that there occurs a substantial fall of average collector current, which fall is proportional to the signal strength. Thereafter a certain time is required to reach the state of equilibrium at the higher slightly pulsating value of collector current. It has been found that for a pulsation frequency of 70000 cycles per second, no substantial response is had for applied signals of frequency lower than about 300000 cycles but a rapidly increasing sensitiveness is found as the signal frequency is increased above this value to 750000 cycles or more. By changing the proportions and adjustments of the system it is feasible to change the sensitive frequency range. The average current in the anode circuit follows the audio frequency variations in collector current, and hence telephones connected in either circuit respond to the signal fluctuations.

An effect which is of value in the operation of this tube is the increase of electronic emission from the cathode at any given temperature caused by the presence of sodium or the like. In my Patents 1,477,868 and 1,477,869 I have disclosed means for increasing elec-

tronic emission of a cathode by depositing upon it metallic sodium secured by electrolysis from the walls of the glass vacuum tube. In the present new form of tube, sodium for this purpose may be derived from the anode. As may easily be understood, some of the positive sodium ions produced at or near the anode are attracted to the filament and deposited thereon, losing their charge and becoming simply sodium molecules. I have found that a cathode when so coated with sodium emits electrons at a given rate when maintained at a substantially lower temperature than would a simple filament of tungsten, molybdenum or tantalum. Unless the sodium coating is continually renewed by arrival of ions from the anode or otherwise it will in time pass off into the space as a neutral vapor and become exhausted, but in the structure I have shown there is provision for such continuous renewal. To secure this effect to the most useful degree it is desirable that the sodium should reach the filament in ionic form, and consequently the operation of a simple cathode in an atmosphere of neutral sodium vapor is ordinarily insufficient and the full effect will not be had unless the sodium is at least in part ionized. Similar effects are had from other electropositive metals which I have described as useful in this type of tube, although the increase of emission for a given temperature is partly incidental to and independent of the sensitive detection effects described.

For convenience in mounting I prefer to carry the four terminals 11, 33, 14 and 17ª to the contacts of a standard four-prong lamp base such as is commonly used with three electrode vacuum tubes. To prevent spilling when a molten anode is used, the tube may be operated in the position shown by Figs. 1 and 2 or the lamp base may be mounted below the main anode (which is in this instance carried by a depression in or cup attached to the top of the stem), the filament and collector supporting wires running downward through the press and stem, but the anode, cathode and collector being maintained in substantially the same relative positions shown in the drawings. Other variations of structure and adaptations of the principles and novel features of the invention herein disclosed will occur to those familiar with the use of vacuum tubes in high frequency signaling.

I claim:

1. A vacuum tube containing an alkali metal anode, a curved electrode, a double terminal cathode interposed between said anode and said electrode and disposed substantially at the center of curvature of said curved electrode, and a resistance element in series with said cathode and contiguous to said tube.

2. A vacuum tube having a press and containing an alkali metal anode, a curved electrode, a double terminal cathode interposed between said anode and said electrode, lead-in wires for said electrodes, all of said lead-in wires passing through said press, and a resistance element in series with said cathode and contiguous to said tube.

3. An electric discharge device comprising a base, an envelope disposed on said base and containing an alkali vapor, a double terminal cathode, an anode, a control electrode, and means in the base to heat said anode.

4. An electric discharge device comprising a base, an envelope disposed on said base and containing a vapor, a cathode, control and anode electrodes, and means in said base to heat one of said electrodes.

5. An electric discharge device comprising a base, an envelope disposed on said base and containing an alkali vapor, a cathode electrode, a control electrode, and an anode electrode composed of an alkali metal, and means in said base to heat said anode electrode.

6. An electric discharge device comprising an envelope containing an alkali vapor, a cathode, a control and an anode electrode, said cathode disposed between said control and anode electrodes, and electrical means, exterior of said envelope to heat said alkali vapor while said device is in operation.

7. An electric discharge device comprising an envelope containing a vapor, a double terminal cathode, a control and an anode electrode, and an electrical resistance means exterior of said envelope to heat said vapor, said electrical resistance means and said double terminal cathode being connected serially.

HAROLD POTTER DONLE.