G. W. PIERCE.

APPARATUS FOR AMPLIFYING OR DETECTING ELECTRICAL VARIATIONS.

APPLICATION FILED NOV. 26, 1913.

1,112,549.

Patented Oct. 6, 1914.

3 SHEETS—SHEET 1.

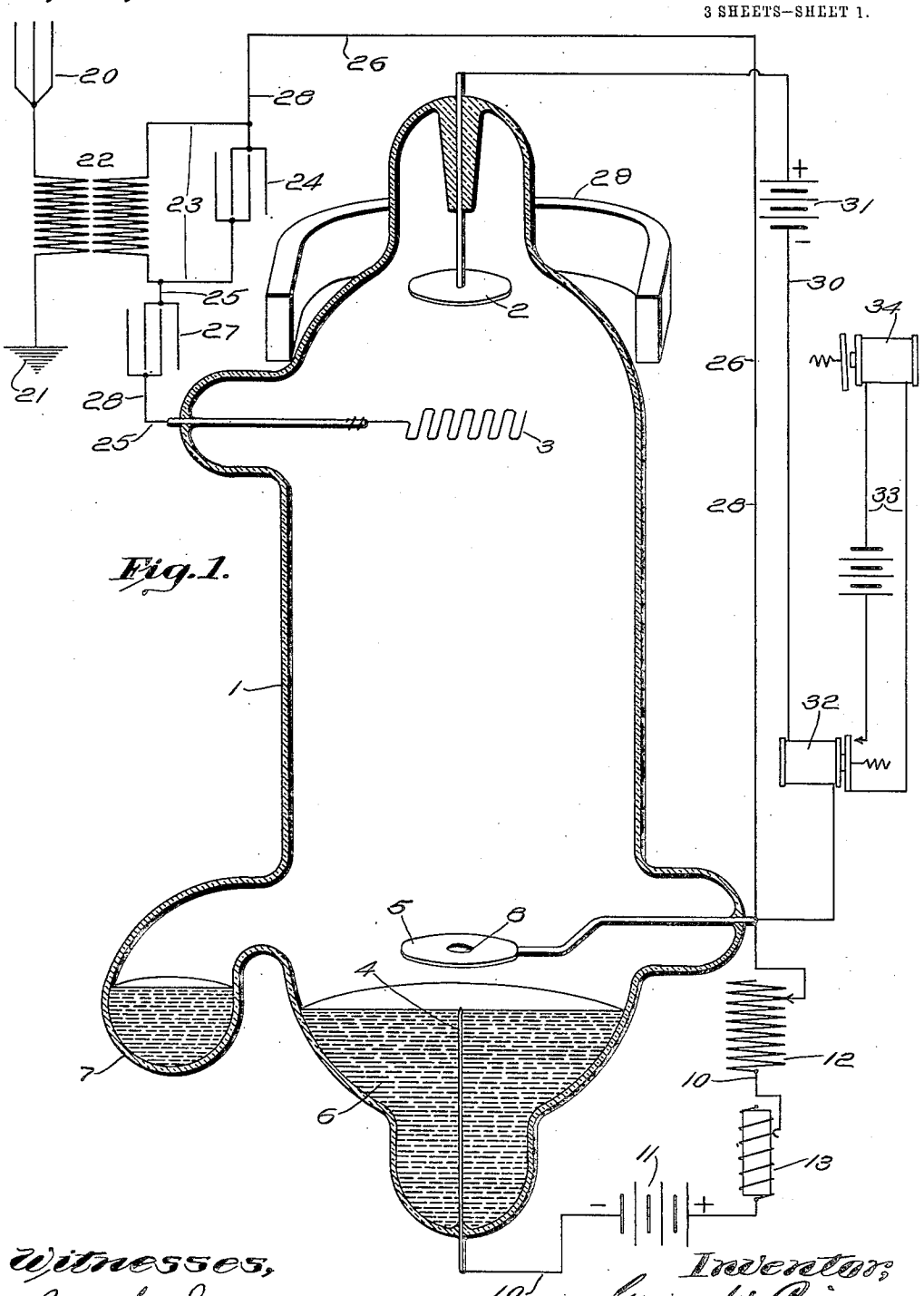

Fig. 1.

Witnesses,
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3 SHEETS—SHEET 2.

Fig. 2.

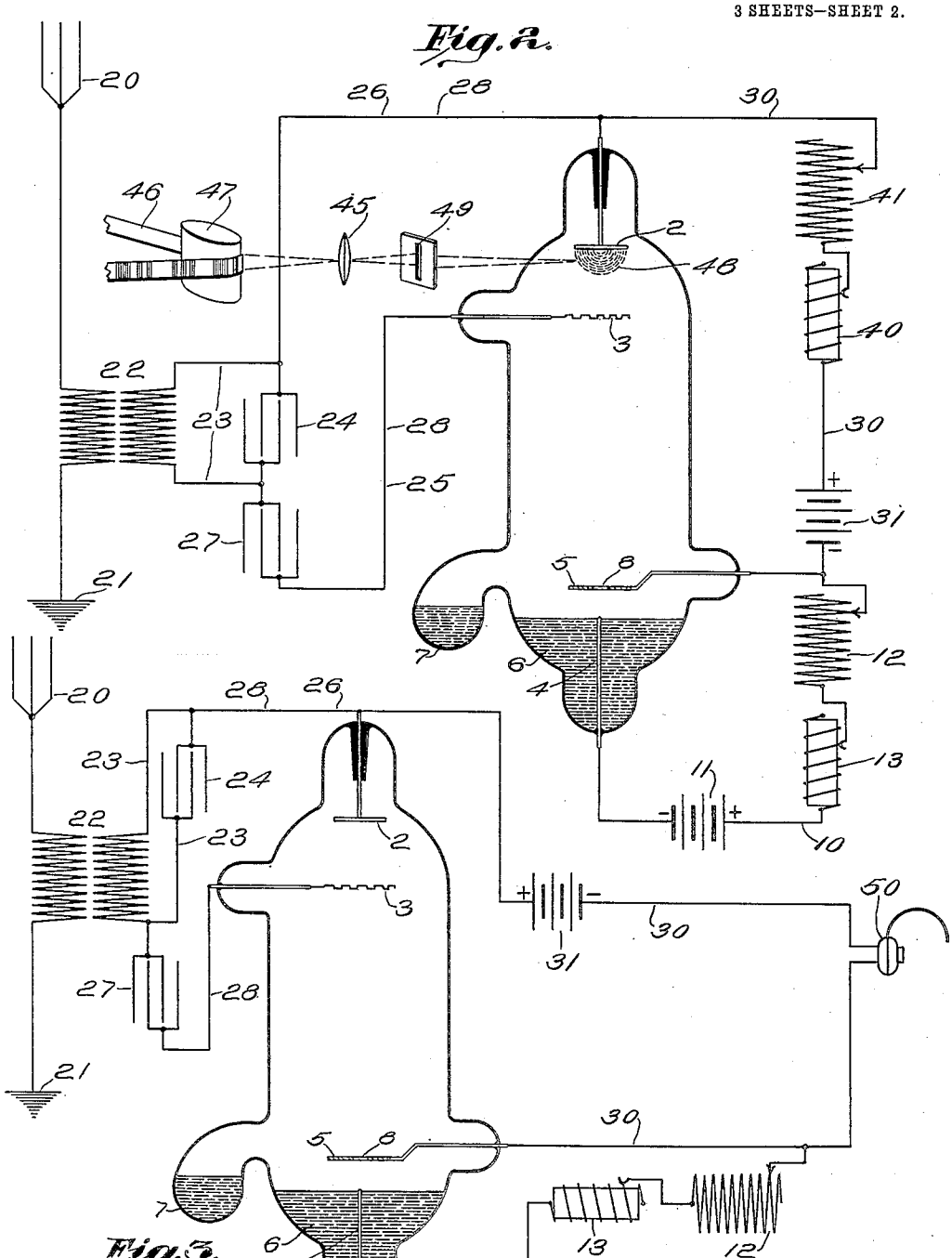

Fig. 3.

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3 SHEETS—SHEET 3.

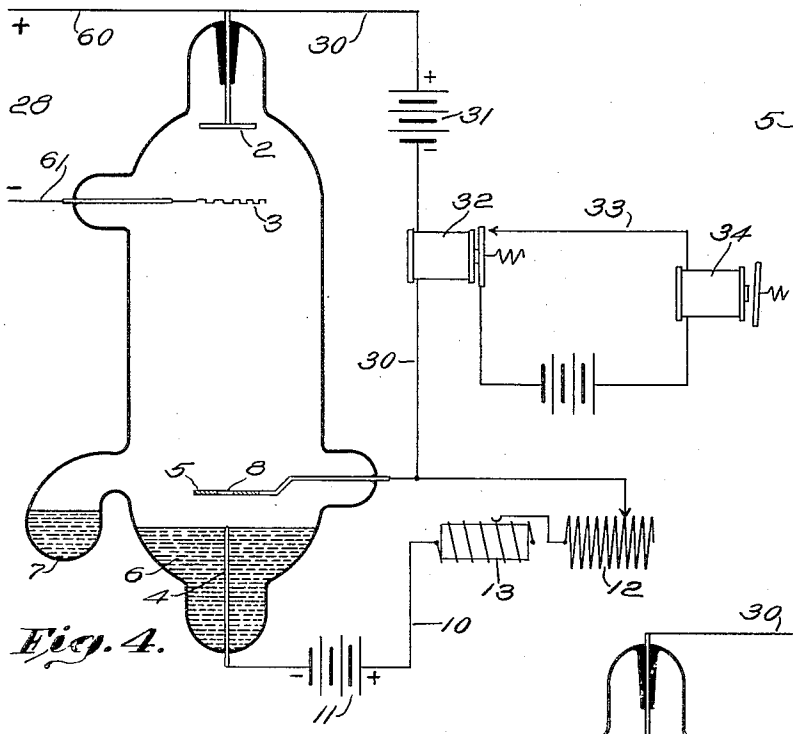

Fig. 4.

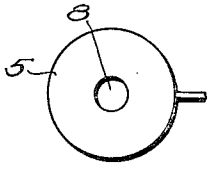

Fig. 6.

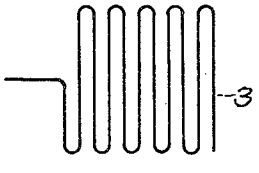

Fig. 7.

Fig. 5.

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UNITED STATES PATENT OFFICE.

GEORGE W. PIERCE, OF CAMBRIDGE, MASSACHUSETTS.

APPARATUS FOR AMPLIFYING OR DETECTING ELECTRICAL VARIATIONS.

1,112,549. Specification of Letters Patent. **Patented Oct. 6, 1914.**

Application filed November 26, 1913. Serial No. 803,357.

To all whom it may concern:

Be it known that I, GEORGE W. PIERCE, a citizen of the United States, residing at Cambridge, in the county of Middlesex and State of Massachusetts, have invented certain new and useful Improvements in Apparatus for Amplifying or Detecting Electrical Variations; and I do hereby declare the following to be a full, clear, and exact description of the invention, such as will enable others skilled in the art to which it appertains to make and use the same.

The present invention relates to apparatus for amplifying or detecting electrical variations.

The apparatus comprises a gaseous conducting medium upon which the electrical variations are impressed in such a manner as to modify the current in a local circuit through the gas.

The object of the invention is to make an improved apparatus of this type which is sensitive, reliable and rapidly responsive to the variations to be amplified.

The apparatus is particularly applicable to the amplification or detection of the electric signal variations or impulses of wireless telegraphy, wireless telephony, or telephony and telegraphy over wires and cables.

The present invention is preferably embodied in an apparatus comprising a mercury vapor device in which an evacuated space or region is ionized and rendered conducting by means of a mercury arc. The electrical variations to be amplified or detected are impressed by means of a controlling circuit upon a region in the ionized conducting gas or vapor and vary its apparent conductivity. A local or controlled circuit has a current path through the conducting gas or vapor. The change in the apparent conductivity of the gas causes variations in the current in the controlled circuit. These variations in the controlled circuit may be detected by some translating device in the controlled circuit or connected indirectly therewith.

In the drawings which illustrate the preferred embodiment of the present invention, Figure 1 is a diagrammatic view of the mercury vapor device connected with the receiving apparatus of a wireless telegraphy system and serving to operate a telegraphic relay; Fig. 2 shows the mercury vapor device connected with the receiving apparatus of a wireless telegraph system and having provision for photographically recording the signals; Fig. 3 shows the mercury vapor device used in connection with the receiving apparatus of a wireless telegraph or telephone system in which the received signals are detected by means of a telephone receiver; Fig. 4 shows the mercury vapor device used in connection with wire telegraphy; Fig. 5 shows the mercury vapor device used in connection with wire telephony; Fig. 6 is a plan view of the shield; and Fig. 7 is a plan view of the grid-like electrode.

The mercury vapor device *per se* will first be described and then the electrical connections and the mode of operation will be described and pointed out.

The mercury vapor device comprises an evacuated glass bulb or tube 1. Supported on a leading-in wire which is sealed through the top of the tube is an electrode 2 which consists of a flat circular plate or disk of platinum or iron. A short distance below the electrode 2 is another electrode 3 which consists of a piece of platinum or iron wire bent back and forth to form a grid, as shown in Fig. 7, and connected with a leading-in wire sealed through the side of the tube. The electrode may have the form of a grid, as illustrated, or may be made of a foraminate plate or of wire fabric or other open work structure. Sealed through the bottom of the tube is a platinum wire 4 which projects a little distance into the tube. Above the platinum wire and supported by a leading-in wire sealed through the side of the tube is an electrode 5 which consists of a flat circular plate or disk of iron with a hole 8 through it. This hole is situated directly above the point of the platinum wire 4. The tube contains a body of liquid mercury 6, the level of which is normally such that the point of the platinum wire 4 projects slightly from the surface of the mercury. An extension 7 is blown into the side of the tube near the bottom into which the surplus mercury may be spilled to adjust the mercury level with respect to the platinum wire. The circular perforated plate 5 and the body of mercury 6 form the electrodes or terminals for a mercury arc which is maintained by means of a "keep alive" circuit 10 which includes the battery 11 and ballast resistance 12 and inductance 13. The platinum wire 4 acts to keep the arc from skipping around over the surface of the mercury and holds it at the point of the platinum wire. The ac-

tion of the mercury arc in conjunction with the controlled circuit 30 hereinafter described is believed to cause a stream of negative ions or electrons to arrive at the electrode 2 by flowing chiefly through the hole 8 in the plate 5. The plate intercepts the electrons around the hole 8 and so shields the upper part of the tube from the electrons discharged from the arc with the exception of the stream flowing through the hole 8 or a comparatively unimportant indirect flow around the edge of the plate 5. Since the arc is centered below the hole 8, a concentrated and directed stream of electrons is directed through the hole 8 and upon the electrode 2 at the top of the tube. The plate 5 besides being the positive electrode or anode for the mercury arc has, as above pointed out, the function of substantially shielding the upper part of the tube from the electrons given off by the arc except for the directed stream through the hole 8, and, therefore, may be designated for convenience as the "shield."

While the dimensions of the mercury vapor device may be varied, it is found that a mercury vapor device having substantially the following dimensions operates successfully. The distance from the surface of the mercury to the shield 5 is about one-half inch. The distance from the shield 5 to the electrode 3 is about five inches. The distance from the electrode 3 to the electrode 2 is about one and one-quarter inches. The shield 5 is about an inch in diameter and has a hole of about one-quarter inch diameter through its center. The electrode or grid 3 has substantially a square outline of about one and one-eighth inch across. The electrode 2 is a little less than an inch in diameter. The tip of the platinum wire 4, the hole 8, the electrode 3 and the electrode 2 are all in line, so that the stream of electrons shot off from the mercury arc passes through the center of the grid-like electrode 3 against the middle of the electrode 2.

As far as the construction of the tube itself and the battery connections for maintaining the mercury arc are concerned, the modifications illustrated in the several figures of the drawings are identical.

In the apparatus illustrated in Fig. 1, 20 indicates the antenna of a wireless receiving system connected to ground at 21. The antenna circuit is coupled by means of an oscillation transformer 22 to a closed oscillation circuit 23 which contains the condenser 24. Tapped from the oscillation circuit 23 on opposite sides of the condenser 24 are receptor leads 25 and 26. The receptor lead 25 is connected with the electrode 3. The receptor lead 26 is connected with one of the electrodes of the mercury arc, preferably the anode plate or shield 5. It is apparently immaterial whether the lead 26 is connected to one of the arc terminals or whether it is connected to the electrode 2, as indicated in the wiring diagrams of some of the other figures. A condenser 27 is interposed in one of the receptor leads, preferably the lead 25. The leads 25 and 26 and their connections with the receiving apparatus constitute what may be termed the "controlling" circuit 28 by means of which the electrical potential variations set up in the receiving apparatus by the received waves are impressed upon the sensitive ionized mercury vapor in the tube. The electrode 2 is connected with one of the arc terminals, preferably the anode plate or shield 5, by means of the electric circuit 30 including a battery 31 and a relay or similar translating device 32. The circuit 30, since its current is varied or controlled by means of the mercury vapor device, may, for convenience, be designated as the "controlled" circuit. The positive pole of the battery 31 is connected to the electrode 2. The stream of negative electrons discharged from the mercury arc and impinging on the electrode 2 is believed to constitute the current path through the inclosed gaseous or vapor medium by means of which the controlled or local battery circuit 30 is completed through the mercury vapor device. The mercury arc thus forms the cathode for this discharge of electricity through the gaseous medium and the electrode 2 forms the anode or anti-cathode or target for the electrons. While the battery 31 may have a considerable range of voltage, depending upon the size of the mercury vapor tube, the distance between the electrodes and the resistance in the circuit 30, a voltage of about sixteen volts is found to be satisfactory when a telegraphic relay is used in the circuit 30. The relay 32 operates, upon a decrease in the current in the circuit 30, to close a sounder circuit 33 and operate the telegraph sounder or buzzer 34. While the relay is ordinarily operated by a decrease in current in the circuit 30, nevertheless, for certain adjustments of the voltage of the battery 31 the current in the circuit 30 increases under the action of the electric waves, and this increase in current may be utilized to operate a relay. When a train of Hertzian waves strikes the antenna, corresponding very rapid variations in potential are impressed upon the mercury vapor by the controlling circuit 28. The action of the impressed series of rapid variations or oscillations is usually to decrease the conductivity of the current path of the controlled circuit 30, cut down the current therein and to cause the relay 32 to open under the action of its spring and operate the sounder 34. As soon as the train of waves constituting the dot or dash of the signal has passed, the tube restores itself to

its original condition of increased conductivity, the armature of the relay 32 is attracted and the sounder 34 indicates the end of the signal. While the operation of the mercury vapor device is not perfectly understood, it is believed that a rectifying action takes place at the electrode 3 and that this action is such that the electrode 3, as a result of the cumulative effect of the train of oscillations, accumulates a negative charge which repulses the stream of electrons shot upward from the mercury arc and more or less prevents them from reaching the electrode 2, thus diminishing the current in the controlled circuit 30. Apparently there seems to be a tendency of the electrode 3 to retain its negative charge after the train of oscillations has ceased, so that there may be an appreciable time of recovery during which the electrode 3 is losing its negative charge and before the original conductivity of the tube is completely restored. Ordinarily the potential of the battery 31 or the position of a magnet 29 is adjusted to the intensity of the received impulses, so that the electrode 3 loses its negative charge very rapidly and the tube quickly recovers its conductivity, so that, for example, in the case of telegraphy, the dots and dashes are sharply defined and of the proper length. A magnet 29 is placed around the tube, preferably a little lower than the level of the electrode 2, so that a magnetic field is maintained in the tube. This magnet 29 modifies the required applied voltage of the battery 31 and increases the sensitiveness and stability of the device. This magnet is not an essential part of the invention and while it is preferred to use it, nevertheless, it may be dispensed with. It is to be understood that this magnet 29 may, if desired, be used with the mercury vapor device, as shown in the other figures of the drawings. If the relay 32 has a low resistance and a battery 31 of sufficient electro-motive force is employed, the space immediately below the electrode 2 is luminous. This luminous region is usually substantially hemispherical in form, being convex downwardly and extending from the electrode 2 nearly to the electrode 3. The characteristics of this luminous region apparently depend upon the strength of the current in the circuit 30 for when the current in the circuit 30 is diminished as a result of the train of oscillations impressed upon the electrode 3, the luminous area changes in size or luminosity or vanishes. By watching the luminous area, the dots and dashes which make up the received signal may be read. The apparatus is very sensitive, and comparatively minute electrical variations impressed upon the vapor device by the controlling circuit 28 produce comparatively large variations in the current in the controlled circuit 30. The electrical dimensions of the apparatus may be so adjusted that the period of recovery of the vapor device after the cessation of the received variations is very short, so that the mechanical or audible signals given by the sounder 34 or the visual signals caused by the change in the luminous region correspond very exactly in duration to the signals transmitted by the trains of Hertzian waves.

In Fig. 2 is illustrated a modification of the apparatus particularly adapted for photographically recording wireless telegraph signals. The antenna 20 is coupled with the oscillation circuit 24 by means of the oscillation transformer 22. The controlling circuit 28 by means of which the signal impulses are impressed upon the mercury device includes the receptor leads 25 and 26 connected to the electrode 3 and the electrode 2, respectively. While the lead 26 is shown connected to the electrode 2, apparently it is immaterial whether it is so connected or as shown in Fig. 1 is connected to one of the arc terminals. Moreover, under some circumstances, it appears to be advantageous for the controlling circuit to have a uni-lateral connection with the vapor device as shown, for example, in my copending application, Serial No. 783,088. In case of uni-lateral connection, the electrode is directly connected to one end of the secondary of the oscillation transformer, this being the only connection of the controlling circuit with the tube. If it is desired, the electrode 3 may be connected directly with the antenna. Under some circumstances, the mercury vapor device will operate satisfactorily with the electrode 3 connected to ground and the controlling circuit connected to other of the electrodes. Therefore, the invention is not to be limited to the illustrated electrical connections but also includes equivalent electrical connections. The controlled electric circuit 30 has a battery 31 and may have a reactance 40 and a resistance 41, which are adjusted so as to cause a proper luminous region to appear beneath the electrode 2 as indicated by reference numeral 48. This circuit contains no translating device for giving mechanical or audible signals, the translating means in the circuit 30 being the mercury vapor tube itself which indicates the signals by virtue of the visible luminous region in the tube. At one side of the tube is a suitable photographing recording apparatus which is diagrammatically indicated by the slit 49, the lens 45 and the sensitive photographic film 46 continuously traveling around the drum 47. The battery 31, the reactance 40 and resistance 41 are adjusted so that a proper luminous region 48 is present beneath the electrode 2. The light from this luminous region is focused on the mov-

ing photographic film 46. Changes in the intensity of the luminous region will be recorded upon the photographic film and thus a record of the received message may be had. For the sake of more readily indicating this, the light affected portions of the film are shaded in the drawing, although it will be understood that in practice the film would be developed to render visible the light affected portions. By using a very low resistance in the circuit 30 and a battery 31 of proper voltage, the apparatus may be adjusted so that upon the reception of a train of signals, the luminous region will vanish. By increasing the resistance in the circuit 30 and the voltage force of the battery, the luminous region may be prevented from entirely vanishing when the current in the controlled circuit 30 is reduced by a train of received oscillations. The received oscillations, however, cause the luminous region to change and thus the signals may be detected.

Fig. 3 illustrates a modification particularly adapted to wireless telegraphy or telephony in which the received signals are detected by means of a telephone receiver. In this modification of the apparatus, the controlling circuit 28 connects the receiving apparatus of the wireless system to the electrode 3 and the electrode 2. The controlled circuit 30 includes the battery 31 and a telephone receiver 50. By properly adjusting the electro-motive force of the battery 31, the telephone may be silent, or a sustained musical note may be audible in the telephone receiver. The effect of a train of oscillations upon the mercury vapor device is to produce a note in the receiver or in case a note already exists the effect of the waves is to silence this note or change its pitch or intensity. A condenser is sometimes shunted around the telephone receiver 50 to accentuate the persistent note.

Fig. 4 is a modification particularly adapted for amplifying electric signals in wire or cable lines. The controlling circuit 28 consists of the line wires 60 and 61 over which are transmitted the variations to be amplified and which are connected with the electrode 2 and electrode 3, respectively. The line wires are connected so that the wire 60 which is connected to the electrode 2 and the wire 61 which is connected to the electrode 3 are positive and negative, respectively. The controlled circuit 30 is connected between the electrode 2 and the arc terminal 5 and contains a battery 31 and a relay 32 which controls a sounder or tape machine 34. The potential increase between the line wires 60 and 61 due to closing the telegraphic key at the sending station cause a potential variation between the electrode 3 and the electrode 2, the electrode 3 becoming more negative with relation to the electrode 2. This diminishes the current in the controlled circuit 30 and through the relay 32 operates the sounder or tape machine 34.

In Fig. 5 is illustrated another modification of the apparatus particularly adapted for amplifying electric signals in wire or cable telephone lines. In this modification the telephone line 70 is coupled by means of a transformer 71 with the controlling circuit 28 which is connected between the electrode 3 and the arc terminal 5. A condenser 27 is interposed between the transformer 71 and the electrode 3. By means of the transformer, the variations in potential in the line 70 are impressed upon the mercury vapor device to change the apparent conductivity of the sensitive vapor therein. The controlled circuit 30 is connected between the electrode 2 and a tap taken off from the resistance 12 of the "keep alive" circuit 10 of the mercury arc. The potential drop in the portion of the resistance 12 around which the controlled circuit 30 is shunted, is the equivalent of the battery 31 shown in the other modifications and like this battery maintains the electrode 2 positive with relation to the arc electrodes. The controlled circuit 30 is connected to the primary 75 of a transformer 76, the secondary 77 of which is connected to a directly suitable translating device such as a telephone receiver, or is connected to another line wire by means of which the amplified impulse may be relayed along to a distant station. In case of telephonic signals, the impressed potential variations have frequencies of hundreds and thousands of waves per second. This frequency of the telephonic waves is low enough so that the variations impressed upon the mercury device will cause corresponding amplified variations of telephonic frequency in the controlling circuit 30. The ability of the vapor device to amplify and transmit individual waves or variations of telephonic frequency is to be contrasted with the action of waves or variations of Hertzian frequency upon the device, the individual waves of Hertzian frequency not being amplified, but instead having a cumulative or integrated effect. The apparatus illustrated in Fig. 5 may be used in connection with wireless telegraphy or telephony by coupling the controlling circuit 28 with the oscillation circuit of the wireless receiving apparatus. In the case of wireless telephony the variations of telephonic frequency which take place in the intensity of the train of waves of Hertzian frequency cause current variations of corresponding telephonic frequency to be set up in the controlled circuit 30. The waves of Hertzian frequency are apparently rectified at the screen 3 and by virtue of their cumulative effect the potential changes of

the screen 3 apparently correspond to the changes in intensity of the train of Hertzian waves. For this work, the vapor device has to be adjusted to have a very rapid recovery so that the electrode 3 gains or loses its charges with the variations in intensity of the train of Hertzian waves which variations are of telephonic frequency. Thus faint wireless telephone messages may be received and amplified. The region between the electrodes to which the controlling circuit is connected has impressed upon it static variations of electro-motive force and these static variations are apparently accompanied by more or less of a transfer of electricity between said electrodes, particularly when a rectification of waves of Hertzian frequency takes place. It will be noted that the region in the tube which is subject to the action of the controlling circuit is not co-extensive with the region which forms the current path of the controlled circuit and that these regions, therefore, have a part only in common. The electrical variations in the controlled circuit whether they are detected by a relay or telephone receiver or the luminous region in the tube, not only correspond very exactly to the variations in the controlling circuit which it is desired to amplify but are usually of very much greater energy.

The expression "controlling circuit", as used in the specification and claims, is intended to define an electric circuit by means of which the electrical variations to be amplified are impressed upon the sensitive conducting gaseous medium, and the expression "controlled circuit", is intended to define the electric circuit which is controlled thereby.

While a number of adaptations of the apparatus of the present invention are illustrated and described, it is to be understood that these are not all of the possible adaptations and that the invention is not limited to the forms of apparatus illustrated, but may be embodied in other constructions within the scope of the invention as particularly pointed out in the following claims.

I claim:

1. An apparatus for amplifying or detecting electrical variations having, in combination, an evacuated vessel containing at least three electrodes, a conducting body of mercury vapor therein, a controlling electric circuit connected with two of the electrodes, and a controlled electric circuit including a source of electrical energy connected with two of the electrodes, one at least of the controlled circuit electrodes being other than the controlling circuit electrodes.

2. An apparatus for amplifying or detecting electrical variations having, in combination, an evacuated vessel containing at least four electrodes, means for maintaining a mercury arc between two of the electrodes, a controlling electric circuit connected with two of the electrodes, and a controlled electric circuit including a source of electrical energy connected with two of the electrodes, one at least of the controlled circuit electrodes being other than the controlling circuit electrodes.

3. An apparatus for amplifying or detecting electrical variations having, in combination, an evacuated vessel containing a plurality of electrodes, a conducting body of mercury vapor therein, a controlling circuit connected with one or more of the electrodes, and a controlled circuit including a source of electrical energy connected with a plurality of the electrodes, one at least of the controlled circuit electrodes being other than the controlling circuit electrode or electrodes.

4. An apparatus for amplifying or detecting electrical variations having, in combination, an evacuated vessel containing at least four electrodes and provided with means for maintaining an arc between two of the electrodes, a controlling circuit connected with one or more of the electrodes, and a controlled circuit including a source of electrical energy connected with a plurality of the electrodes, one at least of the controlled circuit electrodes being other than the controlling circuit electrode or electrodes.

5. An apparatus for amplifying or detecting electrical variations having, in combination, an evacuated vessel, an electrode therein, means including a mercury arc spaced from the electrode and a circuit containing a source of electrical energy connected between the mercury arc and the electrode for maintaining a luminous region in the neighborhood of the electrode, a second electrode between the arc and the electrode, and means for impressing electrical variations upon the second electrode so as to vary the characteristics of said luminous region.

6. An apparatus for amplifying or detecting electrical variations having, in combination, an evacuated vessel, an electrode, means including a mercury arc spaced from the electrode and an electric circuit containing a source of electrical energy connected between the electrode and mercury arc for maintaining a luminous region in the neighborhood of the electrode, a second electrode between the arc and electrode, a controlling electric circuit connected to the second electrode so as to vary the characteristics of the luminous region, and light-operated means for indicating the variations in the luminous region.

7. An apparatus for amplifying or detecting electrical variations having, in com-

bination, an evacuated vessel, mercury in the bottom of the vessel, an arc terminal in the neighborhood of the mercury, means for maintaining the arc between the mercury and the terminal, an electrode, an electric circuit including a source of electrical energy and a translating means connected between the electrode and the mercury arc, a second electrode between the mercury arc and first electrode, and an electric circuit connected therewith for impressing the electrical variations upon the second electrode whereby the current in the controlled electric circuit is varied.

8. An apparatus for amplifying or detecting electrical variations having, in combination, an evacuated vessel containing a body of mercury, a perforated shield above the mercury, an electrode, a second electrode between the first electrode and shield, means for maintaining a mercury arc between the mercury and shield, a controlling electric circuit connected with the second electrode, and a controlled electric circuit including a source of electrical energy connected between the first electrode and the mercury arc.

9. An apparatus for amplifying or detecting electrical variations having, in combination, an evacuated vessel, a body of mercury therein, a perforated arc terminal above the mercury, an electric circuit for maintaining an arc between the mercury and said arc terminal, said arc terminal serving to shield the upper part of the evacuated vessel from the electrons emitted by the arc with the exception of the stream of electrons flowing through the perforated arc terminal, a controlling electric circuit having an electrode within the vessel to vary the characteristics of the electronic stream, and a controlled electric circuit having a current path through the vessel so as to have its current varied by the variations in the characteristics of the electronic stream.

10. An apparatus for amplifying or detecting electrical variations having, in combination, an evacuated vessel, a body of mercury therein, an arc centering point at the surface of the mercury, an arc terminal above the mercury consisting of a plate having a hole in it directly over the arc centering point, an electric circuit for maintaining an arc between the mercury and said arc terminal, said plate serving to shield the upper part of the evacuated vessel from the electrons emitted by the arc with the exception of the stream of electrons flowing through the hole in the electrode, a controlling electric circuit having an electrode within the vessel to vary the apparent conductivity of the electronic stream, and a controlled electric circuit having a current path through the vessel so as to have its current varied by the variations in the electronic streams.

11. An apparatus for amplifying or detecting electrical variations having, in combination, an evacuated vessel, a conducting body of mercury vapor therein, means for impressing static electrical variations upon a region in the conducting vapor, and a controlled circuit including a source of electrical energy and having through the conducting vapor a current path which has a part only in common with said region.

12. An apparatus for amplifying or detecting electrical variations having, in combination, an evacuated vessel, a conducting body of mercury vapor therein, means for maintaining a magnetic field in the conducting vapor, means for impressing static electrical variations upon a region in the conducting vapor, and a controlled circuit including a source of electrical energy and having through the conducting vapor a current path which has a part only in common with said region.

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