Apr. 3, 1923.

1,450,749

G. W. PIERCE

APPARATUS FOR AND METHOD OF CONTROLLING ELECTRIC CURRENTS

Filed Mar. 11, 1914 3 sheets-sheet 1

Fig:1.

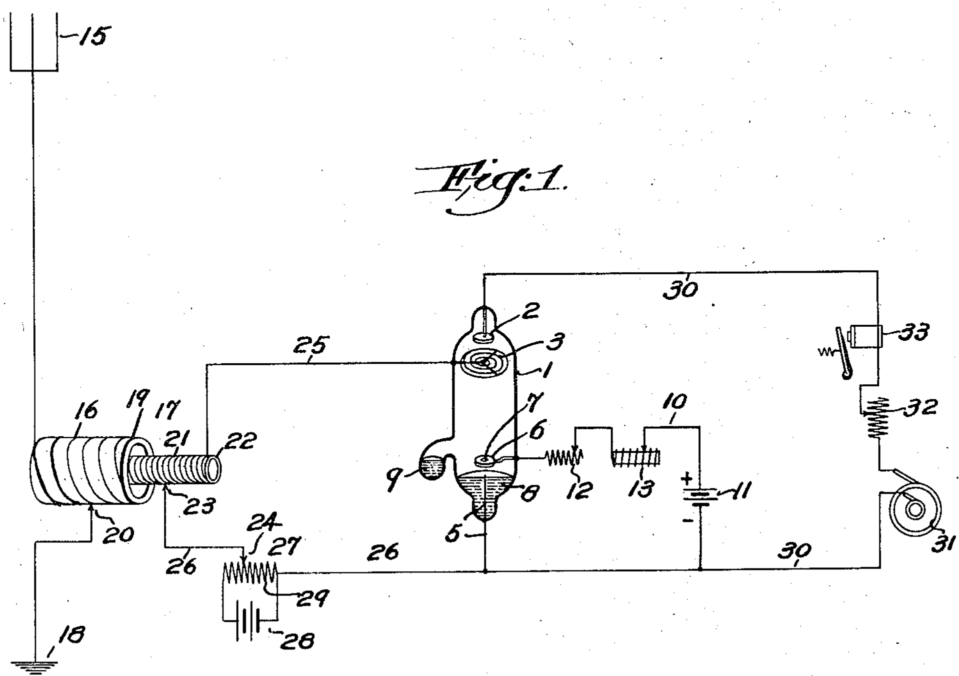
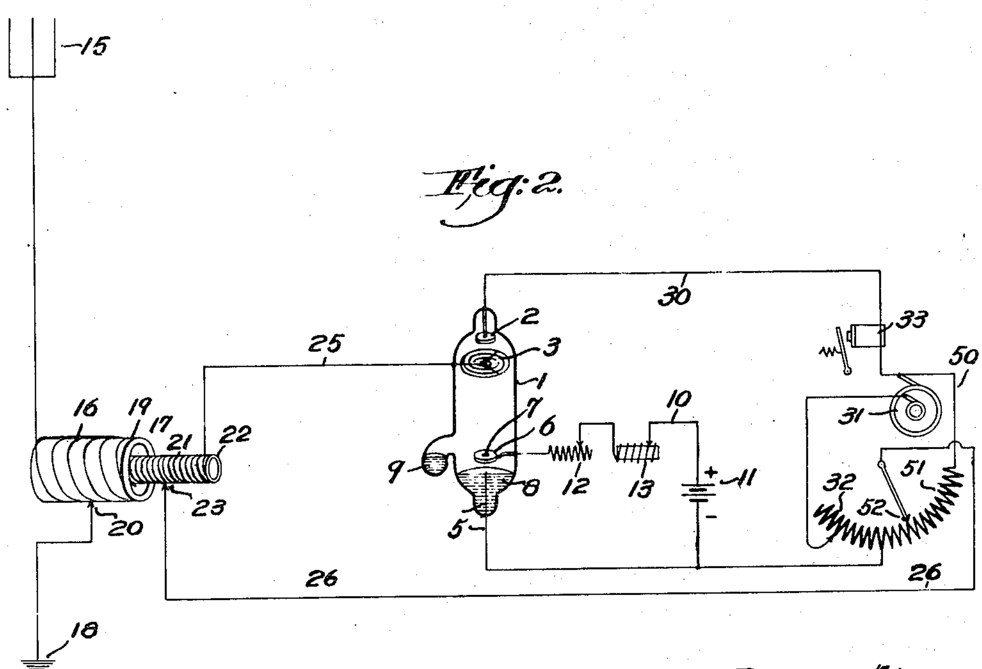


Fig:2.



Witnesses,
Geo. C. Stebbins.
Alice Ackroyd

Inventor;
George W. Pierce
by his attorneys
Phillips, Van Everen & Fish

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Filed Mar. 11, 1914 3 sheets-sheet 2

Fig: 3.

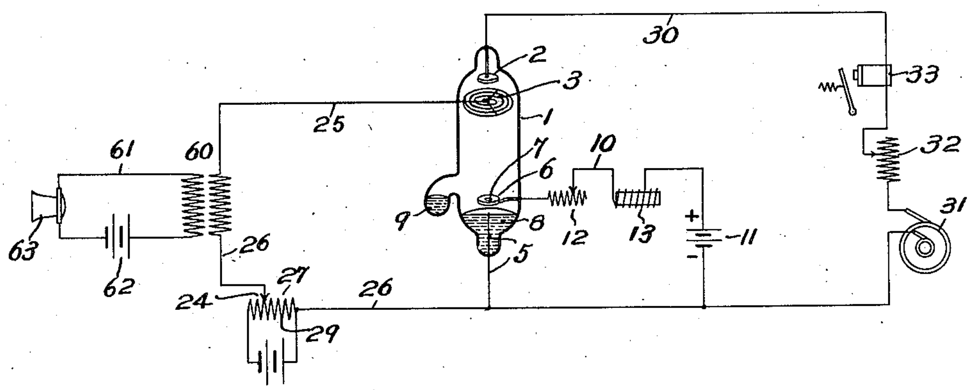
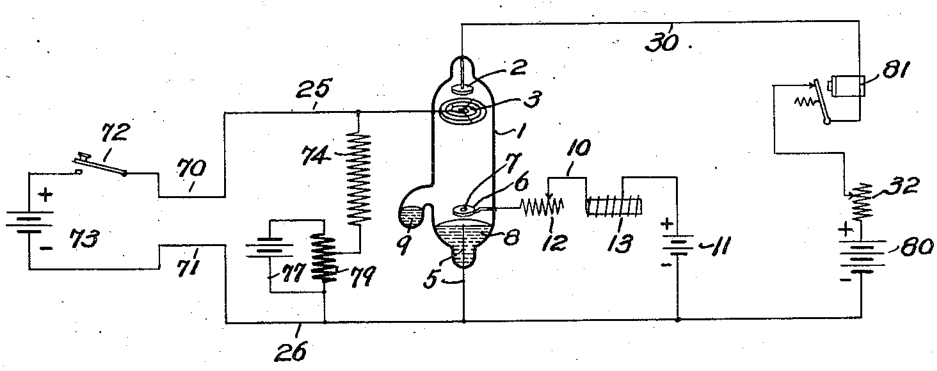


Fig: 4.



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APPARATUS FOR AND METHOD OF CONTROLLING ELECTRIC CURRENTS

Filed Mar. 11, 1914 3 sheets-sheet 3

Fig: 5.

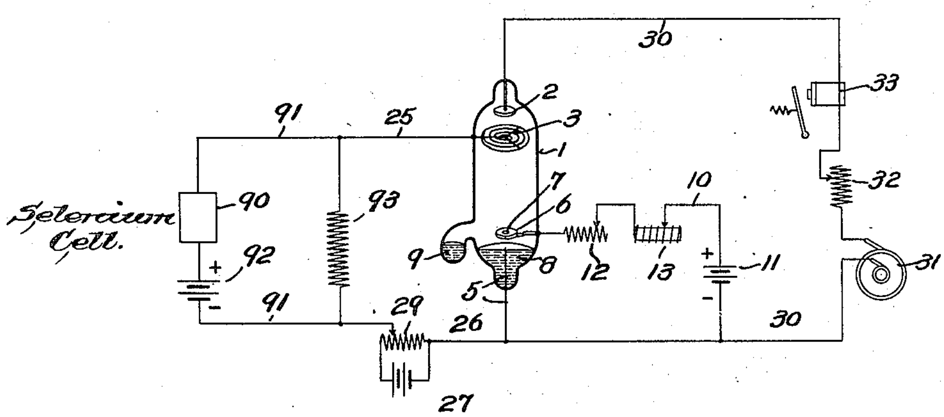
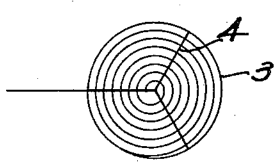


Fig: 6.



Witnesses,
Geo. E. Stebbins,
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Inventor;
George W. Pierce
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Patented Apr. 3, 1923. 1,450,749

UNITED STATES PATENT OFFICE.

GEORGE W. PIERCE, OF CAMBRIDGE, MASSACHUSETTS, ASSIGNOR TO PETER COOPER HEWITT, OF RINGWOOD MANOR, NEW JERSEY; THE FARMERS' LOAN AND TRUST COMPANY, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK, EXECUTORS OF SAID PETER COOPER HEWITT, DECEASED.

APPARATUS FOR AND METHOD OF CONTROLLING ELECTRIC CURRENTS.

Application filed March 11, 1914. Serial No. 824,035.

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 and Method of Controlling Electric Currents; 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 an apparatus for and a method of controlling electric currents. The object of the invention is the control of a comparatively strong electric current by means of a comparatively feeble expenditure of energy, and particularly the rapid and reliable control of a periodic current furnished by a comparatively strong local source of electro-motive force by means of comparatively feeble electrical variations or impulses, or the control of a periodic current by another current or electro-motive force the character of which it is desired to alter. With the above object in view the present invention consists in the apparatus for and method of controlling electric currents hereinafter described and particularly pointed out in the claims.

The present invention is particularly applicable to apparatus employed for electric signalling in which it is desired to control a comparatively strong local current by means of comparatively feeble signal impulses. The present invention is, however, not limited to signalling apparatus, but may be employed wherever it is desired to effect a sensitive and reliable control of electric current where the energy available for effecting the control is comparatively feeble, or is of a character which it is desirable to transform.

The method of the present invention will be explained in connection with the description of the construction and mode of operation of the preferred embodiment of the apparatus of the invention.

In the drawings which illustrate the preferred embodiment of the apparatus of the present invention, Fig. 1 is a diagrammatic view of an apparatus in which an alternating current is controlled by the received impulses of a wireless telegraph system; Fig. 2 is a modification of the apparatus shown in Fig. 1, the drop over resistance in the alternating current circuit being employed instead of a battery in the controlling circuit; Fig. 3 is a diagrammatic view of an apparatus in which an alternating current is controlled by means of a microphone; Fig. 4 is a diagrammatic view of an apparatus in which an interrupted current is controlled by means of a telegraph line or cable; Fig. 5 is a diagrammatic view of an apparatus in which an alternating current is controlled by a selenium cell; and Fig. 6 is a plan view of the open-work electrode or grid.

The present apparatus is an improvement in the general type of apparatus disclosed in my Patents No. 1,112,655, Oct. 6, 1914, No. 1,112,549, and No. 1,087,180, Feb. 17, 1914, and embodies some of the features of construction therein shown.

The sensitive conducting gaseous space, the apparent conductivity of which is varied to control the current, is enclosed in an evacuated glass tube or vessel 1. While the degree of vacuum may vary somewhat, it is preferable to pump the vessel 1 to a high vacuum. Supported on a leading-in wire which is sealed through the top of the vessel is an electrode 2 which consists of a flat circular disc 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 coiled into an open-work spiral, as shown in Fig. 6, to form a grid which is supported by a leading-in wire sealed through the side of the tube. The spiral is stiffened by supporting wires or arms 4. The size of the spiral is such as to substantially extend across the interior of the tube. Sealed through the bottom of the tube is a platinum leading-in wire 5 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 6, which consists of a flat circular plate or disc of iron with a hole 7 through it. This hole is situated directly above the point of the platinum wire 5. The tube contains a body of liquid mercury 8 the level of which is normally such that the platinum wire projects slightly from the surface of the mercury. An extension 9 is blown in 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 6 and the body of mercury 8 form the electrodes or terminals for a mercury arc which is maintained by means of a "keep alive" circuit 10 which includes a battery 11 and a ballast resistance 12 and inductance 13. The platinum wire 5 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 action 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 7 in the plate 6. The mercury vapor tube or device just described is substantially like that illustrated in my Patents Nos. 1,112,549 and 1,087,180, the only essential difference being that the open-work electrode or grid 3 extends substantially across the entire width of the tube. While the dimensions of the tube may be varied, it is found that a tube having substantially the following dimensions has operated successfully. The distance from the surface of the mercury to the plate 6 is about one half an inch. The distance from the plate 6 to the grid 3 is about six inches. The distance from the grid 3 to the electrode plate 2 is about two and one-half inches. The arc terminal plate 6 is about an inch in diameter and has a hole about one quarter of an inch in diameter through its center. The plate 2 is about three quarters of an inch in diameter. The tube 1 has an external diameter of about two and three quarters inches and the grid 3 has a diameter of about two inches.

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, 15 indicates the antenna of a wireless telegraph receiving system. The antenna is connected through the primary coil 16 of an oscillation transformer 17 to the earth at 18. The oscillation transformer 17 is an air-cored transformer. The primary 16 consists of a few turns of wire wound on a hollow drum 19. A movable contact point 20 in the primary circuit is employed to include more or fewer of the turns of the primary in circuit so as to tune the primary. The secondary of the transformer is wound on a drum 22 which is concentric with and inside of the drum 19. The secondary drum 22 is longitudinally movable with respect to the primary drum 19 so that more or less of the secondary coil may be positioned inside of the primary coil. The transformer secondary is connected with the tube 1 by means of receptor leads 25 and 26. The receptor lead 25 is connected from the electrode 3 to the end of the secondary coil 21 which is farthest from the primary. The receptor lead 26 is connected to the leading-in wire 5 which goes to the mercury 8 in the tube. The other end of the receptor lead 26 terminates in a movable contact point 23 which is movable along the secondary coil 21. The leads 25 and 26 and their connections through the transformer constitute what may be termed the "controlling" circuit by means of which the electric potential variations set up in the receiving apparatus by the received Hertzian waves are impressed on the sensitive conducting ionized mercury vapor in the tube. By moving the movable contact point 23, more or fewer of the turns of the transformer secondary may be included in the controlling circuit so as thereby to tune this circuit. Since the impressed electromotive force in the controlling circuit apparently causes little if any current to pass through the tube between the electrode 3 and the other electrodes, the controlling circuit forms an "open-ended" secondary oscillation circuit by means of which variations of potential or static charges are impressed upon the electrode 3. It is found that with the arrangement of the open-ended tuned secondary circuit herein shown, the apparatus is much more sensitive than with the usual secondary oscillation circuit which is closed through a condenser. It is desirable that the maximum available electro-motive force should be impressed on the electrode 3, and consequently the end of the secondary coil which is farthest from the primary and therefore subject to the minimum capacity effect is connected to the electrode 3. The movable contact points 20 and 23 are adjusted to tune both the primary and secondary circuits to the received oscillations and with the transformer herein shown sharp tuning can be obtained. Included in the lead 26 is a source of electro-motive force 27 which consists of a battery 28 and a resistance 29. The electro-motive force drop over resistance 29 is impressed on the controlling circuit. This electro-motive force may be adjusted by moving the movable contact point 24 along the resistance 29. The value of the electro-motive force thus applied to the controlling circuit, as well as its polarity, depends upon a number of conditions, which probably include the degree of vacuum in the tube, the distance between the electrodes, and the voltage of the periodic electro-motive force in the controlled circuit.

It will be noted that the controlling circuit forms a conductive electrical connection between the open-work electrode 3 and the leading-in wire of the mercury arc, and that the condenser which was interposed in one of the receptor leads of the wireless receiving apparatus shown in my Patents Nos. 1,112,655 and 1,112,549 is omitted. The expression "conductive" electrical connection as used in this application with reference to this circuit is intended to define an electrical connection in which a condenser is not interposed.

The circuit 30 which may be designated as the "controlled" circuit is connected between the electrode 2 and the leading-in wire 5 which goes to the mercury. The connection of the receptor lead 26 to the leading-in wire 5 constitutes a conductive connection between the controlling and controlled circuits. The circuit 30 includes a source of alternating electro-motive force such as generator 31, an adjustable ballast resistance 32 and translating or signal indicating device such as a sounder or buzzer 33. Of course a transformer or other means for impressing an alternating electro-motive force on the circuit might be employed in place of the generator, and other indicating devices such as tape recorders, hot wire instruments, or audible indicating devices of the diaphragm type might be used instead of a sounder. In order to efficiently operate with the audible indicating devices in the controlled circuit, the periodic electro-motive force preferably has a low frequency. The expression "low frequency" where used in the specification and claims with reference to the frequency of the periodic electro-motive force and the current, is intended to include all frequencies up to the upper limit of audibility, as contrasted with "high frequency" waves or oscillations which are above the limit of audibility. The invention in its broader aspects is, however, not limited to the use of a low frequency electro-motive force or current in the controlled circuit.

The apparatus has been found to operate successfully when an alternating electro-motive force of 110 volts taken from the ordinary electric lighting mains has been impressed on the controlled circuit 30. The value of the current in the controlled circuit with such an electro-motive force may amount to several amperes. The energy thus available in the controlled circuit is enormously greater than the received energy of the wireless system which serves as a control.

Not only is the magnitude of the electrical energy of the received signals increased, but also the character of the electrical energy is changed in that the electrical oscillations in the controlling circuit which are of such high frequency as to be not readily directly detectable, cause the production in the controlled circuit of a current of low frequency which may efficiently operate the indicating or translating devices. The invention is not limited however, to the production in the controlled circuit of a current having a frequency lower than the frequency in the controlling circuit, but may be employed where the frequency of the controlled circuit current is higher than the frequency in the controlling circuit.

In using the apparatus the alternating electro-motive force is impressed on the tube by means of the controlled circuit 30. If an appreciable current flows through the tube, as can readily be detected by the operation of the sounder and the appearance of a glow in the tube, the battery 28 is so connected as to maintain the electrode 3 at a potential negative with respect to the mercury 8. The contact point 24 is adjusted to vary the electro-motive force applied by the battery until the current of the controlled circuit 30 is just prevented from passing through the tube 1. If, on the other hand, when the alternating electro-motive force is impressed on the controlled circuit 30 no current passes through the tube, the battery 27 is so connected as to maintain the electrode 3 positive with respect to the mercury 8, and the contact point 24 is adjusted so that the current of the controlled circuit is just prevented from passing through the tube. It may be that some tubes will be such that the alternating current will just be prevented from passing through the tube without the use of a battery 28. However, it has been found in practice that most tubes are either too conducting and must have the battery 29 connected so as to maintain the electrode 3 at a negative voltage, or not sufficiently conducting and must have the battery 29 connected so as to maintain the electrode 3 at a positive voltage. The tube is thus adjusted to a critical condition and is very sensitive to the received impulses in the controlling circuit. When no received impulses are impressed on the electrode 3 the current of the controlled circuit does not flow through the tube 1. When, however, the received impulses are impressed on the electrode 3, the current of the controlled circuit flows through the tube. When the train of received impulses has ceased, the tube restores itself to its normal condition of no current flow. When no current is passing through the tube from the controlled circuit 30, the upper part of the tube is dark. However, as soon as the current of the controlled circuit 30 passes through the tube, the whole tube glows brilliantly thus giving a visual signal, and the sounder 33 operates as an audible signal. The current energy in the controlled circuit may amount to several hundred or more watts and is powerful enough to produce strong and decided signals which will compel the attention of the operator or to produce powerful enough currents to retransmit the message if desired.

The action of the tube in controlling the circuit 30 is believed to be as follows: The mercury arc produces negative ions or electrons in the tube, and the action of the arc, combined with the electro-motive force in the controlled circuit, tends to cause a negative current to flow through the tube from the arc to the electrode 2 during those halves of the cycles of electro-motive force which maintain the electrode 2 positive with respect to the mercury arc. For convenience, the half cycles which impress a positive electro-motive force on the electrode 2 will be designated as the positive half cycles, while the half cycles of the alternating electro-motive force which impress a negative electro-motive force on the electrode 2 will be designated as the negative half cycles. According to the well known rectifying action of the discharge of electricity through a mercury arc, the current can flow between the mercury and the electrode 2 in one direction only, so that the tendency of the mercury arc and alternating electro-motive force is to cause a rectified current to pass through the tube, the negative half cycles being suppressed. When the tube is in normal condition and the source of electro-motive force 27 properly adjusted, the tube is sufficiently non-conducting so that the negative electrons from the mercury arc are prevented from arriving at the electrode 2 in sufficient quantities to cause an appreciable current to flow through the controlled circuit 30. However, if a positive increment of electro-motive force is impressed on the electrode 3, the apparent conductivity of the tube is so increased that the controlled circuit causes a current to flow through the tube during the positive half cycles of the alternating electro-motive force. It is believed that the positive electro-motive force of the electrode 3 exerts a sufficient added attraction upon the negative electrons to cause them to pass from the arc to the upper part of the tube and arrive at the electrode 2. On the other hand, if a negative increment of electro-motive force is impressed on the electrode 3, the apparent conductivity of the tube is decreased, due, it is believed to an increased repulsion of the negative electrons. In the form of apparatus shown in Fig. 1, the electrode 3 has impressed upon it both positive and negative potentials because of the rapid oscillations in the transformer 17, and the electrode 3 is charged positively and negatively a number of times during each half cycle of the alternating electro-motive force. As the electro-motive force of the positive half cycle of the alternating current increases, the electrode 3 is being alternately charged positively and negatively so as to alternately assist and oppose the passage of the current through the tube 1. It is believed that when the electro-motive force of the positive half cycle is increased to such a value that with the assistance of the momentary positive charge of the electrode 3, the apparent conductivity of the tube is sufficiently increased, the controlled circuit sends a sudden rush of current through the tube which breaks down its resistance, and that the current thus started continues to flow until the electro-motive force decreases to such a value that it can not longer maintain a current flow through the tube. It is believed that the point on the half cycles at which the current starts is near the middle or peak of the cycle, and that the point on the cycle where the current ceases is near the end of the cycle. When the end of the positive half cycle is nearly reached, the controlled current is suppressed by the action of the mercury arc, because as above pointed out the arc-like discharge between the mercury and the electrode 2 can take place in but one direction, and consequently during the subsequent negative half cycle no current flows from the controlled circuit 30 through the tube. When the next positive half cycle takes place the current of the controlled circuit again flows through the tube. The rectified current continues to flow so long as the received oscillations are impressed on the electrode 3. If the train of received oscillations ceases during a negative half cycle of the alternating electro-motive force, the controlled current is prevented from passing through the tube upon the next positive half cycle. If the train of received oscillations ceases during a positive half cycle after the current flow has been established, the current flow continues until nearly the end of the positive half cycle. Apparently after the controlled current is once established through the tube, there is a great reduction in the apparent resistance of the tube, so that any subsequent oscillations in the potential of the electrode 3 either positive or negative have little if any effect upon the controlled current which continues to flow until nearly the end of the positive half cycle when the controlled current of itself ceases because its electro-motive force approaches a zero value. In other words the current flow in the controlled circuit is started by an expenditure of energy in the controlling circuit which is entirely insufficient to stop the flow of current once established in the controlled circuit. The controlling circuit serves as a delicate electrical trigger to release a comparatively great store of electrical energy in the controlled circuit, which once released continues irrespective of the controlling circuit until it stops of its own accord when the electro-motive force in the controlled circuit drops to so low a value as to no longer maintain a current flow through the now greatly reduced resistance of the tube. From the nature of the gaseous conductor employed it is much easier to start the flow of current through the tube than it is to stop the flow of the current when once established. The two most important factors in the control of a comparatively great store of current energy in the controlled circuit by a very small expenditure of energy in the controlling circuit are believed to be, first, the capacity of the apparatus for a sensitive adjustment so that the tube is normally maintained in a critical condition in which a comparatively slight expenditure of energy in the controlling circuit serves to release the current in the controlled circuit, and second, the employment in the controlled circuit of a periodic electro-motive force which periodically assumes minimum values insufficient of themselves to continue a current flow through the controlled circuit after the expenditure of the energy in the controlling circuit has ceased.

While the theory above explained is believed to be the correct theory of the operation of the apparatus and is here inserted for the purpose of more clearly explaining the invention, it is to be understood that the invention does not reside in the theory and should not be limited thereby, because, whatever the theory of operation may be, apparatus constructed as herein set forth has been found to operate successfully.

In Fig. 2 is illustrated a modification of the apparatus in which a potential drop in the alternating circuit is employed instead of a battery for adjusting the potential of the electrode 3 with respect to the mercury. The controlled circuit 30 includes a generator 31, a sounder 33 and the adjustable resistance 32. A branch circuit 50 shunts the generator 31 and the resistance 32 and includes a comparatively high resistance 51. The receptor lead 26 has a movable contact 52 which may be adjusted along the resistances 32 and 51. By varying the position of the contact 52, the electrode 3 may be maintained at the same potential as the mercury 8 or a higher or lower potential. The electrode 3 has impressed upon it by means of the voltage drop in the resistance 32 or 51 an alternating potential which is in phase with or in opposite phase to the alternating potential impressed on the mercury 8 by the controlled circuit 30. For the sake of simplicity in explanation, the negative half cycles of alternating electro-motive force may be disregarded. If the tube 1 has too small an apparent conductivity, the contact 52 is moved to the right along the resistance 51 so that during a positive half cycle the electrode 3 is maintained positive with respect to mercury 8. If the tube 1 has too great an apparent conductivity the contact 52 is moved to the left on the resistance 32 and the electrode 2 is maintained at a potential negative with respect to the mercury 8. The effect of the adjustment afforded by the resistances 32 and 51 is therefore substantially the same as the battery 27 and the resistance 29 of Fig. 1, in adjusting the tube to a critical condition.

The amount of electrical energy released in the circuit 30 is enormously greater than the energy available in the controlling circuit. For example, a current of several amperes under an electro-motive force of 110 volts is started and stopped by the signal trains of waves received by a wireless antenna. While the current in the controlled circuit probably starts and stops near the middle and near the end respectively of its positive half cycles instead of at the exact beginning and end of the train or trains of waves which make up the signal, nevertheless this slight time difference of a small fraction of a second, even when an alternating current as slow as sixty cycles per second is employed, has no appreciable effect upon the length of the dot or dash signal indicated by the sounder 33 and the glow in the tube.

In Fig. 3 is illustrated a modification of an apparatus in which the current in the controlled circuit is controlled by a microphone. The controlled circuit is the same as that in Fig. 1. In the receptor lead 26 is a source of potential 27 having the same function as the source 27 in Fig. 1. The receptor leads 25 and 26 are connected with the secondary of a transformer 60. The primary of the transformer 60 is connected to the microphone circuit 61 which includes a battery 62 and a telephone transmitter 63. The electric potential waves of telephonic frequency are impressed upon the electrode 3 and serve to vary the apparent conductivity of the tube in a manner similar to the potential oscillations impressed on the electrode 3 by the apparatus illustrated in Fig. 1. This form of apparatus may be adjusted so that a whisper several feet in front of the telephone transmitter controls a current of several amperes in the controlled circuit. This form of apparatus is useful wherever it is desired to get strong electric signals controlled by sound waves as for example in submarine signalling by sound waves, or in directing mechanisms at a distance by sound. The frequency of the controlled currents may be higher than the frequency of the sound waves, and may be above the limit of audibility, particularly in case it is desired to modify by sound waves the high frequency oscillations of a wireless telephone transmitting apparatus.

In Fig. 4 is illustrated another modification of the apparatus in which the controlled current is an intermittent current produced in a direct current circuit by means of a vibrator. The controlling circuit is connected to a telegraph line or cable circuit. The receptor lead at 25 is connected to one wire 70 of the telegraph circuit and the receptor lead at 26 is connected with the other wire 71. When the telegraph key 72 at the distant sending station is closed the electromotive force of the battery 73 is applied so as to give the electrode 3 a proper electromotive force with respect to the mercury 8 and permit a current to flow in the controlled circuit 30. The voltage drop over a resistance 79 in circuit with a local battery 77 may be applied through a high resistance 74 between the electrode 3 and the mercury and serves to adjust the tube to a critical condition as pointed out in connection with the resistance 29 and the battery 27 of Fig. 1. The controlled circuit 30 includes a battery 80 the positive pole of which is connected to the electrode 2. The controlled circuit 30 also includes a vibrating current interruptor 81 which serves to cause a periodic electromotive force of the nature of an interrupted electro-motive force to be impressed on the controlled circuit 30. The action of the interrupted electro-motive force is similar to that of the positive waves of an alternating electro-motive force. Apparently when the conductivity of the tube 1 is increased by the action of the controlling circuit the resistance of the tube is suddenly and greatly reduced and the current flows until the electro-motive force in the controlled circuit is reduced to zero upon the interruption of said circuit, and is prevented from starting again after the controlling signal has ceased. Other kinds of periodic currents may be employed with the apparatus of the present invention as it is apparently only requisite that the periodic current shall periodically assume maximum values insufficient of themselves to start a current flow through the tube, but sufficient with the increase in conductivity of the tube due to the added effect of the controlling circuit on the tube, and that the periodic current shall periodically assume minimum values insufficient of themselves to continue the current flow through the tube after the controlling circuit has ceased to increase the apparent conductivity of the tube, in order that the controlled current may then stop.

The interrupted current shown in Fig. 4 may be employed with the controlling circuits shown in the other figures and the telegraph operated circuit shown in Fig. 4 may be employed with controlled circuits shown in the other figures. The controlling circuit may include other sources of electrical impulses than those illustrated in the drawings and may be otherwise connected to the tube; for example, other ways of connecting the controlling circuit to the tube are shown in my applications above referred to.

In Fig. 5 is illustrated another modification of the apparatus in which an alternating current is controlled by means of a selenium cell. The controlled circuit 30 has the same connections as those shown in Fig. 1. The selenium cell 90 is included in the local circuit 91 which includes a battery 92 and resistance 93. The receptor lead 25 is connected to the end of the resistance 93 which is maintained positive by the battery 92 and the receptor lead 26 is connected to the other end of the resistance 93. In the receptor lead 26 is an adjustable resistance 29 and a battery 27 having the same function as the resistance 29 and battery 27 of Fig. 1. When light strikes the selenium cell its resistance is lowered and more current is permitted to flow through the local circuit 91. The voltage drop across the resistance 93 is increased and the electrode 3 is made more positive in potential. This, as above explained, increases the apparent conductivity of the tube and permits the current to flow in the controlled circuit. This form of device is very sensitive and it has been found that the light of a candle across a room focused on the selenium cell is sufficient to effect the control of several amperes in the controlled circuit.

The application of a periodic current according to the principles of the present invention is believed to be fundamentally new. The present invention is not limited to the use of any particular kind of periodic current. For example, instead of an alternating or an interrupted current on oscillating or an undulatory current might be employed. Neither is the invention limited to the particular form of apparatus for controlling the periodic current, nor is the invention limited to apparatus in which the controlling circuit forms a part of a signal receiving or transmitting system, but the present invention may be applied in many other forms of apparatus in which a sensitive and delicate control is desired. The present invention is therefore not limited to its preferred apparatus or method but may be embodied in other constructions of apparatus and other methods within the scope of the invention as pointed out in the following claims:—

1. An apparatus for controlling electric currents having, in combination, an evacuated vessel, an ionizing agency in the vessel, an electrode in the vessel, a controlled electric circuit connected between the ionizing agency and the electrode including a source of periodic electro-motive force, an openwork electrode interposed between the ionizing agency and the first electrode and extending substantially across the interior of

the vessel, and means including a controlling electric circuit for varying the potential of the open-work electrode, substantially as described.

2. An apparatus of the character described having, in combination, an oscillation transformer, a tuned receiving circuit connected through the transformer primary, a gaseous detecting device comprising a plurality of electrodes, and an open-ended controlling circuit through the transformer secondary tuned to the receiving circuit and having one of its free ends connected to one of the electrodes, substantially as described.

3. An apparatus of the character described having, in combination, an oscillation transformer comprising a primary coil and a secondary coil having one end projecting longitudinally beyond the primary coil, a receiving circuit connected through the transformer primary, and a detecting device, an open-ended tuned controlling circuit having a connection between the detecting device and the end of the secondary coil which is farthest from the primary coil, substantially as described.

4. A gaseous detector of radiant energy having a cathode, an anode, and potential gradient changing means, and means to impose amplitude variation upon the currents of a circuit of said detector, thereby to render said detector self-restoring, substantially as described.

5. A gaseous detector of radiant energy having a cathode, an anode, and potential gradient changing means, said detector having a local circuit, and means to interrupt said circuit at sufficiently short periods to maintain the detector effectively sensitive to receive signals, substantially as described.

6. That step in the method of controlling the action of a gaseous detector of radiant energy which comprises the effecting of a drop to zero value of a local current of said detector, at sufficiently short periods to maintain the detector effectively sensitive to receive signals, substantially as described.

7. A gaseous amplifier of feeble electrical currents having an anode, a cathode, a potential gradient changing means, and a secondary controlled circuit; said amplifier constituting a part of said circuit, and means to interrupt electrical currents through said circuit at sufficiently short periods to maintain the detector effectively sensitive to receive signals, substantially as described.

8. A gaseous detector of radiant energy having a cathode, an anode, and potential gradient-changing means, a local current source controlled by the action of said detector, and of the circuit whereof the detector constitutes a part, and means to cause a drop of said local current to zero value at sufficiently short periods to compel the effective stopping of ionization of the gas in said detector, and thereby to maintain the detector in a condition of high insulating resistance, substantially as described.

9. A gaseous detector of radiant energy having a cathode, an anode, and potential gradient-changing means, a local current source controlled by the action of said detector, and of the circuit whereof the detector constitutes a part, and means automatically to cause a drop of said local current to zero value, at sufficiently short periods to maintain the detector in a condition of high insulating resistance, thereby to effect self-restoration of said detector, substantially as described.

10. A gaseous detector of radiant energy, comprising an evacuated vessel having a grid and anode and a cathode with provision for ionizing the evacuated space, a controlled electric circuit connected between the anode and the cathode and including means to cause a drop of the current in said controlled circuit to zero value at sufficiently short periods to maintain the detector in a condition of high insulating resistance, and means for varying the potential of the grid including a controlling circuit having a conductive electrical connection between the grid and the controlled circuit, substantially as described.

11. A gaseous detector of radiant energy, comprising an evacuated vessel, a grid, an anode and a cathode therein with provision for ionizing the evacuated space, a circuit connected to the anode and cathode and controlled by the action of the detector, a source of alternating current in said controlled circuit for impressing an alternating electromotive force across the evacuated space between the anode and cathode, and means for impressing the received oscillations on the grid and thereby decreasing the apparent resistance of the evacuated space sufficiently to allow a rectified current to flow in one direction between the anode and cathode breaking down the resistance of the evacuated space during the half-cycles of current flow but permitting the self-restoration of the detector to its initial condition of high resistance and thereby maintaining the detector effectively sensitive to receive signals, substantially as described.

12. A gaseous detector of radiant energy, comprising an evacuated vessel, a grid, an anode and a cathode therein with provision for ionizing the evacuated space, a circuit connected to the anode and cathode and controlled by the action of the detector, and including means for impressing on the evacuated space between the anode and cathode an electro-motive force which assumes zero values at sufficiently short intervals to render the detector self-restoring, and means for impressing the received oscillations on the grid and acting normally to de-

crease the apparent resistance of the evacuated space and permit a greatly increased current to flow through the controlled circuit, said last named means including an uninterrupted conductive electrical connection between the grid and the controlled circuit for preventing the accumulation of a negative charge on the grid, substantially as described.

13. A gaseous detector of radiant energy having a cathode, an anode, and potential gradient changing means normally acting by increasing the current of the controlled circuit and means to impose amplitude variations upon the currents of a circuit of said detector to render said detector self-restoring when the potential gradient changing means acts to increase the current of the controlled circuit to a point where the detector breaks down, substantially as described.

14. A gaseous detector of radiant energy having a cathode, an anode, and potential gradient changing means normally acting by increasing the current of the controlled circuit and means to cause a drop to zero value of the current in the controlled circuit at sufficiently short intervals to render said detector self-restoring, substantially as described.

15. A gaseous detector of radiant energy having a cathode, an anode, means intermediate said cathode and anode for changing the potential gradient between them, normally acting by increasing the current of the controlled circuit, and means to impose amplitude variations upon the currents of a circuit of said detector to render said detector self-restoring when the potential gradient changing means acts to increase the current of the controlled circuit to a point where the detector breaks down, substantially as described.

16. A gaseous detector of radiant energy having a cathode, an anode, means intermediate said cathode and anode for changing the potential gradient between them, normally acting by increasing the current of the controlled circuit, and means to cause a drop to zero value of the current in the controlled circuit at sufficiently short intervals to render said detector self-restoring, substantially as described.

17. A gaseous detector of radiant energy having electrodes, a substantially continuous ionizing means, a source of local current, potential gradient changing means for causing an increased flow of said local current through said detector, and means to interrupt said current at sufficiently short intervals to maintain the detector effectively sensitive to receive signals, substantially as described.

18. Apparatus for controlling electric currents, comprising an evacuated vessel, means for maintaining a space therein in a sensitive conducting condition including an electron-emitting cathode in the vessel, a plate in the vessel, a grid in the vessel interposed between the cathode and plate, means including a controlled circuit for impressing a periodic electromotive force between the cathode and plate, and means including a controlling circuit for varying the potential of the grid to thereby control the current flow between the cathode and plate, substantially as described.

19. Apparatus for controlling electric currents, comprising an evacuated vessel, means for maintaining a space therein in a sensitive conducting condition including an electron-emitting cathode in the vessel, an anode in the vessel, means including a controlled circuit for impressing a periodic electromotive force between the cathode and anode, an electrode in the vessel, and means including a controlling circuit for varying the potential of the last mentioned electrode so as to control the current flow between the cathode and anode, substantially as described.

20. Apparatus for controlling electric currents, comprising an evacuated vessel, a continuously operating ionizing agency in the vessel, an electrode in the vessel, means including a controlled circuit for impressing a periodic electromotive force between the ionizing agency and the electrode, another electrode in the vessel, and means including a controlling circuit for varying the potential of the last mentioned electrode so as to control the current between the ionizing agency and the first mentioned electrode, substantially as described.

21. Apparatus for controlling electric currents, comprising electrodes in a region which is maintained in a sensitive conducting condition, means including a controlled circuit for impressing a periodic electromotive force between the electrodes, another electrode interposed between the first mentioned electrodes, and means for including a controlling circuit for varying its potential so as to control the current flow between the first mentioned electrodes, substantially as described.

22. Apparatus for controlling electric currents, comprising electrodes in a region which is maintained in a sensitive conducting condition, means for impressing a periodic electromotive force between said electrodes, and means located between said electrodes for varying the electrostatic field between said electrodes so as to control the current flow between them, substantially as described.

23. Apparatus for controlling electric currents, comprising an evacuated vessel, means for maintaining a space therein in a sensitive conducting condition including an electron-

emitting cathode, an anode in the vessel, an electrode in the vessel, means including a controlling circuit for varying the potential of the last mentioned electrode to thereby control the current flow between the cathode and anode, and means including a controlled circuit for impressing between the anode and cathode a periodic electromotive force having minimum values insufficient of themselves to maintain the current flow between the cathode and anode whereby said apparatus is rendered self-restoring, substantially as described.

24. Apparatus for controlling electric currents, comprising electrodes in a region which is maintained in a sensitive conducting condition, means for varying the electrostatic field between two electrodes so as to control the current flow between them, and means for impressing between said two electrodes a periodic electromotive force having minimum values insufficient of themselves to maintain the current flow between said two electrodes whereby the apparatus is rendered self-restoring, substantially as described.

25. Apparatus for controlling electric currents, comprising an evacuated vessel, a continuously operating ionizing agency in said vessel for maintaining the space therein in a sensitive conducting critical condition, an electrode in said vessel, means for impressing between the ionizing agency and the electrode a periodic electromotive force having minimum values insufficient of themselves to maintain a current flow between the ionizing agency and the electrode whereby the apparatus is rendered self-restoring, another electrode in the vessel for varying the electrostatic field between the ionizing means and the first mentioned electrode, and means for energizing the second electrode so as to cause an electrical breakdown of the gaseous space between the ionizing means and first mentioned electrode, substantially as described.

26. Apparatus for controlling electric currents, comprising an evacuated vessel, a continuously operating ionizing agency in said vessel for maintaining the space therein in a sensitive conducting critical condition, an electrode in said vessel, means for impressing between the ionizing agency and the electrode a periodic electromotive force having minimum values insufficient of themselves to maintain a current flow between the ionizing agency and the electrode whereby the apparatus is rendered self-restoring, another electrode in the vessel for varying the electrostatic field between the ionizing means and the first electrode, means for energizing the second electrode so as to cause an electrical breakdown of the gaseous space between the ionizing means and first mentioned electrode, and means for adjusting the potential of the second mentioned electrode with respect to the ionizing means and the first mentioned electrode, substantially as described.

GEORGE W. PIERCE.

Witnesses:
GEORGE E. STEBBINS,
ALICE ACKROYD.