W. C. WHITE.

ELECTRICAL DISCHARGE DEVICE.

APPLICATION FILED MAR. 20, 1914.

1,159,307. Patented Nov. 2, 1915.

Fig. 1.

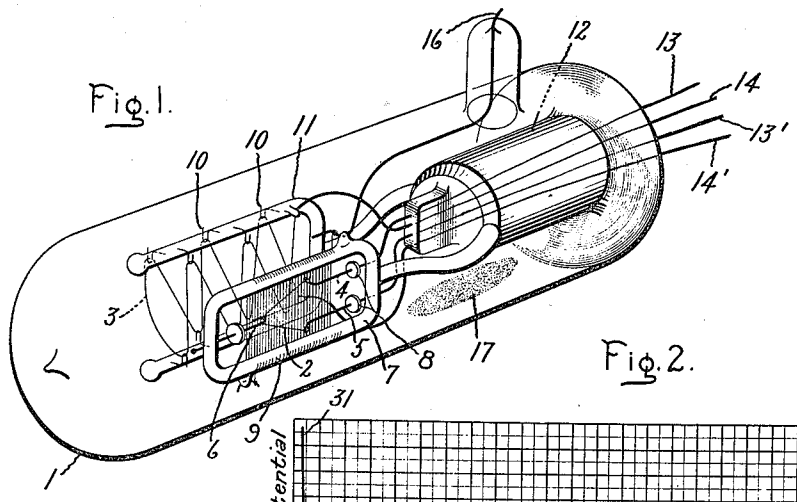


Fig. 2.

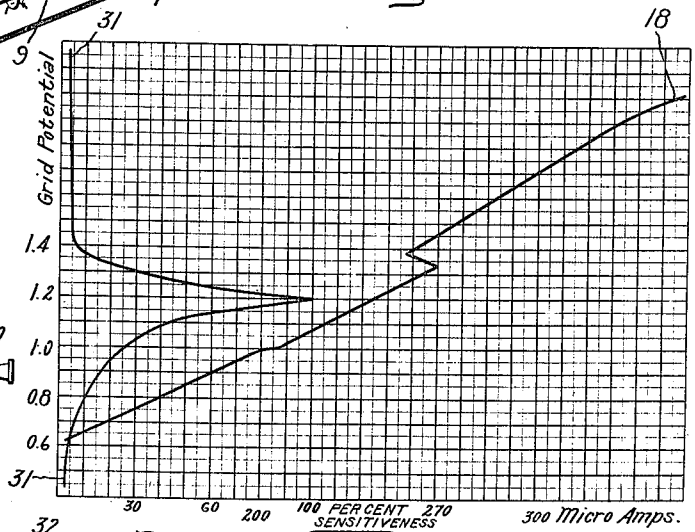


Fig. 3.

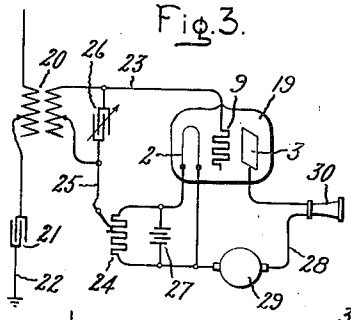


Fig. 4.

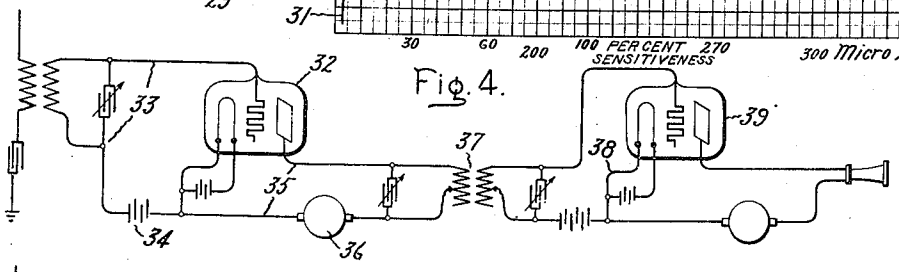
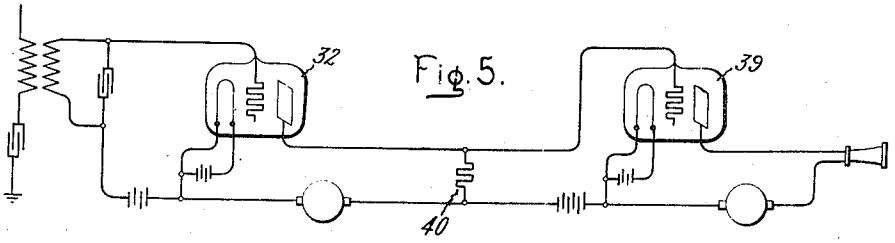


Fig. 5.



Witnesses:
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UNITED STATES PATENT OFFICE.

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ELECTRICAL-DISCHARGE DEVICE.

1,159,307. Specification of Letters Patent. Patented Nov. 2, 1915.

Application filed March 20, 1914. Serial No. 826,027.

To all whom it may concern:

Be it known that I, WILLIAM C. WHITE, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Electrical-Discharge Devices, of which the following is a specification.

My present invention comprises certain improvements in vacuum electric devices and is of particular value in connection with the detection of high frequency oscillations used in electro-magnetic wave signaling systems.

My improved detector is in construction somewhat similar to the well-known "audion" set forth in U. S. patent to De Forest #879,532, and is also similar in construction to the vacuum tube device described and claimed in an application filed by Irving Langmuir, October 16, 1913, Serial No. 795,610. In both of these prior devices an exhausted glass tube is provided having a cathode adapted to be heated to incandescence by some suitable source of current, an anode or plate connected in a local circuit with one terminal or leg of the incandescent cathode, and a conductor or grid located in proximity to the cathode and upon which a varying potential is impressed, the variations of which affect the amount of current flowing in the vacuum space between the cathode and the plate or anode. The change in current in this local circuit bears no necessarily definite relation to the change of potential on the grid, but is very greatly affected by the nature of the vacuous space in which the electrodes are located. Thus, in the vacuum relay or amplifier of the type shown in the said Langmuir application, the tube is exhausted to the highest possible degree of vacuum, the gas being driven out of the walls of the tube as well as out of all of the metal electrodes. Under these conditions the current flow in the tube between the incandescent cathode and the plate or anode is due to a pure electron discharge from the heated cathode, and is not dependent upon the presence of residual gas as a conducting medium. In a tube thus highly exhausted, current in the local circuit or plate circuit increases with increase of grid potential and decreases with decrease of grid potential, but the difference in the amount of increase for a given variation of grid potential is not so far different from the decrease caused by a decrease of grid potential as to make the device a good detector of high frequency oscillations. In other words, the asymmetry of current flow in the local circuit due to a series of high frequency oscillations is not sufficiently great to enable the device to operate effectively in connection with a telephone or other receiver for detecting such high frequency impulses. The device is more especially valuable as a relay or amplifier of such oscillations. If, however, a certain amount of residual gas be present in the tube then the operation of the device becomes quite different. Such a construction and mode of operation is that characteristic of the so-called audion. In the audion, if very low voltage be used in the local or plate circuit, the device is relatively very insensitive, or in other words, the change of current in the local circuit is very small for a given change of potential on the grid. The device becomes more sensitive as the voltage in the local circuit is increased. There is a limit however to the voltage which may be used in the local circuit because as the voltage is increased, ionization of the gas in the tube increases, a blue glow appears followed by deterioration of the electrodes, disengagement of more gas therefrom and finally destruction of the operative qualities of the tube. The voltage impressed on the local circuit is therefore made as high as possible consistent with the avoidance of these limited conditions. In the audion as thus constituted, a decrease of potential on the grid causes a decrease of current in the local circuit while increase of potential on the grid causes an increase of current in the local circuit, but the decrease of current is of a magnitude very much greater than the increase of current caused by an increase of potential on the grid. The result is that when high frequency oscillations are impressed upon the grid their presence is made known by a decrease of current in the local or plate circuit, which decrease is detected by the telephone or other indicator placed in the local circuit.

I have found that by maintaining within the evacuated container of a device of the general nature already described, a certain definite pressure of gas, which in amount is very much less than that which is necessary to make the so-called audion operative, and not greatly more than would be tolerated

in a device such as disclosed in the Langmuir application, very remarkable results are secured in the relations which then exist between the current in the plate circuit and the changes of potential on the grid. With this definite pressure of gas or vapor in the device, I have found that the variation of current in the plate circuit with variation of potential on the grid follows the law of a pure electron discharge tube such as that of the Langmuir application, except within a small range of voltage in the plate circuit. Within this small range there appears to be a condition of instability such that when high frequency oscillations are impressed upon the grid there always follows a sudden decrease of current in the local circuit. The explanation of this phenomenon is decidedly obscure but the existence of the phenomenon is very real. Within the range of voltage indicated, the application of high frequency oscillations or of continuous high frequency waves, causes the current in the local circuit to decrease so suddenly that a very distinct signal is produced in the telephone receiver or other indicating device in the local circuit. The sharpness of the signal thus produced is such that my improved device is not only extremely sensitive to receive high frequency impulses but because of the sharpness of the signals the effect of "static" is not nearly so serious as in other detecting devices.

While my improved detector is dependent upon the presence of a small but definite gas pressure in the space including the electrodes, its operation is not accompanied by blue glow or any other well recognized evidences of positive gas ionization. The amount of gas or vapor present is perhaps not more than $\frac{1}{10}$ of that which characterizes the so-called audion.

The sensitiveness of my improved devices varies with the potential impressed upon the grid and becomes a maximum at a certain definite potential. To secure this maximum sensitiveness a definite potential which varies according to the particular device is impressed upon the grid circuit. As this potential is changed by the high frequency oscillations, the current in the plate circuit is suddenly decreased, thereby producing the desired signal.

In producing and maintaining the desired gas pressure in my improved device it is not sufficient to leave in the tube a certain amount of residual gas during exhaustion since this gas does not remain constant in amount but generally will decrease upon operation of the device by the well-known clean-up action, though in some cases the amount of gas present increases rather than decreases, due to other causes. To secure the necessary definite gas or vapor pressure in the tube, I therefore provide a substance with the desired vapor pressure and place this in the tube. Among other things I have found that amalgam is suitable for the purpose. Mercury alone appears to be unsuitable, as it has too high a vapor pressure at ordinary temperatures though by lowering the temperature of the mercury the desired vapor pressure may be obtained.

The novel features of my invention are pointed out with greater particularity in the appended claims, and for a better understanding of my invention reference may be had to the following description taken in connection with the accompanying drawing in which—

Figure 1 is a perspective view of one type of apparatus embodying my invention; Fig. 2 illustrates by means of curves some of the electrical characteristics of the device; Figs. 3, 4 and 5 are diagrams of connections illustrating how the new device may be used in radio-telegraphic receiving systems.

As shown in Fig. 1 the discharge device comprises an inclosing envelop 1, which may be of glass, in which are mounted an electron-emitting cathode 2 and an anode 3. In the device illustrated both the cathode and anode consist of wire preferably of tungsten, tantalum, or other highly refractory metal which can be readily freed from ionizable gas. The anode need not be a wire but may be a plate properly freed from gas and it has been thus diagrammatically indicated in Fig. 3. The cathode 2 is a short V-shaped tungsten filament connected to terminal conductors 4, 5 and supported at its bight by a hook 6, both the supply conductors and the hooks 6 being mounted on a frame 7 so that the filament is located in a plane passing through the side arms of the frame.

The cathode supports 4, 5 and 6 are provided with small glass disks 8 which reduce the tendency of a short circuit between the cathode and the grid by vaporized metal deposited on the frame 7. Around the outside of the frame is wound a wire 9 with closely spaced turns. This conductor 9 commonly called the grid, serves the purpose of varying the electric field near the cathode and thereby varying the electron current between cathode and the anode. The anode wire is conveniently supported by hooks 10 located upon a forked glass support 11. The frame 7 and the support 11 are mounted upon a glass stem 12 sealed into one end of the envelop. Leading-in conductors 13, 13′ which supply heating current to the cathode and the conductors 14, 14′ which are connected to the terminals of the anode are sealed into the stem 12 in the usual manner. The anode is provided with current connections at each terminal so as to enable it to be heated during the evacuation of the device. But one electrical connection is made

to the grid by means of conductor 16 sealed into the envelop as the grid may be sufficiently freed from gas without heating it by passage of current.

Before the envelop is sealed off there is placed in it (in a manner hereinafter described) a small amount of vaporizable material 17, for example, an amalgam, sulfur, phosphorus pentoxid, tungsten hexachlorid, and in general substances having a suitable vapor pressure at the operating temperature of the device. Substances having too high a vapor pressure, for example, mercury, may be used if maintained during operation at a suitable low temperature, as in a side chamber. Gases at proper pressure will give the desired effect but the effective pressure, and possibly also the character of the gas are changed by some chemical or electrochemical action in the tube so that gases act only temporarily. The material 17 is either loosely placed in the main envelop as indicated, or placed in a side chamber. The character of this material, depends upon the temperature and voltages at which the device is operated, as will be hereinafter explained, its purpose being to maintain in the space, vapor at a definite low pressure.

For the evacuation of the device the glass walls of the tube are heated so as to free them from moisture and both the anode and the cathode are heated by passage of current so as to drive out the gases. When an amalgam is to be used as the source of vapor, the metal to be amalgamated, for example, silver, preferably is placed in the envelop before evacuation. The mercury is preferably placed in a side chamber which is kept cool during the preliminary bake-out. The evacuation of the tube is carried out by the most approved methods of incandescent lamp exhaust, and the last traces of gas are removed by either a Gaede molecular pump or by some chemical evacuating means, such as the use of vaporized calcium or magnesium. The last traces of ionizable gases are removed from the electrodes by heating them to incandescence and preferably at the same time operating the grid as the anode for an electron discharge, the impressed voltage being increased step by step as the gas is removed. After the parts of the device and the silver, or other metal to be amalgamated has been freed from gas, mercury vapor is permitted to diffuse into the envelop. For example, clean mercury may be kept at a relatively low temperature in a side chamber during the exhaust. When the exhaust is completed the mercury may be permitted to reach room temperature or even a higher temperature, thus diffusing into the main envelop to form silver amalgam. At room temperature one or two days are required for the amalgamation. All excess unalloyed mercury must be removed from the tube. This may conveniently be done by warming the bulb slightly and surrounding the mercury side tube in a freezing mixture, or in liquid air. The mercury side container may then be sealed off. When evacuation of the envelop has been carried to a pressure low enough to enable the pure electron discharge to take place and ionizable gas has been removed from the anode to a sufficient extent to prevent the blue-glow phenomenon which is an indication of positive gas ionization, the envelop is sealed off. A device thus prepared will operate at ordinary room temperatures with a substantially pure electron discharge between anode and cathode without positive ionization, even when the impressed voltage is as high as 300 to 400 volts, or even higher. However, when the voltage between anode and cathode is within a certain range an irregularity is observed in the electron discharge current, as already described. This voltage range is illustrated by curve 18 in Fig. 2, which will be more fully understood by first considering the connections shown in Fig. 3. In this figure a device 19 constructed as above described is connected in a secondary circuit of a transformer 20, the primary of which is included in series with a condenser 21 in a grounded antenna circuit 22. The grid 9 is connected by a conductor 23 to one terminal of the transformer and the negative terminal of the cathode 2 is connected through a potentiometer 24 and a conductor 25 to the other terminal of the transformer secondary. Connected in shunt to the secondary of the transformer is a variable condenser 26 so that by varying either the capacity or inductance of the circuit it may be tuned to resonance with the incoming oscillations to be detected. The battery 27 serves to heat the cathode to incandescence and also determine the potential of the grid 9 with respect to the cathode. In the plate circuit 28 between the cathode 2 and anode 3, is included a source of direct current, for example, a direct current generator 29 and also a suitable indicator, such as a telephone receiver 30.

In order to receive signals the potentiometer 24 is adjusted so as to maintain the grid at a certain definite potential with respect to one end of the cathode. With a suitable potential between the cathode and anode, for example, 50 to 250 volts, a steady direct current will flow in the plate circuit which will not affect the telephone receiver. When oscillations are received by the antenna and superimposed upon the potential of the grid the electric field about the cathode is changed correspondingly and a decrease of current is noted with each oscillation or series of oscillations, thereby producing sounds in the receiver. With a given electron detector it

will be observed that the sensitiveness varies very markedly with the grid potential, there being a certain point at which the signals may be most strongly heard and a variation of grid potential above or below this value produces a decrease of audibility of the signals.

In Fig. 2 there are shown for the purpose of illustration curves of the characteristics of one particular detector made in accordance with my invention. For the curve 18 the ordinates represent grid potentials with respect to negative end of filament and the abscissæ the relayed current in micro-amperes. The curve indicates the current values obtained with a given terminal voltage between the cathode and the anode for the indicated range of grid voltages with respect to the cathode. This current is commonly known as the "plate current." The sensitiveness of the device is indicated by curve 31 which is plotted with the ordinates in grid potential and the abscissa in percentages of maximum sensitiveness. In other words this curve indicates the degree of change in plate current produced by impressed oscillations at different grid potentials. It will be observed at 1.2 volts the curve of sensitiveness reaches a maximum. It will also be observed that for a certain range of grid voltage on each side of this critical value, the plate current exhibits an irregularity and then at higher grid voltages again increases at the rate it had increased before the period of irregularity or off-set in the curve.

In the device here illustrated a sudden change of grid potential as produced by impressed oscillations produces a marked decrease of current in the plate circuit 28 providing the grid potential is not far from 1.2 volts positive. With a pure electron discharge device such as described in Langmuir application, Serial No. 795,610 an increase of positive grid potential will produce an increase of plate current. In the Langmuir device a positive impulse or charge on the grid produces a corresponding increase in the proportion of electron current taken by the grid itself.

On either side of the region of greatest sensitiveness indicated by the off-set of the curve 18 of grid potential the characteristic of my device is substantially that of a pure electron discharge. The vapor pressure necessary to produce this peculiar effect varies with the character of the material used. For mercury vapor in the type of apparatus illustrated the pressure should be between the limits of .00006 and .00040 millimeters of mercury. Sulfur, for example, operates best at a pressure of .0002 to .003 millimeters of mercury. If a greater responsiveness to the received oscillations is desired than can be obtained with the connections illustrated by Fig. 3, my new detecting device may be used in cascade with the pure electron discharge apparatus or relay described in the Langmuir application above referred to. Electrical connections suitable for this purpose are shown in Figs. 4 and 5.

In Fig. 4 the electron relay 32 has its grid circuit included in a local tuned circuit 33, the various parts of which correspond to those described in connection with Fig. 3. It need only be noted that the potential of the grid is determined by a battery 34. The plate circuit 35 contains a generator 36 or other suitable source of direct current of desired voltage. The variable plate current is impressed upon the primary of an air core transformer 37, the secondary of which is connected to the grid circuit 38 of a detector 39 made in accordance with my invention. The incoming oscillations are magnified by the relay 32 which produces in its plate circuit an amplified current similar in character to its received oscillations which is then transformed and detected as already described in connection with Fig. 3. In some cases the relay 32 and my novel detector 39 may be to advantage coupled through a resistance 40 instead of a transformer, as shown in Fig. 5.

In the operation of my novel detector it is not necessary that the source of current in the electrode circuit should be of invariable voltage. An ordinary generator even though its voltage varies slightly due to commutation, and so forth, may be used as indicated in Fig. 3. When using an audion a current source with a steady voltage is necessary as an ordinary generator will cause noises in the telephone. The device is also less affected by "static," or atmospheric disturbances than devices depending on gaseous ionization. It can be operated under the most sensitive conditions without the danger of static causing the discharge to burst into blue glow.

The high apparent resistance of the device renders changes of resistances in the external circuit of little effect. For example, two or three telephone receivers or more may be used in series in the receiver circuit without any noticeable change in the loudness or clearness of the signals.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. An electrical discharge device comprising a gas-tight envelop and an electron-emitting cathode and an anode, the space within said envelop being evacuated to such degree that current conduction can take place from cathode to anode by means of substantially pure electron discharge, and means in said envelop for maintaining therein a gas at a definite pressure at which the device possesses a critical region of sensitiveness to changes of electrical field near the

cathode while carrying current independently of gas conduction.

2. A device for detecting high frequency oscillations comprising a cathode adapted to be heated, an anode, a grid located near said cathode, an inclosing envelop, and means for maintaining within said envelop gas at a substantially constant pressure at which the device possesses a region of maximum sensitiveness to oscillations impressed on said grid when said grid is at a critical potential with respect to the cathode, the gas pressure being so low that a discharge between cathode and anode is substantially independent of positive ionization at grid charges materially more positive than said critical potential.

3. A detector for high frequency signals comprising a highly evacuated envelop, a cathode adapted to be heated to incandescence, an anode, a discharge-controlling conductor, and means for maintaining in said envelop gas of such character and pressure that there is a decrease conductivity for variations of potentials of the discharge controlling conductor from a critical potential, the electrodes of said device being freed from gas so completely and the gas pressure therein being so low that the electrical characteristics at current values both lower and higher than the critical region substantially follow the law of pure electron conduction.

4. An electrical discharge device comprising an envelop, an electron-emitting cathode, an anode, a discharge-controlling conductor located near said cathode, said device being deprived of gas to such degree as to be capable of operation with a substantially pure electron discharge at several hundred volts and a vaporizable substance in said envelop.

5. A device for detecting high frequency oscillations comprising an envelop, a cathode adapted to be heated to incandescence, an anode, means for varying the electrical field near the cathode, said device being deprived of ionizable gas to such degree as to operate with a pure electron discharge free from positive ionization at impressed terminal potentials as high as 200 volts and an alloy of mercury and silver in said envelop.

6. An electrical discharge device comprising an envelop, an electron-emitting cathode, an anode, the interior of said envelop being deprived of gas to such low pressure that positive ionization is substantially absent when normally operating and a substance in said envelop exposed to the evacuated space having a vapor pressure of about six to forty hundred-thousandths of a millimeter of mercury.

7. An electrical discharge device comprising an envelop, an electron-emitting cathode, an anode, the interior of said tube being deprived of gas to such low pressure that positive ionization is substantially absent at impressed terminal potentials of several hundred volts, and an amalgam in said envelop exposed to the evacuated space, said amalgam having a vapor pressure at ordinary temperatures of about .00006 to .0004 millimeters of mercury.

8. The method which consists in producing an electron discharge in a space evacuated to such degree that positive ionization of gas present in said space is absent, supplying to said space gas at a constant pressure too low to cause appreciable ionization but high enough to cause a sudden decrease of electron current when the electrical field near the cathode is increased or decreased by high frequency waves.

In witness whereof, I have hereunto set my hand this 19th day of March, 1914.

WILLIAM C. WHITE.

Witnesses:
BENJAMIN B. HULL,
HELEN ORFORD.