July 17, 1934. A. HUND 1,967,009

SPACE DISCHARGE TUBE CONSTRUCTION

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Fig. 1

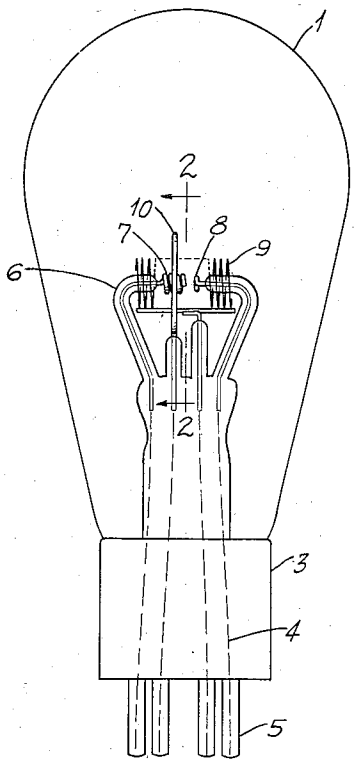


Fig. 3

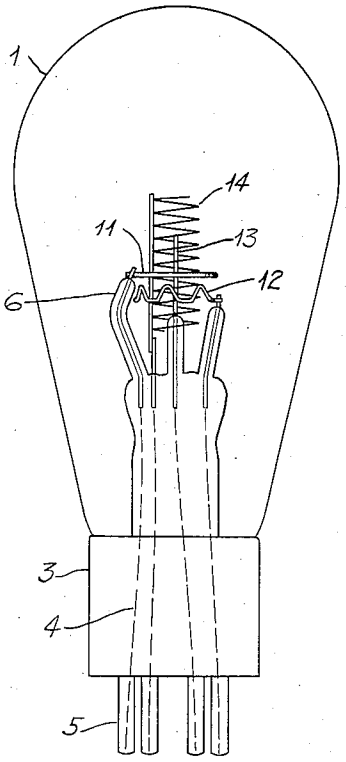


Fig. 2

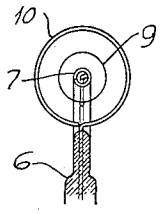
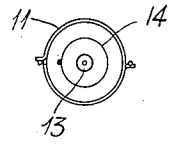


Fig. 4



INVENTOR
August Hund
BY
Wm. J. Herdman
ATTORNEY

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Fig. 7

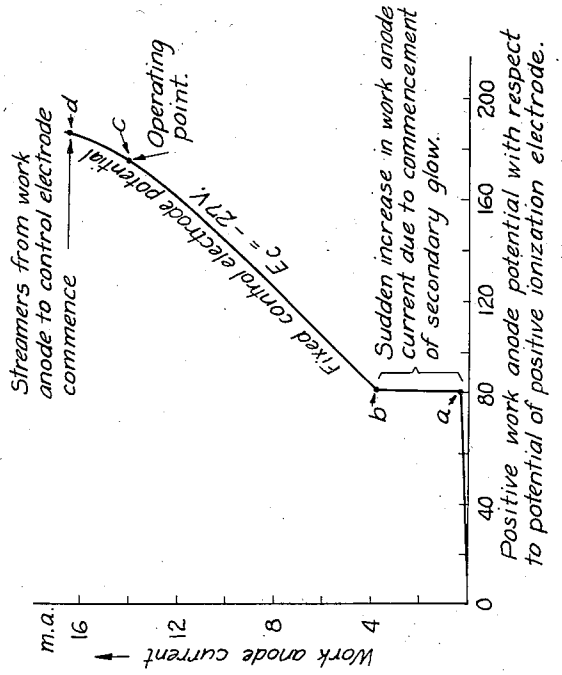


Fig. 5

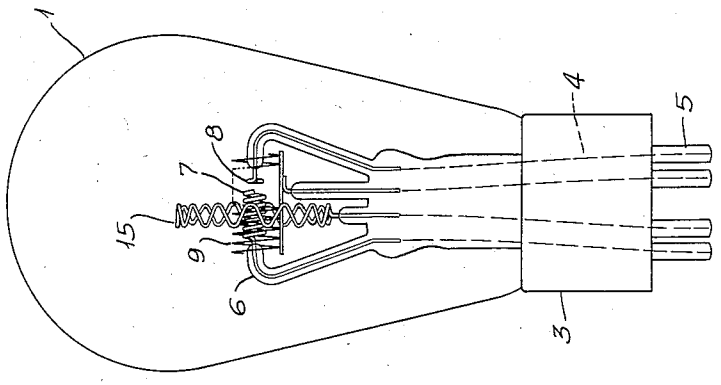
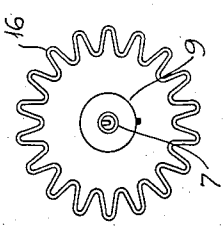


Fig. 6



INVENTOR
August Hund
BY
Wm. J. Herdman
ATTORNEY

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FIG. 8

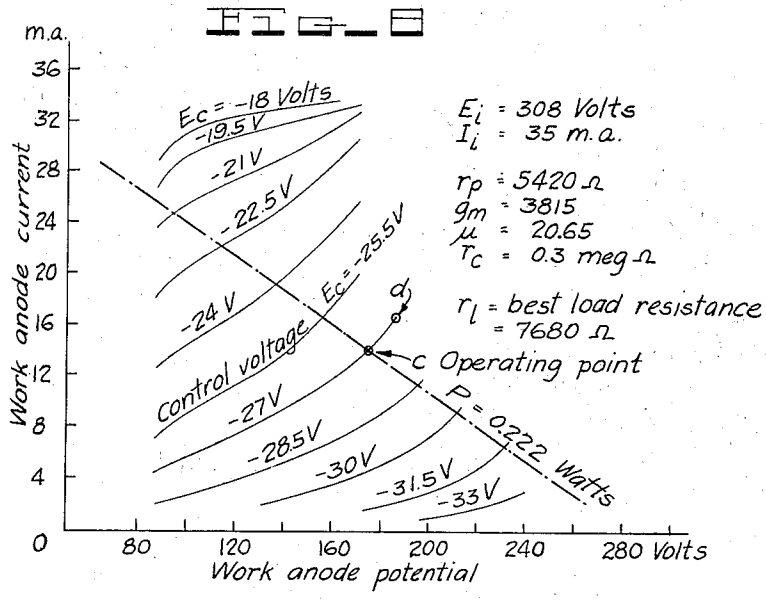
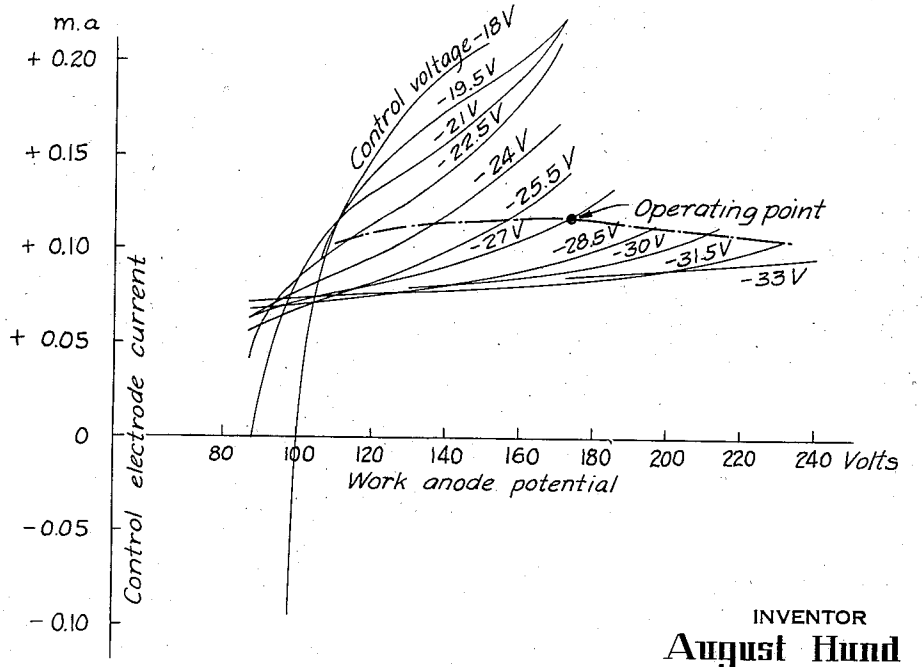


FIG. 9



INVENTOR
August Hund
BY
Wm. J. Herdman
ATTORNEY

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UNITED STATES PATENT OFFICE

1,967,009

SPACE DISCHARGE TUBE CONSTRUCTION

August Hund, West Orange, N. J., assignor to Wired Radio, Inc., New York, N. Y., a corporation of Delaware

Application July 27, 1932, Serial No. 624,920

10 Claims. (Cl. 250—27.5)

This invention relates to glow discharge tubes and has particular reference to the structural details thereof and to the adaptation of such tubes for a wide range of uses in electrical circuits generally.

An object of my invention is to provide a glow discharge tube of this character comprising a plurality of electrodes of conformity suitable to the peculiar manner of activating such tubes.

Another object of my invention is to provide a tube of the class described which functions so as to exhibit a primary and a secondary glow discharge, thereby rendering it suitable in a variety of circuits; for example, as in an oscillator, a detector or an amplifier.

Another object of my invention is to so proportion the respective activated areas of the electrodes and to envelop the electrodes in a suitable gas at a suitably attenuated pressure so that optimum conditions may be obtained for the operation of such tubes.

Another object of my invention is to provide a glow discharge tube of the class described, in which the electrodes are suitably disposed in a medium of attenuated gas or mixture of gases so as to exhibit a high degree of power gain between the input and output circuits of the tube, a minimum wattage consumption being required in the ionizing circuit, as well as in the work circuit.

These and other objects are attained by a novel construction of the glow discharge tube, as will be more fully understood from the following description and by reference to the accompanying drawings, in which:

Fig. 1 depicts in elevation one embodiment of a glow discharge tube having its ionizing electrodes disposed internally of the work electrode system;

Fig. 2 is a sectional view of the electrodes along the line 2—2 of Fig. 1;

Fig. 3 is an alternative embodiment of the glow tubes of my invention showing the ionizing electrodes disposed externally of the work electrode system;

Fig. 4 is a plan view of the electrode system shown in the tube of Fig. 3;

Fig. 5 shows a modified tube somewhat similar to that of Fig. 1, but having a work anode of cylindrically crimped formation;

Fig. 6 shows the work anode crimped in a plane; and

Figs. 7, 8 and 9 are curve diagrams illustrating some of the operating characteristics of one of the glow tubes of my invention.

In my copending application, Serial No. 590,561, filed February 3, 1932, I have shown several forms of space discharge tubes, each having a plurality of not less than four electrodes. In that application it was pointed out that desirable results could be obtained by the employment of two ionization electrodes independent of the other electrodes called work electrodes. The tubes of my invention as herein disclosed, while adapted to function in a similar manner, have certain improvements of structural detail as compared with the tubes of the aforementioned application.

In my copending application, Serial No. 613,710, filed May 26, 1932, one of the uses of a tube of the class herein described and its manner of operation in an oscillator circuit is illustrated. It will be understood, however, that these tubes may be used in a great variety of different circuits for the achievement of new and desirable results.

The herein described tubes may be distinguished from those of my above-mentioned copending application, Serial No. 590,561, in that the electrodes are differently formed and otherwise characterized so as to set up a glow, or secondary ionization, in the region of the work anode, provided a suitable potential is applied to the latter.

My discovery, which resulted from the construction and manner of operation herein shown, appears to go directly contra to previously accepted theories, in that the operating characteristics of glow tubes such as mine are greatly improved when this secondary ionization takes place. In the space between the primary and secondary ionization a control electrode may be suitably disposed so that very considerable space currents passing toward the work anode may be controlled by a very small voltage variation impressed upon the control electrode.

Referring now to Figs. 1 and 2, a glow discharge tube is shown having a suitable envelope 1, and base 3 of well-known type. The several electrodes of the tube are connected by leads 4 with the prongs 5. The leads are suitably insulated as by the glass tubes 6, so as to prevent the possibility of ionization in unwanted regions.

In the embodiment of my invention as shown in Fig. 1, there are provided an ionizing cathode 7 and an ionizing anode 8, each of which consists preferably of one or more convolutions of a simple wire helix. In place of the helix construction, however, it is within the scope of the invention to employ either solid or hollow cylinders or electrodes having other suitable shapes. In general, however, the effective working area of the ionization cathode 7 is usually greater than that of the ionization anode 8. This area rela-

tionship provides the advantage that an excess of negatively charged ions and electrons is available at the ionizing cathode 7 for building up the space current toward the work anode 10. This space current may then be suitably modulated as it passes through the mesh of the control electrode 9, when variations of potential are applied to the latter.

A preferred form of control electrode 9 is that of a simple wire helix. The work anode 10 may, if desired, be a round or flat wire ring and its location is found to be satisfactory when the plane of the ring substantially bisects the working area of the cathode 7.

As shown in Fig. 1, each of the electrodes is of circular formation and they are arranged concentrically with respect to one another.

Referring now to Figs. 3 and 4, the embodiment of my invention as therein shown includes the envelope 1, base 3, leads 4, prongs 5, and insulation tubes 6, the same as described with respect to Fig. 1. In this embodiment, however, I provide an ionizing cathode 11 in the form of a wire ring and an ionizing anode 12 in the form of a crimped ring. These ionizing electrodes are external to the centrally disposed work anode 13 and to the helix-shaped control electrode 14. In the arrangement shown, primary ionization takes place in the region intervening between the ionizing cathode 11 and the ionizing anode 12. This ionization, however, is more or less localized in those regions where the bends in the anode 12 approach the cathode 11. The effective working area of the cathode 11 is, therefore, greater than that of the anode 12 notwithstanding the fact that the two rings have substantially the same diameter and an even greater developed length of wire is used in the anode 12 than in the cathode 11. Due to this construction, therefore, it is possible to set up a stream of negatively charged ions and electrons in the region of primary glow discharge, which stream is centripetally projected through the mesh of the control electrode 14 and toward the centrally disposed work anode 13, where secondary ionization takes place.

The results obtained from the operation of the tube as shown in Figs. 3 and 4 are comparable with those hereinbefore described with respect to Figs. 1 and 2. The operation of both tubes will, therefore, be understood in view of the foregoing description.

Referring now to Fig. 5, a third modification of my invention is shown wherein the ionizing electrodes 7 and 8 are centrally disposed and surrounding them is the control electrode 9, the same as shown in Fig. 1. In this embodiment, however, a crimped formation of the work anode 15 is provided. The zig-zag pattern may be cylindrically crimped as shown in Fig. 5, or, alternatively, it may conform to a plane as in Fig. 6.

In the embodiments of my invention shown in Figs. 1, 2, 5 and 6, primary ionization takes place as before mentioned between the centrally disposed ionizing electrodes, whence streams of negatively charged ions and electrons are centrifugally projected through the mesh of the control electrode and toward the outwardly disposed work anode 10, 15 or 16, as the case may be. Secondary ionization takes place in all cases in the region of the work anode. The operation of the tubes of these modifications is, therefore, similar to that of the tube embodiments previously described.

In order to illustrate some of the operating characteristics of the tubes of my invention, actual values of such characteristics as found for a particular tube are shown in the curve diagrams of Figs. 7, 8 and 9. It will be understood, however, that in carrying out my invention I am in no way limited to the values given, since other tubes made and operated in accordance with my disclosure may exhibit other characteristics widely at variance with these curves.

Referring to the particular tube from which the curves of Figs. 7, 8 and 9 were plotted, the gas within the envelope was nitrogen at a pressure of 24 mm. mercury. Across the ionizing electrodes was a drop of 308 volts with an ionization current of 35 milliamperes. The ionization power was, therefore, only 10.8 watts.

Fig. 7 shows the relation between the work-anode potential and the work-anode current when a bias E_c of -27 volts is impressed upon the control electrode with respect to the potential of the positive ionization electrode. Due to the scale on which the current variations were plotted, the curve appears to start at O and ascends very slightly to the point *a*. Careful measurements, however, showed that, with no external voltage applied between the work anode and the positive ionization electrode, a minute flow of current could be observed which apparently is due to the primary ionization pressure (or spill) towards the work anode. This minute current is comparable in magnitude with that customarily found in thermionic tubes when the plate is directly connected to the filament, i. e., without plate battery. It is of no significance in the ordinary uses of these tubes.

At about 84 volts of work anode potential the current curve jumps suddenly between the points *a* and *b*; that is, approximately from 0.25 to 3.8 m. a. This is due to the commencement of a secondary glow discharge in the region of the work anode.

With further increases in the work-anode potential, the work-anode current increases rapidly up to the point *d*, where a streamer discharge sets in between the work anode and the control electrode. The unstable condition of the tube between *a* and *b*, and again, the streamer discharge above the point *d* determine the useful ranges for operating the tube as an ordinary detector or amplifier. The useful ranges are between *b* and *d*, also between O and *a*. The former is much to be preferred, however, since it is possible to control so much more output power with a given fluctuation of input potential applied to the control electrode.

Where the tube is intended to function as a threshold amplifier or trip relay, the operating characteristic may be swung over the range which straddles the critical points *a* and *b* or else above the point *d*, so that a large current may "trigger off" with very slight variation in the control potential.

Fig. 8 shows a number of curves corresponding with that of Fig. 7, but on an enlarged scale and confined to the normal operating range *b*—*d*. The different curves were obtained under the conditions of control electrode bias as shown. The dot-and-dash line running through the operating point *c* indicates the region in which the best operating conditions prevail. It is near the region of saturation and not far from the region of streamer discharge *d*.

The extraordinary power gain which results from operating these tubes in the manner shown will be better understood when it is considered

that the primary flow of negative ions passing through the mesh of the control electrode is increased many fold by the production of new and additional ions as the stream approaches the work anode. Thus, the current flowing towards the work anode is greatly increased by virtue of the secondary ionization and with no need for a corresponding increase in the input power applied to the control electrode.

As was brought out above, streamers set in at the point d. Beyond this point the control electrode becomes flooded with a streamer glow and the tube can no longer function as an amplifier of voice and carrier currents. Many experiments were therefore carried on to shift the point d as far out on the characteristic as possible.

It may be of interest to note here that success in this direction did not result from attempts to completely surround the control electrode, as by a hollow cylinder. The reason for this was that streamers would be set up between the cylinder wall and the control electrode even when very low voltages were applied between the work anode and the ionization anode. Hence the round wire or flat metal ring shaped work anode 10, or the crimped wire work anode 15 and 16 were found to be preferable, as they tend to move the point d practically into the saturation region, thus providing a very powerful output. Substantially the same advantage also accrues from the use of an axially disposed work anode 13, as shown in Fig. 3. For some purposes, however, the wavy ring construction as shown either in Fig. 5 or Fig. 6 is to be preferred.

Fig. 9 gives curves for the control electrode current in relation to the work anode potential. This diagram, when considered in connection with the curves of Fig. 8, provides the means for computing the dynamic plate resistance r_p, the mutual conductance g_m, the amplification factor μ, and the dynamic input resistance r_c.

The load line may be drawn as shown in Fig. 8, passing through the operating point c, and at such an inclination as to avoid distortion in the amplified output current variations. Furthermore, this load line does not extend beyond the streamer points of the several characteristic curves plotted for different control electrode potentials.

The computations show that the dynamic resistance is as low as 5420 ohms, while the amplification factor μ for this particular tube is as high as 20.65. Hence the mutual conductance g_m is as high as 3815. With some of my tubes it is an easy matter to produce a mutual conductance as high as 10,000. Some of my tubes have an amplification factor μ as high as 70 or 80, the dynamic plate resistance being not greater than 10,000 ohms. With a tube of this type, therefore, a very high degree of power amplification is obtainable, while preserving a very low dynamic plate resistance along with a high dynamic input resistance. A further advantage to be had in these tubes is the avoidance of the necessity for adding another control electrode such as found in the so-called pentode tubes for producing a low output resistance.

I claim:

1. A gaseous discharge tube comprising an ionizing cathode, an ionizing anode the activated surface of which is relatively smaller than that of said cathode an output circuit anode for localizing a glowing ionization discharge in a region other than that in which ionization is produced by said ionizing cathode and anode, and an openly constructed control electrode interposed between the two regions of ionization, said output circuit anode being of a crimped ring formation surrounding said other electrodes.

2. A gaseous discharge tube comprising an ionizing cathode of closely wound helical formation, an ionizing anode the activated surface of which is relatively smaller than that of said cathode, an output circuit anode for localizing a glowing ionization discharge in a region other than that in which ionization is produced by said ionizing cathode and anode, and an openly constructed control electrode interposed between the two regions of ionization.

3. An electrical discharge tube comprising a plurality of electrodes enveloped in an attentuated gas two of said electrodes being suitably positioned for setting up a primary ionization discharge therebetween, an output circuit anode suitably arranged to localize a secondary ionization discharge therebetween and a control electrode interposed between the regions of primary and secondary ionization respectively, said output circuit anode being of crimped ring formation surrounding the other electrodes.

4. An electrical discharge tube comprising a plurality of electrodes enveloped in an attenuated gas, one of said electrodes being an ionizing cathode, another of said electrodes being an ionizing anode, said two electrodes being suitably positioned for setting up a primary ionization discharge therebetween, said ionizing cathode being of closely wound helical formation, a third electrode being suitably arranged to localize a secondary ionization discharge thereabout and a control electrode interposed between the regions of primary and secondary ionization respectively.

5. A gaseous discharge tube comprising a pair of ionizing electrodes, an openly constructed control electrode externally disposed with respect to said ionizing electrodes, and means including an output circuit anode of crimped wire ring formation for localizing a glowing ionizing discharge exterior to said control electrode.

6. A gaseous discharge tube in accordance with claim 5 in which said output circuit anode is crimped so as to conform substantially to a cylindrical surface.

7. A gaseous discharge tube comprising, a pair of ionizing electrodes, an openly constructed control electrode operatively disposed with respect to said ionizing electrodes, and means including an output circuit anode of crimped wire ring formation for localizing a glowing ionizing discharge adjacent said control electrode.

8. A gaseous discharge tube in accordance with claim 7 in which said output circuit anode is crimped so as to conform substantially to a cylindrical surface.

9. A gaseous discharge tube comprising a plurality of electrodes enveloped in an attenuated gas, two of said electrodes being ionizing electrodes and another a control electrode operatively related to said ionizing electrodes and one of said plurality of electrodes being in the form of a crimped ring encircling said control electrode.

10. An electrical discharge tube comprising an envelope containing an attentuated gas, a plurality of electrodes within said envelope between certain of which a space current may be established, a control electrode operatively related to said space current electrodes and one of said plurality of electrodes being in the form of a crimped ring surrounding said control electrode.

AUGUST HUND.