

June 29, 1937.

W. M. GOODALL

2,085,094

GAS-FILLED TUBE CIRCUITS

Original Filed April 27, 1932 2 Sheets-Sheet 1

FIG. 1

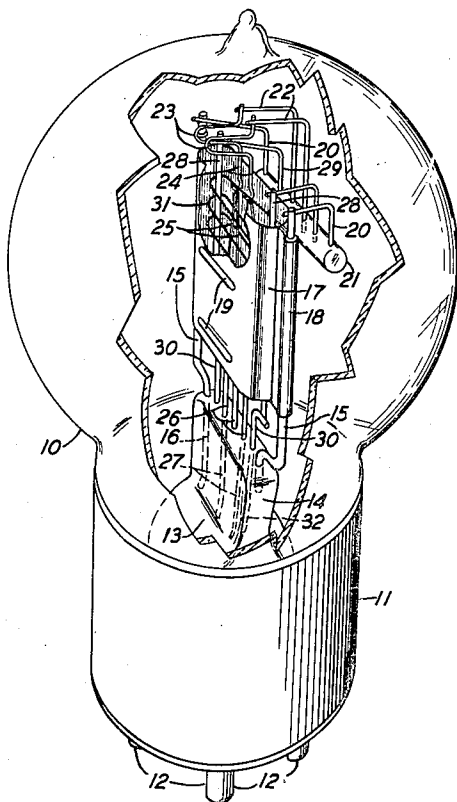


FIG. 2

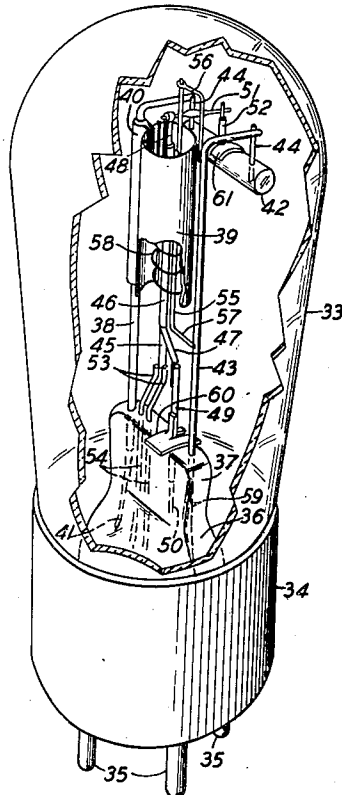


FIG. 3

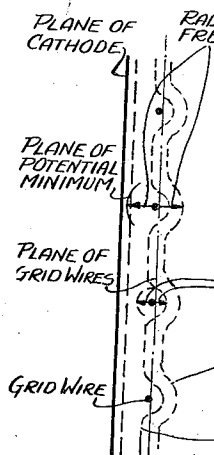
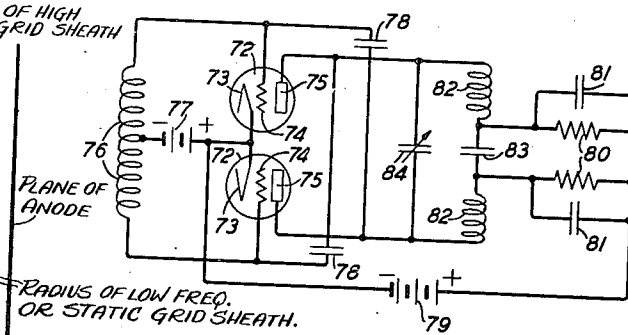


FIG. 5



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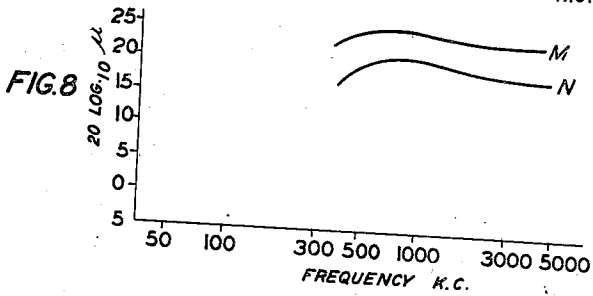
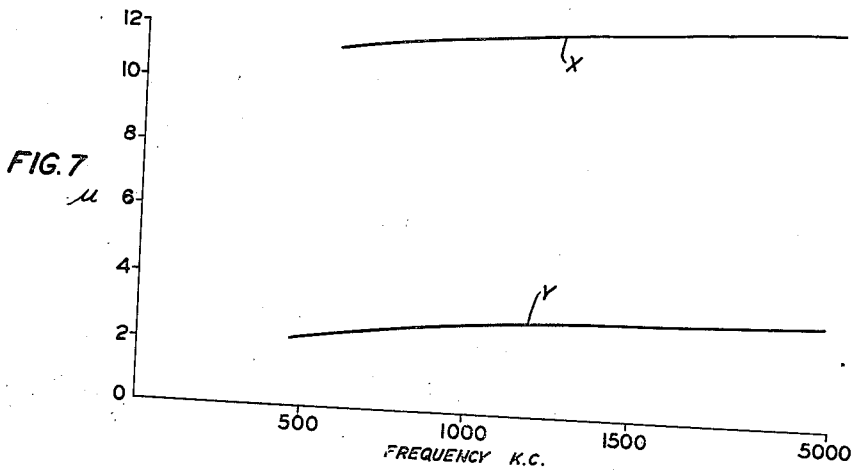
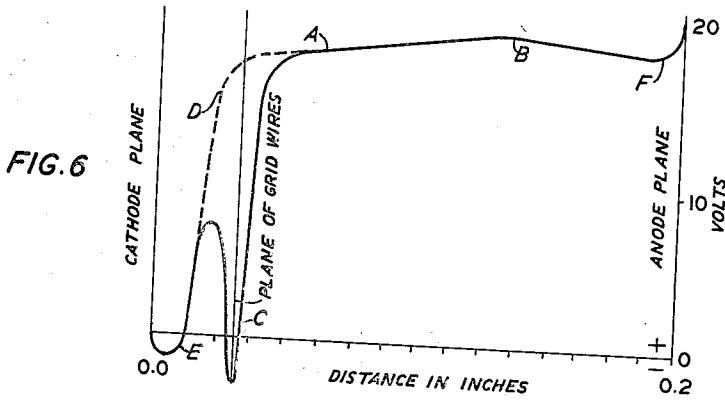
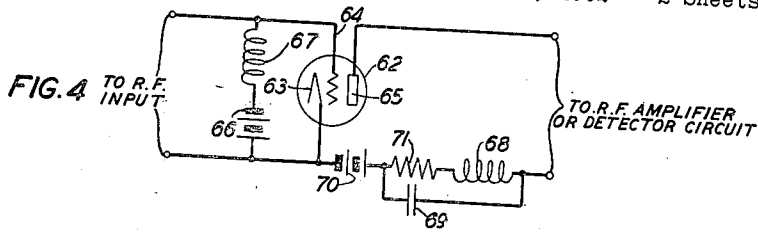
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2 Sheets-Sheet 2



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GAS-FILLED TUBE CIRCUITS

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Original application April 27, 1932, Serial No.
607,679. Divided and this application Febru-
ary 2, 1935, Serial No. 4,601

5 Claims. (Cl. 179—171)

This is a division of my application, Serial No. 607,679, filed April 27, 1932, which has issued as Patent No. 1,998,837.

This invention relates to electric discharge devices and more particularly to such devices adapted for use in radio frequency systems.

An object of this invention is to improve the stability and operating characteristics of electric discharge devices.

In a three-element discharge device comprising an incandescible cathode, a control electrode or grid, an anode, and a filling of a vapor or an inert gas, the operating characteristics, stability and amplification factor of the device are dependent among other factors upon the gas or vapor pressure, the electrode spacing, the emitting characteristics of the cathode, and the structure of the control electrode or grid.

In accordance with this invention, these factors are so correlated that the electric discharge device will be capable of utilization in radio frequency systems and more particularly as an amplifier having a substantially constant amplification factor over a wide range of frequencies and will be stable in operation.

In devices of the type comprehended by this invention when normal voltages are applied to the electrodes, some of the electrons emitted from the cathode generate positive ions by impact with the gas molecules. A portion of the electrons emitted from the cathode remain in the vicinity of the cathode by virtue of their negative charge and form a negative sheath about the cathode. Some of the positive ions generated by impact are drawn to the cathode and form a positive sheath about the electron sheath. A sheath may be defined as the region around an electrode of an electric discharge device in which substantially the whole voltage drop between that electrode and the surrounding media occurs. Some of the positive ions generated by impact are drawn to the grid when a negative potential is applied thereto and form a positive sheath about the grid wires. The total charge on the ions which are attracted to the grid may become of sufficient magnitude to equal the negative charge upon the grid so that a state of equilibrium is established and there is no longer a field adjacent the grid for attracting positive ions. Substantially the entire direct current voltage drop between the grid and the surrounding gas occurs in this grid sheath.

The effect of changing the grid potential, as

for example by an input signal voltage, is to vary the thickness of the grid sheath. When the frequency of the variable signal voltage applied to the grid is low, the thickness of the sheath varies with changes in grid voltage rapidly enough to maintain the condition of equilibrium, and as a result the changes in grid potential are neutralized so that variations in the grid potential have little or no effect upon the space current to the anode. However, at higher frequencies, the ions in the sheath can not move sufficiently rapidly to follow the variations in the grid potential and the grid may then be used to control the space current to the anode, provided the cathode and grid are so disposed that the grid potentials become effective in the field immediately in the vicinity of the cathode.

In accordance with this invention, the cathode and grid are so disposed that the grid and its sheath are on the outer edge or within the cathode ion sheath so that the ion grid sheath will have substantially no effect upon the space current to the anode. The two sheaths about the cathode are of unlike polarity and there is, therefore, a point between the two sheaths at zero potential gradient. When an alternating voltage of high frequency is applied to the grid in a device constructed in accordance with this invention, the ion sheaths of the grid and the cathode coexist or overlap and the grid field becomes effective at the point of zero potential gradient in the field adjacent the cathode, and a change corresponding to the variable voltage applied to the grid occurs in the space current to the anode. The ion grid current is substantially independent of high frequency changes in the grid potential.

Since electric discharge devices in accordance with this invention require the presence of positive ions for their operation, it is essential that the arc should be stable. Accordingly, the spacing of the grid wires should be such that the grid field cannot entirely block the space current even if the grid is highly negative. This may be accomplished by spacing the grid wires a distance greater than the cathode-grid spacing and extending the cathode beyond the ends of the grid. This arrangement provides a high grid-cathode impedance when the grid is biased negatively so that the electron grid current is small at all times and a high operating efficiency is obtained.

The invention will be understood more clearly from the following detailed description with reference to the accompanying drawings, in which:

Fig. 1 is an elevational view in perspective of an electric discharge device constructed in accordance with this invention with a portion of the enclosing vessel and of the anode broken away to show the inner electrodes more clearly;

Fig. 2 is a perspective view of another embodiment of this invention with portions broken away to show details of construction more clearly;

Fig. 3 is a diagrammatic view showing the space relation of the electrodes in an electric discharge device and illustrating the overlapping grid and cathode dynamic sheaths for applied alternating voltage of high frequency in accordance with this invention;

Fig. 4 is a schematic view showing a general circuit incorporating an electric discharge device of the type comprehended by this invention;

Fig. 5 is a schematic view of an oscillator circuit incorporating discharge devices in accordance with this invention;

Fig. 6 represents the potential distribution curve in electric discharge devices of the construction shown in Figs. 1 and 2; and

Figs. 7 and 8 illustrate graphically operating characteristics of electric discharge devices made in accordance with this invention.

Referring now in particular to Fig. 1 of the drawings, an electric discharge device in accordance with this invention comprises an enclosing vessel 10 suitably secured to an insulating base 11 provided with terminal prongs 12 for associating the device with an external circuit. The vessel 10 has a reentrant stem 13 terminating in a press 14 from which the electrodes of the device are mounted. A plurality of rigid bent rods 15 having parallel rectilinear portions extending lengthwise of the vessel 10 are embedded in the press 14 and support a flattened cylindrical anode 17. One of the rods 15 is connected to a terminal prong 12 by a leading-in wire 16. The anode may comprise a plurality of similar juxtaposed sections of carbonized molybdenum having integral flanges 18 secured to the rectilinear portions of the rods 15, and provided with embossments or corrugations 19 for preventing distortion of the anode by temperature variations during the operation of the device. A plurality of angular or bent supports 20 extend from the ends of the rods 15 and are embedded in an insulating block or bead 21. A plurality of rigid L-shaped rods or wires 22 are embedded in bead 21 and support flexible U-shaped members 23 which are provided with hook members 24. An M-shaped filamentary cathode 25 capable of emitting electrons when heated is suspended between the hook members 24 and a plurality of rigid wire stubs 26 embedded in the press 14, the two outer stubs 26 being connected to certain of the terminal prongs 12 by leading-in wires 27 sealed in press 14. A pair of parallel rectilinear rods 28 are supported between angular wires 29 extending from the insulating block or bead 21 and rigid bent stubs 30 embedded in the press 14, and carry a helical wire control electrode or grid 31, which is disposed about the cathode 25 and which substantially conforms in contour to the inner surface of the anode 17. The control electrode or grid 31 is electrically associated with one of the terminal prongs 12 by a leading-in wire 32 connected to one of the stubs 30 and sealed in the stem 13.

The vessel 10 is provided with an ionizable atmosphere of gas or vapor at low pressure, the gas or vapor and pressure being such that the

ionization potential is below the critical value at which disintegration of the cathode will be effected by positive ion bombardment. For example, the critical voltage for oxide coated cathodes is between 20 and 30 volts and suitable gases or vapors for devices embodying such cathodes are argon at a pressure of the order .25 millimeter of mercury and mercury vapor at a pressure corresponding to room temperature. The ionization potential of argon is approximately 15.65 volts and the ionization potential of mercury is approximately 10.4 volts.

In another embodiment of this invention, an electric discharge device as shown in Fig. 2, comprises an enclosing vessel 33 suitably mounted upon an insulating base 34 which carries terminal prongs 35 for associating the device with an external circuit. The vessel 33 is provided with a re-entrant stem 36 terminating in a press 37 from which the several electrodes of the device 20 are mounted. An inverted L-shaped rod or wire 38 extends from the press and supports a hollow cylindrical anode 39 having an integral flange portion 40 secured to the rod or wire 38. The anode 39 is electrically connected with one of the terminal prongs 35 by a leading-in wire 41 extending between the rod 38 and one of the terminal prongs 35 and sealed in the press 37. A rod or wire 43 similar to rod 38 extends from the press 37 and supports an insulating block or bead 42 by rigid short stubs 44 embedded in the block or bead 42 and attached to the free ends of the rods or wires 38 and 43. A cylindrical equi-potential cathode is disposed axially with respect to the anode 39 and comprises a quartz rod 45 having a heater element, not shown, therein and a metallic sleeve 46 crimped about the rod 45. The sleeve 46 is coated with a material, such as barium and strontium oxides, having high electron emission characteristics when heated, and is provided with integral extensions 47, 48. The extension 47 is secured to a short wire 49 which is embedded in the press 37 and connected with one of the terminal prongs 35 by a leading-in conductor 50. The extension 48 is attached to a flexible support 51 mounted on the insulating block or bead 42 by a rigid stub 52. The heating current for the heater element is supplied through conductors 53 extending from the press 37 and electrically connected to certain of the terminal prongs 35 by leading-in wires 54 sealed in the press. A rigid linear wire 55 is supported from the rod or wire 43 by connecting members 56 and 57 and carries a helical wire control electrode or grid 58 which is concentrically disposed between the cathode 46 and the anode 39. The control electrode or grid 58 is electrically connected to one of the terminal prongs 35 through the rod or wire 43 and a leading-in conductor 59 sealed in the press 37. A shield or screen 60 is mounted adjacent the press 37 upon the short wire 49 to prevent the formation of a leakage path upon the press 37 between the wires 43 and 49 by the deposition of the cathode material. Another shield or screen 61 is mounted adjacent the insulating block or bead 42 upon the stub 52 to prevent the formation of a leakage path between the stubs 44 and 52. The enclosing vessel is provided with a suitable gas or vapor filling at an appropriate pressure as described in the embodiment of this invention shown in Fig. 1.

One form of circuit arrangement including an electric discharge device of the type comprehended by this invention is illustrated schemati-

cally in Fig. 4, in which such an electric discharge device is generally designated as 62. The device includes a cathode 63, a control electrode or grid 64, and an anode 65. The input signal 5 is applied between the cathode 63 and control electrode or grid 64, suitable means such as a battery 66 and series inductance 67 being provided for applying a desired biasing potential to the grid 64. The cathode 63 and anode 65 10 are connected to a suitable load, as a detector or radio frequency amplifier circuit, through a tuning circuit including a high impedance choke 68 and shunt capacity 69. A battery 70 and limiting resistance 71 are also provided in the circuit, 15 and are so proportioned that the potential between the cathode and anode will be below the critical potential for the particular gas or vapor forming the ionizable atmosphere within the device. For example, if the device embodies an at- 20 mosphere of argon at a pressure of the order of .25 millimeter of mercury, the critical potential is between 20 and 30 volts, so that the battery 70 and resistance 71 should be adjusted accordingly, that is, the potential applied between 25 the anode and cathode terminals should be of the order of 20 volts and the resistance should be sufficiently large to keep the emission current of the cathode below saturation value.

In accordance with a feature of this invention 30 the various factors determining the operating characteristics of electric discharge devices are so correlated that such devices will have substantially constant amplification factors over a wide range of high frequencies and will be 35 capable of stable operation. This feature will be understood more clearly from the following exposition of the ionic field conditions between the electrodes of devices of the type comprehended by this invention, with negative grid bias 40 and a suitable voltage below the critical potential, applied between the cathode and anode, reference being had particularly to Fig. 6 of the drawings.

Under the conditions noted, when the cathode 45 is heated to incandescence, electrons are emitted from the surface of the cathode and are projected toward the grid. However, with normal voltages between the anode and cathode of the device, if the negative bias upon the grid is of 50 sufficient magnitude, the number of electrons which will reach the grid due to their initial velocities, is substantially negligible. The flow of electrons toward the grid causes the generation of 55 positive ions by impact with the gas molecules within the space between the cathode and grid and because of the negative grid bias some of the positive ions will be attracted to the grid and will form a positive sheath about the grid wires. 60 Simultaneously, a negative field or sheath of electrons will be formed about the cathode and some of the ions generated by impact are drawn toward the cathode and form a positive ion sheath about the electron sheath, which partially re- 65 duces the space charge effect, i. e. the effect of the negative sheath about the cathode, and thereby allows more electrons to leave the vicinity of the cathode.

Since the positive ions generated by impact of 70 electrons with gas molecules are much heavier than the electrons, they will move much slower than the electrons, the velocities being approximately in the inverse ratio of the square root of the masses. That is, if the masses of an ion and 75

an electron are designated by M and m , respectively, the electron will move approximately

$$\sqrt{\frac{M}{m}}$$

times as far as the ion in a given interval of time. Hence, in an electric discharge device of the type described, the electrons will be activated by potentials extant between the electrodes of the device before the ions have had time to move appreciably, and under the proper conditions the 10 grid field may be utilized, therefore, to control the space current to the anode.

In order to secure an amplification effect in an electric discharge device in accordance with 15 this invention the grid should be located in immediate proximity to the cathode and preferably within the region of the cathode drop, i. e., within the cathode sheath. The thickness of this sheath may be ascertained in the manner described hereinafter. 20

For a space discharge device employing an anode and a cathode the ratio of the current densities of the electrons and positive ions at the outer edge of the cathode sheath, as determined 25 by Langmuir (see Phys. Rev., June 1929, pp. 954-989) is represented by the equation

$$\frac{I_e}{I_p} = \sqrt{\frac{m_p}{m_e}} \quad (1) \quad 30$$

where

I_e =electron current density
 I_p =positive ion current density
 m_e =mass of an electron 35
 m_p =mass of a positive ion

This equation is true provided the total emission current is not being drawn from the cathode. As pointed out hereinbefore this condition is met by the proper proportioning of the anode potential 40 and the resistance in the anode-cathode circuit.

Substantially all of the anode current is an electron current and for practical purposes, therefore, the electron current density at the 45 outer edge of the cathode sheath is

$$I_e = \frac{i_a}{A} \quad (2)$$

where

A =area of the outer edge of the cathode sheath 50
 i_a =total anode current

From Equations (1) and (2) it follows that

$$I_p = \frac{i_a}{A} \sqrt{\frac{m_e}{m_p}} \quad (3) \quad 55$$

As set forth in the aforementioned article by Langmuir the thickness of the cathode sheath, assuming the sheath to be composed solely of 60 either electrons or positive ions, in a device having parallel plane electrodes, may be ascertained from the equation

$$I = \frac{1}{9\pi} \left(\frac{2e}{m} \right)^{1/2} \frac{V^{3/2}}{a_0^2} \quad (4) \quad 65$$

where

I =space current density
 e =charge of an electron or ion 70
 m =mass of an electron or ion
 V =potential drop in the cathode sheath
 a_0 =thickness of the cathode sheath

In the case of a double sheath or region, as also noted by Langmuir, the thickness of the region 75

a , when the total emission current is not being drawn to the anode, is given by

$$a = 1.364a_0 \quad (5)$$

By substituting the value of a as given in Equation (5) for a_0 in Equation (4) and solving for the ion current density

$$I_p = \frac{V_a^{3/2}}{9\pi} \left(\frac{2e}{m_p} \right)^{3/2} \left(\frac{1.364}{a} \right)^2 \quad (6)$$

where V_a is the voltage drop in the double sheath. As shown in Fig. 6, V_a is substantially equal to the total voltage drop between the anode and cathode since in devices of the type comprehended by this invention (for which the curves of Fig. 6 are typical) substantially the whole voltage drop occurs in the cathode regions.

Solving Equations (3) and (6) simultaneously

$$a^2 = \frac{.186V_a^{3/2}e^{3/2}A}{m_p\sqrt{m_e}i_a} \quad (7)$$

In a device such as shown in Fig. 2, having concentric cylindrical electrodes,

$$I_p = \frac{2}{9} \sqrt{\frac{2e}{m_p}} \frac{V_a^{3/2}}{r\beta_0^2} \quad (8)$$

where r = radius of the cathode

$$\beta_0^2 = \text{a function of } \frac{a_0}{r}$$

$a = 1.364a_0$ as before

and the remaining characters have the same significance as in Equations (1) and (6).

Values for β_0 may be obtained from table such as given by Langmuir and Blodgett in Phys. Rev. v. 22 (1923) p. 347. a may be obtained from Equations (3) and (8) since

$$A = 2\pi al \quad (9)$$

where l = length of the cathode.

As mentioned previously the values of a as calculated above are for devices having only a cathode and an anode. In a three-electrode device, i. e., where a grid is positioned between the cathode and the anode, if the grid-cathode spacing is less than a as calculated above, the grid will collect some of the positive ions and hence will reduce the effective positive ion current density as given by Equation (3). This in effect enlarges the thickness a of the cathode sheath. Thus the grid may be spaced from the cathode a distance, say a' , somewhat greater than a as calculated in accordance with the equations given hereinbefore and still be within the cathode region.

The maximum value of a' may be approximated in the following manner. Since the grid is operated at a negative potential with respect to the cathode it will collect at least the same density of positive ion current as the cathode. The ion current density to the cathode will therefore be less than that given by Equation (3) multiplied by the ratio of the areas of the cathode and the grid. If this ratio is designated by θ

$$I_p' = \theta I_p = \frac{\theta}{A} i_a \sqrt{\frac{m_e}{m_p}} \quad (10)$$

The values of a' may then be obtained by solving Equations (7) and (10) for the case of parallel plane electrodes and Equations (8) and (10) for the case of concentric circular electrodes.

The equations given hereinbefore are but approximations since they fail to take into account the initial velocities of the ions and of the elec-

trons. However, the values obtained for a and a' by the equations are sufficiently accurate for practical purposes.

The major portion of the space between the cathode positive sheath and the anode, or the plasma, is composed of free positive ions and electrons substantially in equilibrium and the potential gradient in the plasma is very small. This will be evident from Fig. 6 in which the portion of the curve between points A and B denotes the potential distribution in the plasma. The pronounced dip C in the curve indicates the potential distribution through the grid wires and, as is noted, is substantially symmetrical about the abscissa corresponding to the plane of the grid wires. The dotted portion D of the characteristic curve illustrates the potential distribution in the space between the grid wires.

As noted hereinbefore the field immediately adjacent the cathode includes an inner electron sheath and an outer positive ion sheath. Since the sheaths are of opposite polarities, there is a point in the field about the cathode at which the potential gradient is substantially zero. This is indicated at E on the characteristic curve in Fig. 6. The portion F of the characteristic curve immediately adjacent the anode signifies a negative anode drop which results from the fact that the current density of the electron current flowing to the anode is smaller than the electron current density in the plasma near the anode.

It is evident from Fig. 6 that substantially the entire voltage drop between the grid and the surrounding atmosphere occurs immediately adjacent the grid wires, i. e. in the sheath adjacent the grid, and that the drop across the tube is substantially equal to the drop in the cathode region.

If a signal voltage of low frequency is applied between the cathode and the grid in a circuit such, for example, as shown in Fig. 4, the thickness of the grid sheath varies with changes in grid potential and the state of equilibrium adjacent the grid is maintained. The only effect of changing the grid potential, therefore, is to vary the thickness of the grid sheath and since, as has been noted hereinbefore, the entire voltage drop adjacent grid wires occurs in the grid sheath, the grid potential will have no effect upon the space current between the cathode and the anode. However, at higher frequencies the positive ions, because of their mass, cannot follow the changes in grid potential so that the field about the grid is not maintained in equilibrium and the grid potential may be utilized to control the space current to the anode, provided that the grid and cathode are so disposed that under normal operating conditions the grid potential will become effective at a point in the field adjacent the cathode.

The necessary conditions may be attained in one way in accordance with this invention by locating the grid close to the cathode so that the grid and its sheath for normal negative grid bias and anode-cathode potentials are on the outer edge of or within the cathode region as illustrated diagrammatically in Fig. 3. The grid sheath will have substantially no effect upon the space current to the anode. When an alternating potential of high frequency is applied between the cathode and the grid, for example, as illustrated in Fig. 4, the ions in the cathode and grid sheaths, because of their mass, will not move appreciably and hence cannot neutralize the effect of the high frequency grid field. On the

other hand if a low frequency voltage were applied to the grid the positive ions could move fast enough to neutralize the change in the grid field and thus would prevent a change in anode current.

The extent of the grid sheath is different for the positive and negative parts of the cycle of the high frequency potential applied to the grid. At all times, the grid is surrounded by a positive sheath due to its negative bias. On the negative half of the cycle, electrons will be repelled by the grid and a large positive sheath will form about the grid and cathode. On the positive half of the cycle, electrons will be attracted to the grid. Thus, the grid sheath for the positive half of the cycle will be much smaller than for the negative half. It is preferable, therefore, that the cathode and grid should be disposed as close together as is structurally and mechanically feasible in order that the sheaths of the cathode and grid will overlap over a large portion of each half cycle of signal voltage applied to the grid so that stable operation and a high degree of amplification with small distortion may be obtained.

Since electric discharge devices of the type described hereinabove in accordance with this invention, require the presence of positive ions for operation, it is desirable for efficient and satisfactory utilization that the ion current be stable. For this reason the spacing of the grid wires should be such that the grid field due to the negative bias upon the grid cannot entirely block the space current to the anode. A satisfactory grid construction for devices of the form shown in Figs. 1 and 2 is obtained by spacing successive grid wires a distance greater than the grid-cathode spacing and preferably several times the distance between the cathode and the grid, for example, between two and three times the cathode-grid spacing as illustrated diagrammatically in Fig. 3, and/or by extending the cathode beyond the ends of the grid. This construction insures a stable arc and further provides a high grid-cathode impedance so that the input current to the grid is small and a high operating efficiency is obtained for the device.

Furthermore, as indicated in Fig. 3, the anode should be positioned remote from the cathode in order that the grid-anode and cathode-anode capacities will be small to prevent feed-back effects.

In order that devices of the type shown in Figs. 1 and 2 may operate with a minimum of distortion, it is desirable that the amplitude of the signal voltage applied between the cathode and grid should be small and that the initial space current to the anode should be limited, for example, by a resistance 71 as shown in Fig. 4, to prevent the flowing of a saturation current between the cathode and the anode. The cathode should, of course, have such characteristics that the cathode emission will be sufficient to carry the peak anode current without any cut-off or saturation effects.

It has been found that in a device such as described in accordance with this invention, the amplification factor is substantially constant over a wide range of high frequencies. This is indicated graphically in Fig. 7 in which the curve X illustrates the amplification characteristic of a device of the general construction shown in Fig. 1, having a filling of argon at a pressure of 0.25 millimeter of mercury, and curve Y shows the characteristics of a similar device of the general

construction shown in Fig. 1, but in which the grid-cathode spacing is less than that in the device corresponding to curve X.

Although the curves shown in Fig. 7 extend up to about 5000 kilocycles it has been found that devices constructed in accordance with this invention will operate satisfactorily for frequencies up to 40,000 kilocycles.

In a device of a given structure and embodying a gas at a certain pressure, the amplification factor is greater for lower anode currents, since at the lower currents fewer ions are generated by impact and as a consequence the static and dynamic sheaths of the grid are large. This is illustrated in Fig. 8 in which curves M and N show the amplification characteristics of devices of the general form shown in Fig. 1, the space current to the anode corresponding to curve N being substantially twice that corresponding to curve M. A decrease in the space current or in the gas pressure, furthermore, increases the anode impedance. By proper choice of the several factors involved, an electric discharge device may be constructed having a desired amplification factor and anode impedance. However, the gas pressure and space current may not be decreased below a minimum value necessary for the maintenance of a stable arc.

A circuit arrangement in which discharge devices in accordance with this invention may be used as an oscillator is shown in Fig. 5 in which the devices are generally designated as 72, each having a cathode 73, a grid 74, and an anode 75. An inductance 76 is connected between the grids 74 as shown. A resistance may be substituted for the inductance 76. A suitable grid bias is provided by a source such as a battery 77. Suitable coupling or feed-back condensers 78 are connected between the grid of one device and the anode of the other device as shown. An appropriate potential is applied between the cathode 73 and the anode 75 of each device by a source such as a battery 79 through resistance 80 which, as noted hereinbefore, should be of sufficient magnitude to prevent the flow of saturation current to the anodes. Each of the resistances 80 is shunted by a condenser 81. A tuning circuit is provided between the anodes 75 and includes inductances 82 in series with a condenser 83, which has a very low resistance component, and a variable condenser 84 placed in shunt with the inductances 82 and condenser 83.

In a specific embodiment of this invention, an electron discharge device of the general form shown in Fig. 1 may comprise an enclosing vessel having a filling of argon at a pressure of .25 millimeter of mercury. The cathode 46 may be of nickel wire coated with barium and strontium oxides. The grid may be of nickel, or molybdenum preferably carbonized to reduce secondary emission, and may be spaced from the cathode .04 inch. The spacing of adjacent convolutions of the grid should be at least .06 of an inch. The anode may be of carbonized nickel or molybdenum and may be spaced from the cathode 0.19 of an inch. The voltage applied between the cathode and anode, such as by battery 70 as shown in Fig. 4, should be of the order of 20 to 30 volts, and the limiting resistance, such as 71 in Fig. 4, should be of such magnitude that the direct space current to the anode is of the order of 10 to 20 milliamperes.

Although the invention has been described with particular reference to devices having an incandescent cathode, it is equally applicable to elec-

tric discharge devices of the cold cathode type. Moreover, the structures described and the specific values given are to be understood as merely illustrative of the invention and modifications may be made therein without departing from the spirit and scope of this invention as defined in the appended claims.

What is claimed is:

1. In combination, an electric discharge device comprising a vessel enclosing an incandescible cathode, an anode, a control electrode and a gas of such nature and at such pressure that the ionization potential thereof is less than that critical value at which disintegration of said cathode will be effected by positive ion bombardment, an input circuit including said cathode and said control electrode, an output circuit including said cathode and said anode, means for applying between said cathode and said anode a potential difference which exceeds the ionization potential of said gas, resistance means in said output circuit limiting the current through said device to a value less than the temperature saturation current of said cathode, said cathode and said control electrode being relatively positioned in said vessel so that their dynamic sheaths overlap when alternating current waves of high frequency are impressed on said input circuit and means for impressing alternating current waves of high frequency on said input circuit.
2. A circuit for amplifying alternating current waves of high frequency, comprising an electric discharge device consisting of a vessel enclosing an incandescible cathode, an anode, a control electrode and a gas of such nature and at such pressure that its ionization potential is less than that critical value at which disintegration of said cathode will be effected by positive ion bombardment, an input circuit connected to said cathode and said control electrode, an output circuit connected to said cathode and said anode, means negatively biasing said control electrode with respect to said cathode, means applying a potential difference between said cathode and said anode which exceeds the ionization potential of said gas, resistance means in said output circuit limiting the current through said device to a value less than the temperature saturation current of said cathode, the cathode and control electrode being relatively positioned in said vessel so that their dynamic sheaths overlap when alternating current waves of high frequency are impressed on said input circuit and means for impressing alternating current waves of the high frequency to be amplified on said input circuit.
3. In combination, a source of alternating current waves of high frequency, a high frequency amplifying circuit comprising an electric discharge device consisting of a vessel enclosing a cathode, a plate electrode, a control grid therebetween and a gas of such nature and at such pressure that its ionization potential is below that critical value at which disintegration of said cathode will be effected by positive ion bombardment, an input circuit including said cathode and said control grid, to which said source is

coupled, an output circuit including said plate electrode and said cathode, a load circuit coupled to said output circuit, said output circuit comprising in series a plate battery, a limiting resistance and a tuning circuit including a high impedance choke coil and a shunt capacity, said plate battery and said resistance being so proportioned that the potential difference between said cathode and said plate electrode will be below said critical value for said gas, said cathode and said control grid being located sufficiently close to each other so that the dynamic ion sheaths of said cathode and said control grid overlap when alternating current waves of said high frequency are impressed on said input circuit by said source.

4. A wave amplifier having a substantially constant amplification factor over a wide range of high frequencies above 500 kilocycles per second, comprising an electric discharge device consisting of a vessel enclosing an incandescible cathode, an anode, a grid therebetween and argon gas at a pressure of approximately 0.25 millimeter of mercury, an input circuit including said cathode and said grid, on which said waves of high frequency are impressed, an output circuit including said anode and said cathode, means negatively biasing said grid with respect to said cathode, said output comprising in series a plate battery, a limiting resistance and a tuning circuit comprising a high impedance choke coil and a shunting capacity having a low impedance to said high frequencies, the voltage applied by said plate battery between said cathode and anode being of the order of 20 to 30 volts, said limiting resistance being of such magnitude that the direct current space current to the anode is of the order of 10 to 20 milliamperes, and said grid being sufficiently close to the cathode that their dynamic ion sheaths overlap when alternating current waves of said high frequencies are impressed by said source on said input circuit.

5. In combination, an electric discharge device consisting of a vessel enclosing a cathode, an anode and an apertured control electrode spaced from each other, and an ionizable medium, the smallest dimension of each aperture in the control electrode being greater than the spacing between said cathode and said control electrode, an input circuit for said device including said cathode and said control electrode, an output circuit for said device including said cathode and said anode, means for applying between said cathode and said anode a potential difference which exceeds the ionization potential of said medium, means for limiting the current through said device to a value less than the temperature saturation current of the cathode, said cathode and said control electrode being relatively positioned in said vessel so that their dynamic sheaths overlap when alternating current waves of high frequency are impressed on said circuit, and means for impressing alternating current waves of high frequency on said input circuit.

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