

Jan. 19, 1943.

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2,308,523

ELECTRON DISCHARGE DEVICE

Filed Feb. 17, 1940

3 Sheets-Sheet 1

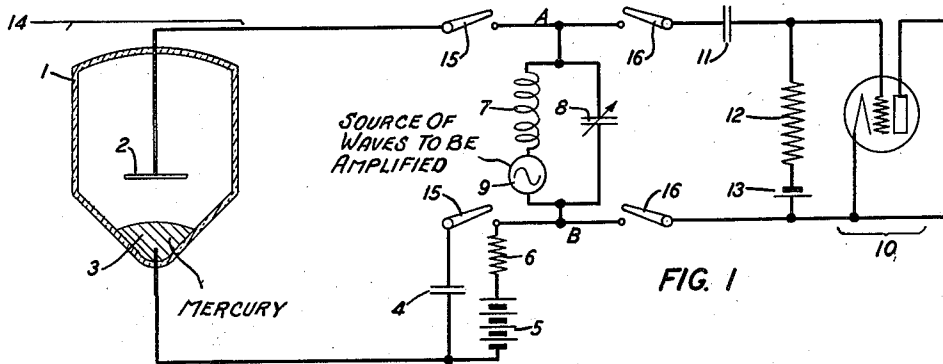


FIG. 1

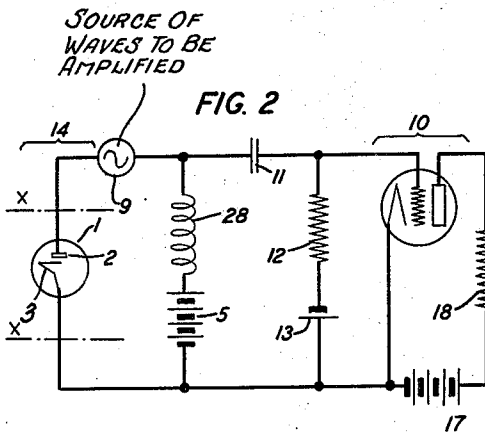


FIG. 2

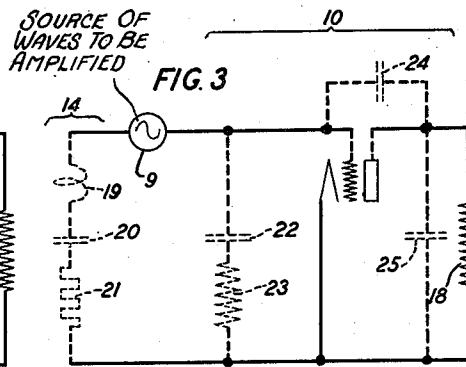


FIG. 3

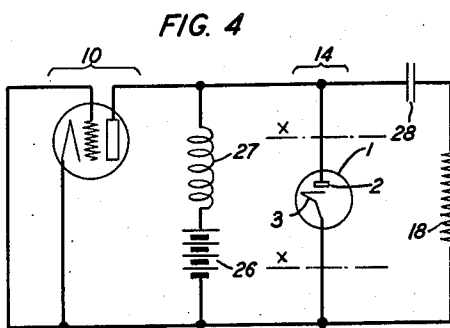


FIG. 4

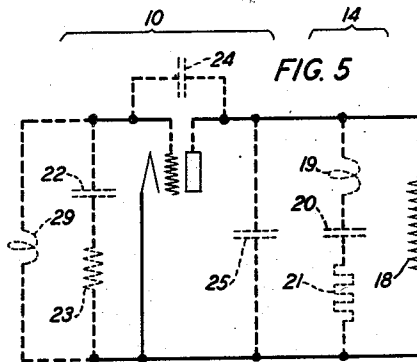


FIG. 5

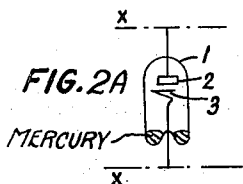


FIG. 2A

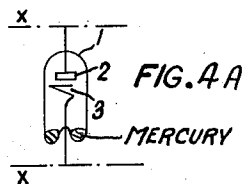


FIG. 4A

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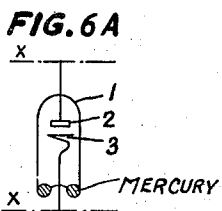
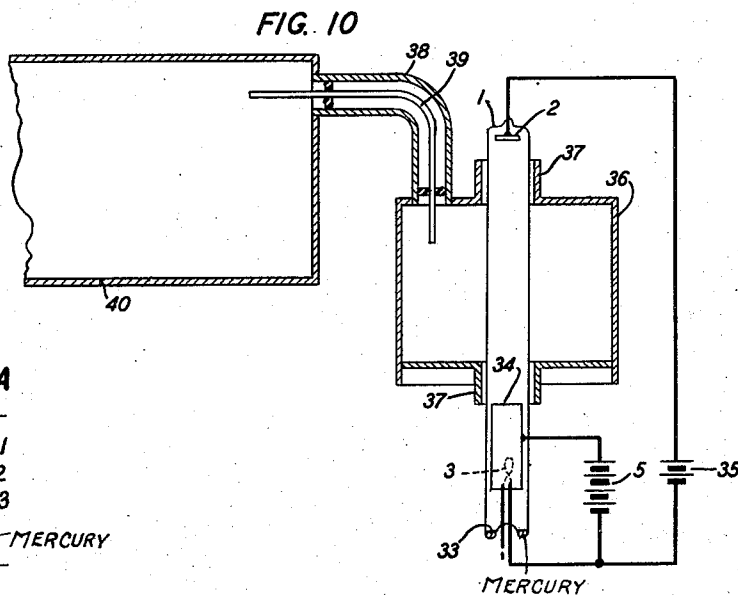
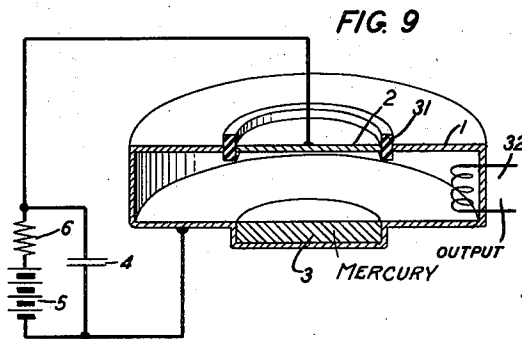
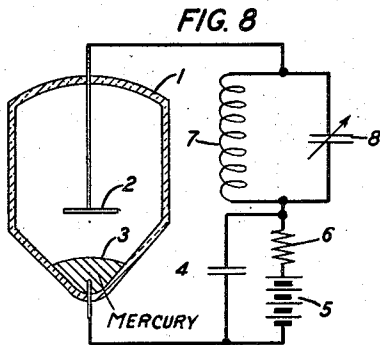
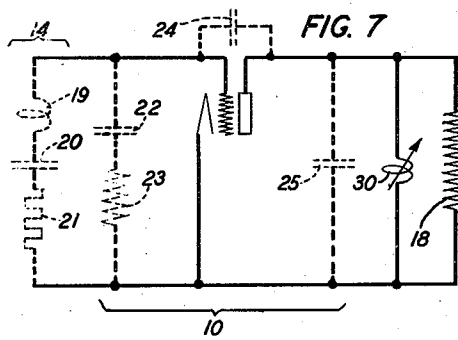
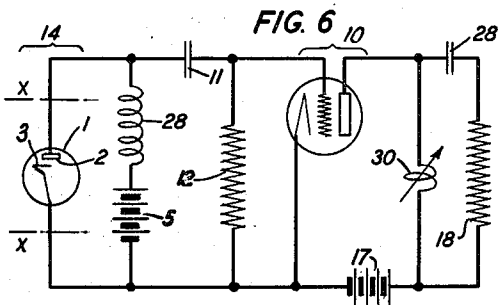
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3 Sheets-Sheet 2



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3 Sheets-Sheet 3

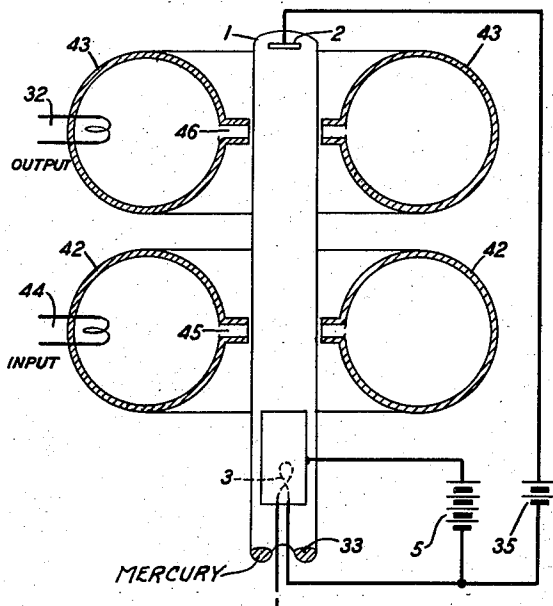


FIG. 12

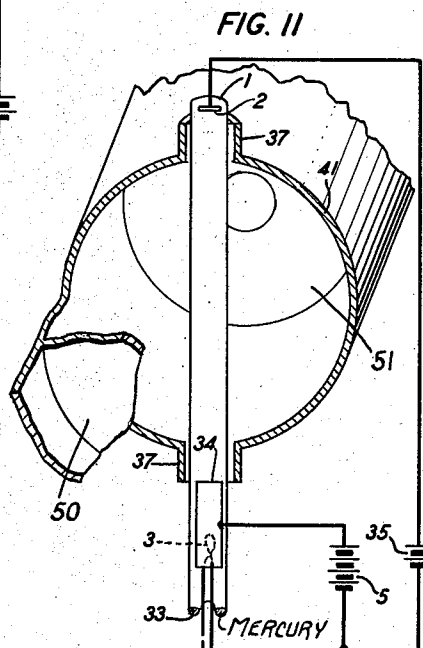


FIG. 11

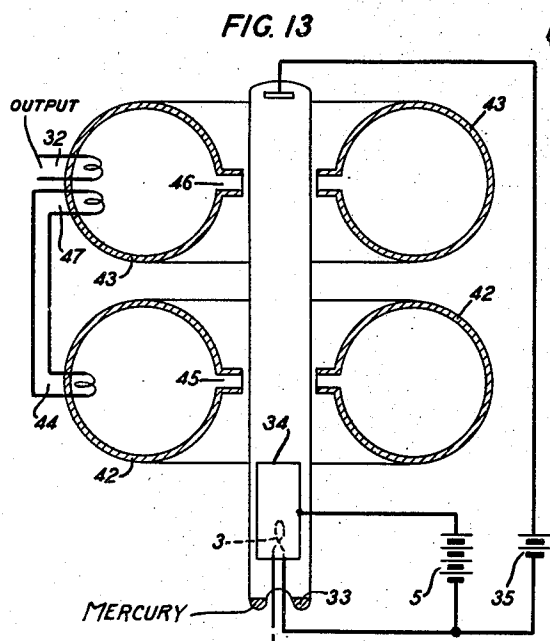


FIG. 13

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ELECTRON DISCHARGE DEVICE

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Application February 17, 1940, Serial No. 319,414

9 Claims. (Cl. 250—36)

This invention relates to high frequency systems employing electron discharge devices characterized by critical transit times.

An object of the invention is to utilize a two-element tube having a critical electron transit time as a component of a resonant circuit.

Another object of the invention is to take advantage in a discharge system having a critical transit time of the increased electron flow obtainable with an atmosphere of gas or ionizable vapor.

An additional object of the invention is to increase the effective electron stream in apparatus employing electron velocity modulation or generally where use is made of the reaction between moving electrons and an electromagnetic field.

The attainment of the first of the above-mentioned objects is desirable from the fact that in electrical circuits for the utilization of very high frequencies difficulties are had in maintaining impedances as high as are wanted and in otherwise caring adequately for the comparatively large losses which appear as operating frequencies are increased. A rather familiar example of the type of problem involved is that of maintaining the voltage at the grid input of a vacuum tube when the grid losses become large, as they may at high frequencies. Contributing to the difficulties as the use of higher frequencies is attempted is the fact that the losses in most physical circuit elements increase rapidly with increase in frequency so that networks and circuit combinations which may be used effectively at low frequencies are often of no value or even a detriment at higher frequencies.

A solution to the problems indicated is had according to this invention through using as a circuit component a diode adjusted to a critical electron transit time such that it exhibits a negative resistance which is used to annul a corresponding amount of positive resistance, or loss, in the associated circuit. In accordance with this feature of the invention a triode translating device which may be an amplifier, detector or oscillator is provided with a resonant circuit comprising a diode having a critical electron transit time.

In accordance with another feature of the invention the negative resistance property of the diode referred to above is enhanced, when desirable, by the introduction of mercury vapor or other ionizable gas to permit greater electron current to flow. An atmosphere of mercury vapor or other ionizable gas may be introduced either by derivation from a mercury pool serv-

ing as a cathode or in conjunction with a solid cathode of usual type. This latter feature of the invention, the introduction of ionizable gas to permit increased electron current, applies generally to applications of electron discharge tubes where, as in the above-described use of the diode, the desired effect results from interaction between the electron stream and the high frequency field through which it passes and the magnitude of the effect is proportional to the electron current. This use of ionizable gas in devices having critical electron transit time is distinct from previous uses of mercury vapor or gas in electronic devices where the important feature has been the particular conducting property of an arc or the gaseous atmosphere. In the use herein disclosed the function of the vapor or gas is to neutralize space charge and allow a greater number of electrons to leave the vicinity of the cathode and be employed usefully in the electron stream.

The various features of the invention will be understood more fully from the following detailed description and the illustrative embodiments shown in the accompanying drawings.

In the drawings:

Fig. 1 illustrates the use of a diode to control the impedance of a grid input circuit;

Fig. 2 shows diagrammatically a triode detector or amplifier circuit in which a diode functions as a tuned circuit component;

Fig. 2A indicates the modification of Fig. 2 to illustrate the use of an ionizable gas in the diode element of Fig. 2;

Fig. 3 indicates the equivalent high frequency circuit corresponding to Fig. 2 and Fig. 2A;

Fig. 4 shows a triode oscillator circuit in which a diode functions as part of the oscillation circuit;

Fig. 4A indicates the modification of Fig. 4 to illustrate the use of an ionizable gas in the diode element of Fig. 4;

Fig. 5 indicates the equivalent high frequency circuit corresponding to Fig. 4 and Fig. 4A;

Fig. 6 shows a triode oscillator circuit in which a "stiff" frequency control circuit is provided through the use of a diode adjusted for critical electron transit time;

Fig. 6A indicates the modification of Fig. 6 to illustrate the use of an ionizable gas in the diode element of Fig. 6;

Fig. 7 indicates the equivalent high frequency circuit corresponding to Fig. 6 and Fig. 6A;

Fig. 8 shows a diode employing mercury vapor connected in an oscillator circuit wherein oscil-

lations are generated by virtue of a critical relation between the transit time of the electrons in the diode and the period of the high frequency oscillations;

Fig. 9 shows an alternate form of diode structure employing mercury vapor in an oscillator circuit which is similar to that of Fig. 8 except that the resonant circuit is in the form of a cavity resonator which is the envelope of the diode;

Fig. 10 shows a section of wave guide used as a cavity resonator in which oscillations are produced by an electron gun containing an ionizable gas;

Fig. 11 shows the production of oscillations in a resonant wave guide by projecting electrons transversely through it by means of an electron gun containing an ionizable gas;

Fig. 2 shows a high frequency amplifier arrangement employing cavity resonators and an electron stream produced by an electron gun containing an ionizable gas; and

Fig. 13 shows a modification of the arrangement of Fig. 12 to produce self-oscillation.

The use, such as above, of the two terms resonant wave guide and cavity resonator is not to be construed as indicating a fundamental distinction between them for practically either may with propriety be substituted for the other in the language of the specification and appended claims. Cavity resonators may take various shapes and one is that of a section of wave guide which is made short or is partitioned off from the balance of a long guide so that it has resonant properties. The more general term cavity resonator is often applied to cavity type structures not obviously in the form of a portion of wave guide or other distinctively named device. However, a resonant wave guide may not necessarily appear to be of the cavity type. This is exemplified by a relatively short wave guide with open ends. It is apparent that any resonant circuit whether it be a cavity type termed cavity resonator, a resonant wave guide, a tuned Lecher system, a tuned coaxial line or a combination of lumped inductance and capacity may function similarly in an electric circuit. The wave guide or cavity type of structure possesses several advantages over other forms of resonant circuit, among which are: that radiation is more readily controlled or prevented and that the conducting material is more favorably distributed to minimize circuit resistance.

Fig. 1 illustrates a type of circuit problem frequently encountered in the use of very high frequencies and a solution therefor by use of a diode as a circuit element to improve impedance conditions according to a feature of this invention. In this figure is shown, as part of a detector or amplifier circuit, a three-element vacuum tube 10 with conventional input blocking condenser 11, grid input resistance 12 and grid bias battery 13 to which may be connected, by means of switch 16, the tuned input circuit consisting of inductance 7 and capacitance 8. It is assumed that the tuned input circuit is energized from an external source indicated symbolically at 9. The diode 14 utilizing the source of direct current power supply, battery 5 and limiting resistance 6, and bypass capacitance 4 may be connected across the tuned input circuit by closure of the two-pole switch 15, 15. With a given amount of energy delivered to the tuned circuit from source 9 a certain voltage is developed between the points A and B, opposing terminals of the tuned input circuit, which may be used to drive the grid of a vacuum tube and for such purpose the tube 10

may be connected to the tuned circuit at A and B by the closure of switch 16. At low frequencies the grid losses in the tube would ordinarily be so low that the voltage developed between A and B by the source 9 would not be greatly affected by the connection. However, with higher frequency operation the grid loss may be so high that when switch 16 is closed the load imposed on the tuned circuit so lowers the effective impedance between points A and B that the energy available from source 9 does not develop sufficient voltage between those points to effectively drive the grid of tube 10. This situation is bettered according to the invention by connection also between the points A and B, through closure of switch 15, of the diode 14 which is adjusted to have a critical electron transit time as will be explained later. The diode 14 consists of the anode 2 and cathode 3 enclosed in the envelope 1 together with the necessary lead-in conductors. The cathode 3 is shown as a mercury pool which is a source of vapor employed to increase the effectiveness of the electron discharge, which feature of the invention will be described in more detail later. The advantage of vapor or other ionizable gas may not always be required for satisfactory results, in which cases any suitable cathode may be employed and the vapor or gas omitted. The anode of the diode 14 is positively charged by source 5 through limiting resistor 6 and inductance 7. Capacitance 4 serves as a high frequency by-pass around source 5 and resistor 6. Briefly, the function of the diode when connected between A and B is to provide a negative resistance to neutralize the positive resistance introduced into the tuned input circuit 7, 8 by the grid loss in tube 10, and also part of that inherent in 7 and 8 if that is desired. This counteracts the lowering of the effective impedance between A and B when the grid of tube 10 is connected and permits source 9 to maintain an effective grid driving voltage. The reactance and resistance characteristics of the diode enable it to function in this desired manner when the electron transit time is adjusted to approximate the period of $1\frac{1}{4}$, $2\frac{1}{4}$, $3\frac{1}{4}$, etc., cycles of the high frequency employed.

For a complete exposition of the theory underlying this property of diodes and methods of designing for such operation reference is made to applicant's copending application Serial No. 156,647, filed July 31, 1937, Patent No. 2,190,668, dated February 20, 1940. It is indicated in that application that a uniform stream of electrons between two equidistant surfaces exhibits the property of negative resistance within a series of high frequency bands. It is also indicated that in a broad form the two surfaces may form part of the bounding walls of an enclosed conducting cavity so dimensioned as to possess an electrical resonance at the operating frequency, and having holes or openings in opposing faces of the bounding walls to allow the electron stream to enter and leave the cavity, the electron stream being directed through the openings by means of an electron gun. The essentials, in any case, are that the electron stream traverse a space occupied by the alternating electromagnetic field associated with a circuit which is resonant at the desired frequency and that the time required for the electrons to traverse the space is approximately the period of $1\frac{1}{4}$, $2\frac{1}{4}$, $3\frac{1}{4}$, etc., cycles. Factors affecting the diode resistance are shown in the theory presented in the above-mentioned copending application, Serial No. 156,647, filed July 31, 1937,

Patent No. 2,190,668, dated February 20, 1940, and Fig. 3 of that application and patent shows graphically the variation of the diode resistance with variation of the electron transit time. It will be noted from this curve that the resistance varies cyclically between positive and negative values, the maximum negative values occurring at transit angles in radians corresponding to the periods of $1\frac{1}{4}$, $2\frac{1}{4}$ and $3\frac{1}{4}$ cycles mentioned above. The transit time is determined by the spacing of the gap between the surfaces of the cathode and anode, which determines the distance through the field traversed by the electrons, by the anode or accelerating voltage used to propel the electrons through the gap space, and to a lesser extent by the space charge density within the gap. It will be noted in the discussion in the above-mentioned copending application, Serial No. 156,647, filed July 31, 1937, Patent No. 2,190,668, dated February 20, 1940, that the magnitude of the negative resistance effect is dependent upon the electron stream current. To quote:

"It will be noted from Equation 6 that the negative resistance, and hence the driving power for the oscillations, is proportional to the density I_0 of the direct electron current."

For the purpose of increasing the electron current and thereby the negative resistance effect when desired, a feature of this invention is to employ for that purpose in the electron discharge tube mercury vapor or other ionizable gas to neutralize space charge and allow electrons to leave more readily the vicinity of the cathode. In this use the density of the gas must be kept sufficiently low that there are relatively few collisions between electrons and gas ions. This condition is maintained by control of temperature and pressure of the gas and is one commonly met in the operation of rectifiers of the hot cathode mercury vapor type. It should be understood, of course, that a diode may be used as a circuit component regardless of the type of cathode employed and either with or without the gaseous atmosphere. The cathode may be cold or of the heated type, and the purpose of the gas is to increase the effectiveness of the diode.

Fig. 1 for illustrative purposes shows conventional forms of inductance and capacitance whereas at very high frequencies, as in the range where this invention is particularly applicable, tube elements and connecting leads though short may be the principal reactance elements of the circuit. For that reason the essentials of Fig. 1 are shown somewhat differently in Figs. 2 and 3. In Fig. 2 and the figures following through Fig. 7, which are schematic diagrams, the triode and diode elements, and the other circuit elements shown, are indicated by conventional symbols therefor. In practice these elements may take various mechanical forms. Fig. 2 shows an amplifier or detector circuit, typical for high frequency operation, which includes a diode as a circuit component for the purpose of improving the performance. The triode amplifier or detector tube is shown here with a direct current plate potential source 17 and a load circuit 18. The diode 14 derives its direct current energy from source 5 through choke 28. The high frequency input between grid and cathode of 10 is represented as originating at 9. Fig. 3 is a schematic of the high frequency circuit shown in Fig. 2 with direct current paths omitted and the reactances and resistances effective under high frequency

operation indicated. The brackets 10 and 14 in these and following figures are to assist in identifying the elements in the equivalent circuit schematics. For instance, the various circuit elements, capacitance, resistance, inductance, included by bracket 14 in equivalent circuits Figs. 3, 5 and 7 exist in the physical diode element included by bracket 14 in Figs. 2, 4 and 6. Similarly, equivalent circuit elements of the triode are included by the bracket 10 in Figs. 3, 5 and 7. The effective capacitance and resistance of the grid circuit of the triode 10 are shown at 22 and 23, respectively. The effective lead inductance, the anode-cathode capacitance and the negative resistance of the diode 14 are shown at 19, 20 and 21, respectively. It will be observed that the resonant input circuit to the triode now includes all these elements 19, 20, 21, 22 and 23 in series and that its impedance and the voltage impressed between the grid and cathode of the triode for a given amount of energy available at 9 will depend upon the net value of the resistance in this circuit, the difference between resistances 21 and 23, 21 being negative and dependent upon the operating condition of the diode 14. Thus a diode adjusted for critical transit time operation may be used to avoid serious depression of the impedance of a grid input circuit due to high frequency grid losses.

Fig. 4 shows a triode oscillator circuit employing a diode as a circuit component. Designations correspond to those of Fig. 2. The direct current plate potential source 26 supplies both diode 14 and triode 10 through choke 27. The oscillator load is connected through blocking condenser 28. Fig. 5, in the same manner as Fig. 3, shows the important elements of the equivalent high frequency circuit of Fig. 4. Connected to the grid of 10 are elements 22 and 23 representing the capacitance and resistance of the grid-cathode circuit and 29 representing the inductance of the external grid-to-cathode lead. These elements constitute a resonant input circuit which may in practice be supplemented, if necessary, by an adjustable tuning element. Such an element may consist of a variable inductance in series with the grid-to-cathode lead represented by inductance 29, a variable capacitance in shunt with that lead or any other desired arrangement. 24 represents the grid-to-plate capacitance and 25 the plate-to-cathode capacitance of triode 10. 19, 20 and 21 represent lead inductance, anode-cathode capacitance and negative resistance, respectively, of the diode 14 making up the resonant output circuit. It will be observed that the complete circuit as indicated schematically in Fig. 5 constitutes an oscillator of the commonly termed tuned-plate tuned-grid type in which the feedback voltage is impressed upon the input circuit through the grid-to-plate capacitance 24. In this circuit the diode enhances the strength of oscillation by compensating with its negative resistance for positive resistance in the oscillator or load circuit.

Fig. 6 shows a triode oscillator circuit in which a diode is used to provide a "stiff" frequency control circuit in much the same manner as a piezoelectric crystal is employed. The diode 14 is connected to the grid of triode 10 through blocking condenser 11 and is energized from source 5 through choke 28. The plate potential of triode 10 is supplied from source 17 through inductance 30. The load 18 is connected through blocking condenser 28. Fig. 7 shows the important elements of the equivalent high frequency circuit of Fig. 6. It will be observed that this is an oscil-

lator circuit of the tuned-plate tuned-grid type similar to that of Fig. 4 and Fig. 5. Here 19, 20 and 21 represent, respectively, the lead inductance, the anode-cathode capacitance and the negative resistance of the diode 14. 22 and 23 represent, respectively, the grid-cathode capacitance and resistance of the triode 10. These elements together, with resistance 23 largely neutralized by the negative resistance 21, constitute the "stiff," low loss, resonant frequency control circuit which, in the manner of a piezoelectric crystal, provides close control of the oscillation frequency. The resonant output circuit, which is tuned to substantially the same frequency as the control circuit, is composed of the plate cathode capacitance 25 of triode 10 and the inductance 30.

In Figs. 2, 4 and 6 the diodes are shown in diagrammatic form indicating a simple hot thermionic cathode. Other forms of cathode may be used, and in accordance with a feature of the invention previously mentioned an ionizable gas may be introduced into the tube for the purpose of increasing the direct electron current. A further embodiment of this method of increasing the electron current is shown in Fig. 8 which illustrates the use of a diode having mercury vapor and a mercury pool cathode in an oscillator circuit wherein oscillations are produced by virtue of critical electron transit time in the diode. The diode comprising the envelope 1, anode 2 and cathode 3 is connected through by-pass condenser 4 to the resonant circuit consisting of inductance 7 and capacitance 8. The anode potential source 5 is connected to the diode through the limiting resistor 6 and inductance 7. As indicated in applicant's copending application Serial No. 156,647, filed July 31, 1937, Patent No. 2,190,668, dated February 20, 1940, previously referred to, oscillations will occur in a circuit of this type when the power generated in the negative resistance of the diode by virtue of critical electron transit time exceeds the losses in the circuit. By the use of ionizable gas in the diode the negative resistance power is increased and oscillations may be had under more adverse conditions or the strength of oscillations may be increased. The gas may be derived in the form of mercury vapor from a mercury pool cathode, as shown in Figs. 8 and 9, from a mercury pool in combination with a hot cathode emitter, as indicated in Figs. 10, 11, 12 and 13, or the proper amount of some other form of ionizable gas, such as argon, may be placed in the diode envelope.

In Fig. 9 is shown an alternative form of diode oscillator arrangement. The circuit is similar to that of Fig. 8 but here the diode envelope 1 is in the form of a conducting resonant cavity which serves also as the oscillatory circuit. The figure shows an axial section of the cavity which is cylindrical in shape. The disc-shaped anode 2 is insulated for direct current from the rest of the cavity at 31. A load circuit may be connected to the output coupling coil 32. The mercury pool at 3 directly opposite the anode serves as a cathode and a source of mercury vapor to increase the electron current. As previously mentioned, another form of cathode may be employed in combination with a mercury pool or with another type of ionizable gas eliminating the mercury. This form of circuit, a resonant cavity, is inherently of low resistance and particularly suitable for use at very high frequencies. Fig. 9 illustrates only one of many possible forms a cavity diode may take and only one embodiment of the principle of using an ionizable gas to increase the

effectiveness of critical electron transit time operation.

Figs. 10, 11, 12 and 13 show other embodiments of the principle of using an ionizable gas to increase the electron current and therefore the energy available from an electron stream which is caused to react with an alternating electromagnetic field for the purpose of transferring energy from the electron stream to the field.

Fig. 10 shows an electron gun, employing mercury vapor as an example of ionizable gas, arranged to excite a short section of wave guide and a method of transferring the high frequency energy generated therein for transmission through a wave guide. In the figure axial cross-sectional views of cylindrical wave guides are shown at 36 and 40. The length of the short section 36 is limited by the end closures to form a resonant cavity of the desired dimensions while 40 is indefinite in length, serving only to transmit the high frequency energy generated in 36. The electron gun comprising envelope 1, anode 2, cathode 3 and hollow cylindrical accelerating electrode 34 is inserted along the axis through the short section of wave guide 36 which constitutes a resonant cavity as described in applicant's copending application Serial No. 156,647, filed July 31, 1937, Patent No. 2,190,668, dated February 20, 1940, previously referred to, and shown in Fig. 10 therein. The present Fig. 10 and the Fig. 10 of the applicant's Patent No. 2,190,668 here referred to are similar in these respects. 31 of Fig. 10 in the patent corresponds to 36 of the present Fig. 10. 33 in the patent corresponds to the openings at the inner ends of 37, 37 in the present Fig. 10. F, 36 and 34 in the patent correspond to 3, 34 and 2, respectively, in the present Fig. 10. The utilization circuit, 38, 39 and 40 of the present Fig. 10, is not included in the Fig. 10 of the patent. In both figures the electron stream is shown to traverse the axis of the resonant chamber and high frequency energy is generated by virtue of the critical relation between the electron transit time across the chamber and the high frequency period. The equivalent diode surfaces between which the electron transit time is measured are the intersecting surfaces of the electron stream and the boundaries of the resonant chamber. These are, the inner edges of the holes 33 in Fig. 10 of the Patent 2,190,668 and the inner edges of the cylinders 37, 37 in the present Fig. 10. That typical diode operation is had with such an arrangement is pointed out in the applicant's above-mentioned patent (2,190,668) where on page 9, second column, beginning line 5 it is stated: "Applicant has discovered, and as may be readily proved by mathematical analysis along the lines presented in the early part of this specification, that an electron stream entering a resonant cavity at high velocity through an orifice in its wall and leaving the cavity through another orifice in the opposite parallel wall, produces the same negative resistance, as compared with the diodes of the earlier numbered figures, when its transit time within the cavity responds to the conditions prescribed for said other type of diode oscillator in the operation of which electrons would correspondingly leave the wall of the cavity from rest." The stream of electrons will react with the type of electric field within the section of guide which is associated with the type of wave designated type E₀ by G. C. Southworth on page 287 of the Bell System Technical Journal, vol. 15 (April 1936) and consists of lines of electric force passing along the axis, then radially to terminate on the enclosing

conductor of the guide and this type of field will be produced by the electrons passing along the axis when their transit time is approximately equal to the period of $1\frac{1}{4}$, $2\frac{1}{4}$, $3\frac{1}{4}$, etc., cycles of the high frequency, as explained in the above-mentioned copending application. The coaxial line consisting of the outer conductor 38 and the inner conductor 39 is arranged to transfer the high frequency energy of such a wave in 36 to the wave guide 40 by virtue of the inner conductor 39 projecting into both sections of guide in a manner to couple with the electric fields. The small projecting cylinders 37, 37 at the openings through which the electron gun is inserted are to prevent loss by radiation through those openings. The accelerating electrode 34 is energized positively with respect to the cathode 3 by potential source 5. The collecting anode 2 is energized positively with respect to 3 by potential source 35. A small amount of mercury is shown at 33 as a source of mercury vapor to serve as the ionizable gas to facilitate the passage of electrons from the cathode to the anode. The increase in electron flow due to the use of an ionizable gas in a device of this kind is beneficial since, as has been previously indicated, the output and efficiency are directly dependent upon the amount of electron current.

A slightly different arrangement of an electron gun, using an ionizable gas, for producing high frequency waves in a wave guide is shown in Fig. 11. Here the electron gun is shown passing transversely through the cylindrical wave guide 41. Other designations are the same as in Fig. 10. In this arrangement the stream of electrons passing transversely through the guide will react with a type of electric field therein which is associated with the type of wave designated by G. C. Southworth as type H₁, page 287 of the Bell System Technical Journal, vol. 15 (April 1936) and consists of lines of electric force passing transverse to the axis substantially parallel to a diameter and this type of field will be produced by the electrons when their transit time is as indicated above in connection with Fig. 10. Here also the advantage of the gas in the tube is in the increased electron current made possible. The arrangement of Fig. 11, like that of Fig. 14 in applicant's copending application Serial No. 156,647, filed July 31, 1937, Patent No. 2,190,668, dated February 20, 1940, previously referred to, requires that the portion of the wave guide immediately surrounding the electron gun be closed off to the proper length with a plunger, as indicated at 50 in Fig. 11, and an apertured diaphragm, 51, to determine the frequency and the coupling to the transmitting portion of the wave guide as indicated in that application and shown in the associated Fig. 14.

Further embodiments of the use of an ionizable gas in an electron tube for the generation and control of high frequency energy is shown in Figs. 12 and 13 representing, respectively, a high frequency amplifier and an oscillator circuit utilizing the principle of velocity modulation, where the electron stream is subjected to different electric field conditions in different parts of its path as shown in applicant's prior Patent No. 2,096,460, issued October 19, 1937. Other applications of the velocity modulation principle are to be found in articles by Messrs. Hahn and Metcalf in the Proceedings of the Institute of Radio Engineers, vol. 27, February 1939, pages 110 to 116, and by Messrs. R. H. Varian and S. F. Varian in the Journal of Applied Physics, vol. 10, February 1939, page 140. In Fig. 12 the electron

gun and sources of operating potentials are designated the same as in Figs. 10 and 11. 42 and 43 represent resonant cavities of the circular reentrant type, with axial openings through which the electron gun is passed at 45 and 46. Cavity 42 serves as the input circuit and is coupled to an input line at 44. Cavity 43 serves as the output circuit and is coupled to an output line at 32. The electron stream from cathode 3 to collector 2 passes through the electric field of cavity 42 for a short distance at 45 and through the field of cavity 43 for a short distance at 46. The alternating field at 45, resulting from the input to the amplifier at 44, reacts upon the electron stream to speed up those electrons which enter the field during one half of each cycle and to retard those which enter during the other half cycles. After leaving the region of the field at 45 the electrons which have had their velocity increased tend to overtake those which have had their velocity reduced, so that by the time the region of 46 is reached a rearrangement of electrons along the path has taken place and the stream is no longer of uniform density. Regions of greater and less electron density alternate in accordance with the effect of the field at 45. In other words, the electron stream has been density modulated in accordance with the input to the amplifier. Now, in passing through the region 46 of cavity 43 the variations in the density of the electron stream will induce a varying field within 43 proportional to the input to 42; so that the input high frequency energy is amplified and delivered through the output line at 32. The alternating field at 46 will oppose the passage of electrons and reduce their velocities. The spent electrons are then collected at relatively low potential by collecting anode 2.

Fig. 13 shows how the amplifier circuit of Fig. 12 may be modified to act as an oscillator. A short transmission line is introduced between 47 and 44 to couple the output and input circuits, thereby exciting the input cavity 42 with energy from the output cavity 43. The line connecting 47 and 44 must be of such length and the electron transit time between 45 and 46 such that the fields within the two cavities 42 and 43 are in the proper phase relation to cooperate in sustaining oscillations. In the devices of Fig. 12 and Fig. 13, as in those previously described, the use of mercury vapor or other form of ionizable gas enhances the output and efficiency by permitting greater electron current to flow.

Other applications of electron tubes operating with critical electron transit time to improve circuit operation and other examples of the beneficial use of an ionizable gas in such tubes will occur to those skilled in the art and it is to be understood that the scope of the invention is not limited to the specific embodiments disclosed but only by the scope of the claims.

What is claimed is:

1. In a high frequency system, an electron discharge device containing an ionizable gaseous atmosphere and electrodes including at least a cathode and an anode, means including electric potential means for causing a stream of electrons to traverse a path from the cathode to the anode, and means for impressing a high frequency electric field upon the electron stream over at least a portion of the path and between two substantially parallel planes transverse to the path, the magnitude of the said electric potential means and the distance between the said trans-

verse planes being such that the electron transit time through the high frequency field substantially equals the period of any whole number of cycles plus one-quarter cycle of the high frequency field.

2. A high frequency system comprising an electron discharge device having an ionizable medium, a pair of substantially parallel electrodes between which a high frequency electric field may be impressed, electric potential means for producing an electron discharge over a path including the space between the said electrodes, the distance between the electrodes and the magnitude of the electric potential means having such relationship as to cause the electron transit time between the electrodes to be a period between that of any whole number of cycles of the operating frequency of the system and that number increased by one-half cycle.

3. A high frequency system comprising an electron discharge device containing an ionizable medium having as electrodes at least a cathode and an anode, means including electric potential means for producing an electron discharge over a path between the cathode and anode, means for impressing a high frequency field upon the electron stream over at least a portion of the path and between two planes substantially parallel and transverse to the path, the path of the electron discharge and the magnitude of the electric potential means being such that the electron transit time through the high frequency electric field between the transverse planes is a period between the period of any whole number of cycles of the high frequency field and the period of that number increased by one-half cycle.

4. In a high frequency system, a resonant circuit, means for predetermining the terminal impedance of the circuit comprising an electron discharge tube containing an ionizable gaseous atmosphere, having a cathode and anode and being electrically coupled to the circuit, means including electric potential means for causing a flow of electrons over a path between the cathode and anode, and means independent of the said electron discharge tube for energizing the said circuit at a frequency substantially equal to its resonant frequency, the coupling between the discharge tube and the circuit including means for impressing upon the electron stream, over at least a portion of the said path and between two substantially parallel planes transverse to the path, a high frequency electric field derived from the high frequency energy in the circuit, the magnitude of the said electric potential means and the distance between the two said transverse planes being such that the electron transit time through the high frequency electric field is a period between that of any whole number of cycles of the high frequency field and that number increased by one-half cycle.

5. In combination, a resonant circuit, energy transfer leads connected thereto, the damping factor of the circuit being dependent upon the losses within the circuit and those imposed by the energy transfer leads and any devices connected to the leads, means for reducing the damping of the circuit to a small magnitude comprising a diode containing an ionizable gaseous atmosphere and having its cathode and anode terminals connected to the circuit, means independent of the said diode for energizing the circuit at substantially its resonant frequency, and means including electric potential means

for causing a flow of electrons between substantially parallel surfaces of the cathode and anode, the magnitude of the electric potential means and the distance between the cathode and anode being such that the electron transit time therebetween is a period between that of any whole number of cycles of the high frequency and that number increased by one-half cycle.

6. A wave translating device having input and output terminals and a resonant circuit, of which the damping is to be reduced, connected with said device comprising a diode containing an ionizable gaseous atmosphere, means external to the resonant circuit for energizing it at substantially its resonant frequency, the diode having substantially parallel electrode surfaces and means including electric potential means for causing a flow of electrons therebetween, the length of the electron path between the two said surfaces and the magnitude of the electric potential means being such that the electron transit time between the two surfaces is substantially the period of any whole number of cycles plus one-quarter cycle of the operating frequency of the device.

7. A thermionic triode translating device having input and output terminals and a resonant circuit for said device comprising a diode containing an ionizable gaseous atmosphere connected between two of said terminals, means external to the resonant circuit for energizing it at substantially its resonant frequency, the diode having substantially parallel electrode surfaces and means including electric potential means for causing a flow of electrons therebetween, the length of the electron path between the said surfaces and the magnitude of the electric potential means being such that the electron transit time between the two surfaces is a period between that of any whole number of cycles of the operating frequency of the device and that number increased by one-half cycle.

8. A device for producing electric oscillations of a desired high frequency comprising a thermionic amplifier with tuned grid and plate circuits coupled to produce electrical oscillations, at least one of the tuned circuits serving as a frequency determining circuit and comprising a diode containing an ionizable gaseous amplifier and having a cathode and an anode, means including electric potential means for causing a stream of electrons to traverse a path between the said cathode and anode, and means for impressing a high frequency electric field produced from the electric oscillations upon the electron stream over at least a portion of the path and between two substantially parallel planes transverse to the path, the magnitude of the said electric potential means and the distance between the said transverse planes being such that the electron transit time through the high frequency field is between the period of any whole number of cycles of the high frequency and that number increased by one-half cycle, the diode being electrically connected to the amplifier to function in the frequency determining circuit therefor.

9. An electron discharge device for producing electric oscillations comprising a thermionic amplifier, a diode containing an ionizable gaseous atmosphere electrically connected to the amplifier to function in a frequency determining circuit therefor, and means including electric potential means for causing a flow of electrons over a path between the cathode and anode of

the diode, the connections between the diode and the amplifier including means for impressing upon the electron stream, over at least a portion of the said path and between two substantially parallel planes transverse to the path, a high frequency electric field derived from the electric oscillations produced by the device, and the magnitude of the electric potential means 5 and the distance between the two said transverse planes being such that the electron transit time through the high frequency field is a period between that of any whole number of cycles of the high frequency field and that number increased by one-half cycle.

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