Jan. 20, 1948. F. H. KROGER 2,434,704

ELECTRIC SPACE DISCHARGE CIRCUIT

Filed March 20, 1944 3 Sheets-Sheet 1

Fig. 1

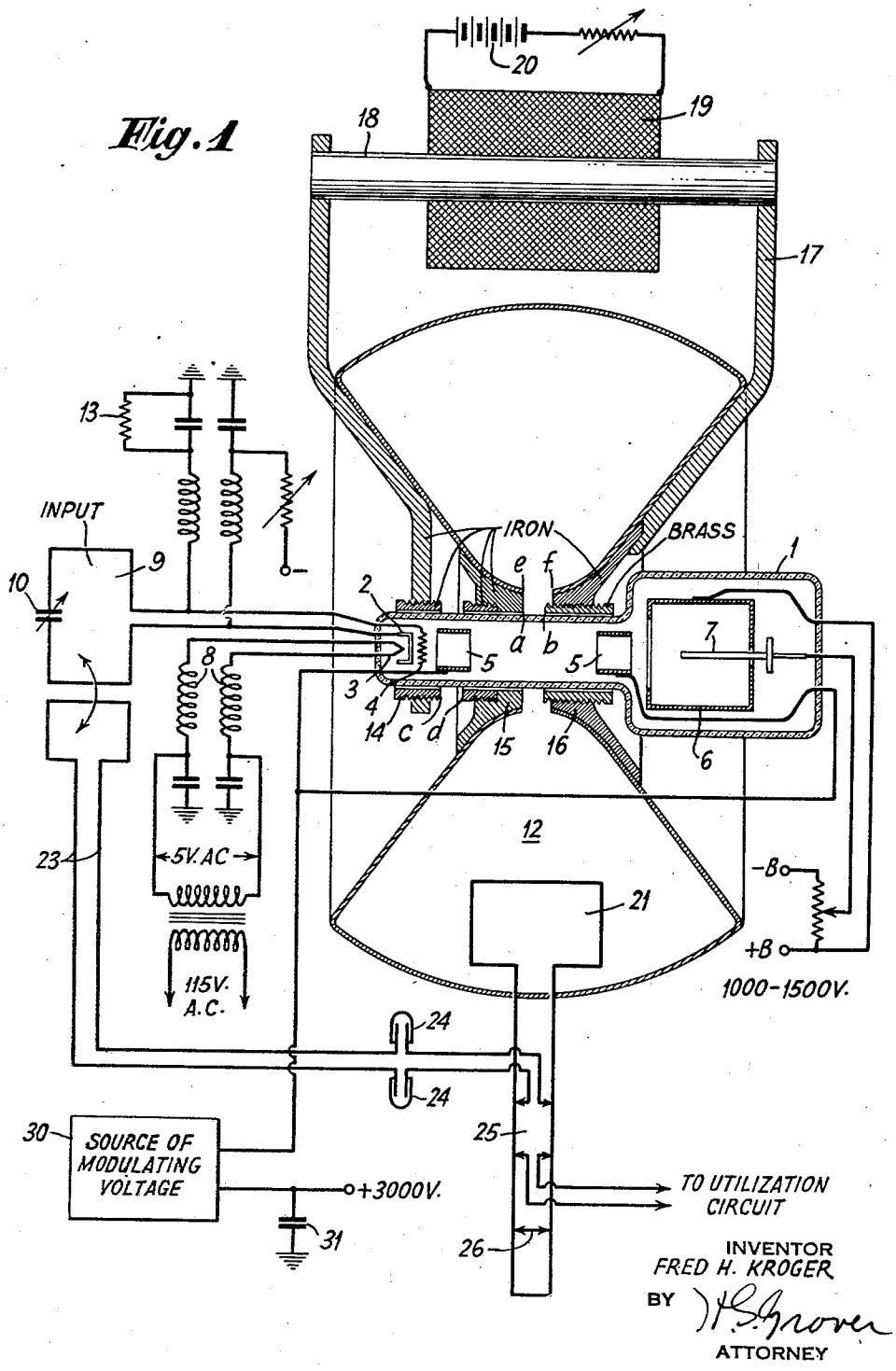


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Fig. 2

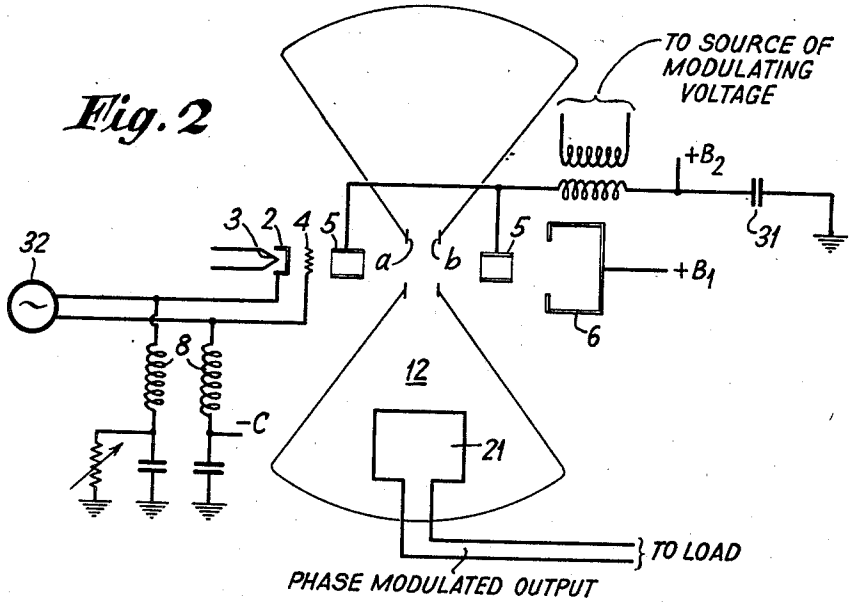
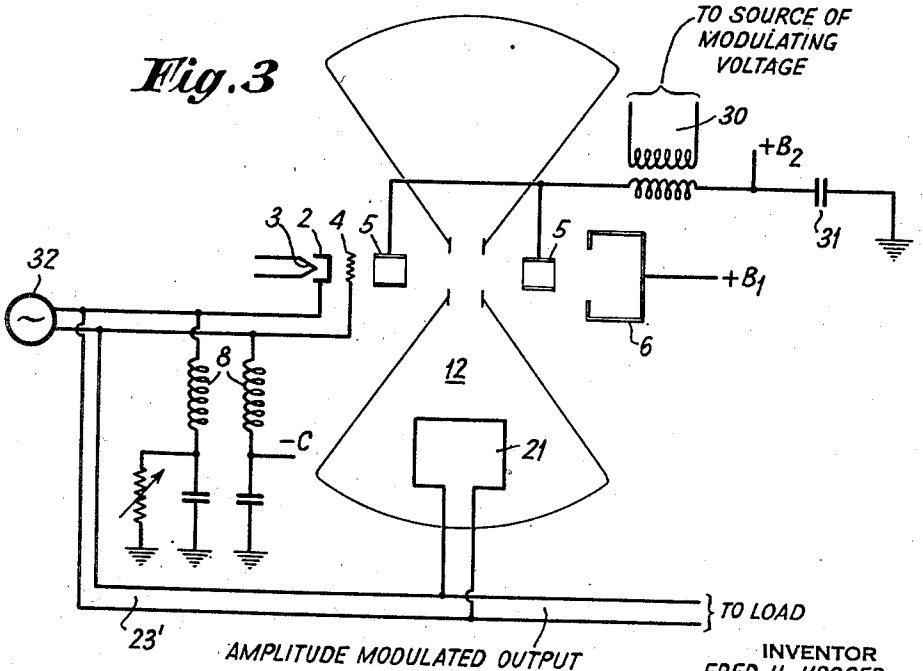



Fig. 3

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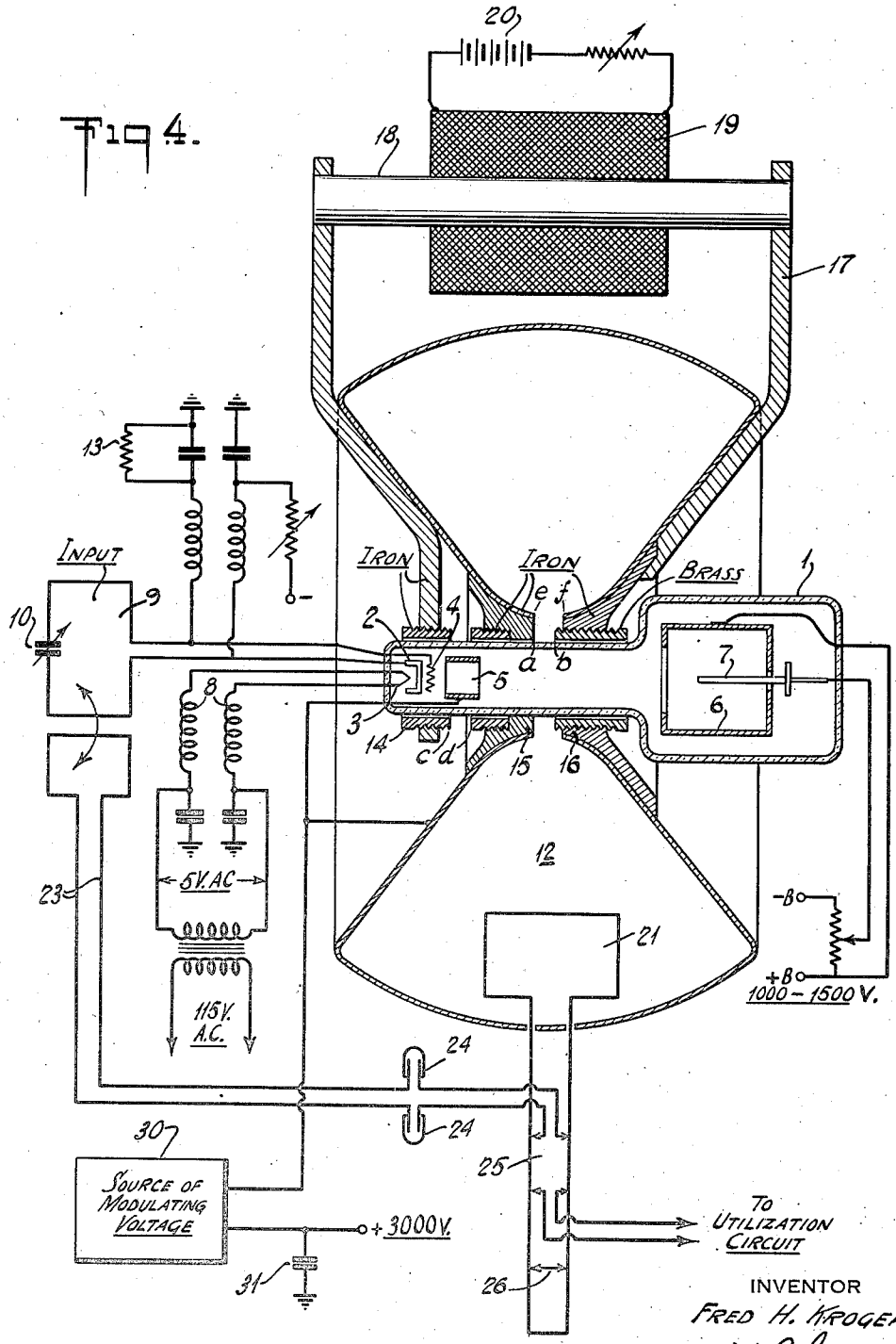
Filed March 20, 1944 3 Sheets-Sheet 3

Fig 4.

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Patented Jan. 20, 1948 2,434,704

# UNITED STATES PATENT OFFICE

2,434,704

## ELECTRIC SPACE DISCHARGE CIRCUITS

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Application March 20, 1944, Serial No. 527,278

46 Claims. (Cl. 179—171.5)

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This invention relates to electron discharge device circuits which have been found to be especially useful on ultra short waves below six meters, and is a continuation-in-part of my copending application Serial No. 326,170, filed March 27, 1940, which is now in the status of a forfeited application. More particularly, the invention relates to a method of and means for varying the phase relation between the excitation voltage and the output induced voltage of an electron beam repeater tube. The principles of the present invention are described hereinafter, by way of example only, in connection with a variable frequency oscillator, a phase modulator and an amplitude modulator, although it will be understood that the invention is not limited thereto.

In the conventional design of electron oscillators it has been necessary to employ auxiliary circuits including additional electron devices where it is desired to maintain a constant average variable frequency and modulate the generated frequency in accordance with a variable control voltage. The use of these auxiliary circuits in such known arrangements not only unduly complicates the entire system but also decreases the efficiency of the system. Further, the cost of such a conventional system is increased by the use of auxiliary circuits necessary to accomplish the foregoing desired result.

The present invention, among other things, overcomes the disadvantages mentioned above by providing an oscillation generator composed of a single electron discharge device which maintains a constant average value of frequency and is also capable of having the frequency directly modulated in accordance with a variable control voltage. The controlling energy required to frequency modulate my improved electron oscillator is very small.

One of the objects of the present invention is to provide an efficient means of varying the relative phase relation of the input and output of an electron discharge device at frequencies ranging from zero into megacycles.

Another object of the present invention is to provide an efficient control of the frequency of oscillations of an electronic oscillator by controlling the transit time of the electron stream.

A further object is to provide a regenerative electronic device having means capable of varying the regeneration at a frequency range from zero into megacycles.

Briefly, the foregoing objects of the present invention and others are achieved by employing

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electron discharge devices having a stream of electrons which require an appreciable interval of time for transit, and providing means for controlling the transit time through variation of the accelerating voltage. It is preferred to employ an electron tube having a cathode, a collector electrode, one or more intermediate accelerating electrodes, and a suitable tank circuit. In one particular embodiment successfully tried out in practice, and described hereinafter, I employ an evacuated electron discharge device of the beam type tube having a cathode at one end, a collector at the other end, a pair of intermediate accelerating electrodes, and an associated cavity resonator for the output, the latter being external of the vacuum tube structure and having a gap across which the electrons pass for inductively exciting the tank. This tank circuit is in the form of a surface of revolution with the central plane of the surface of revolution cutting the axis of the vacuum tube structure substantially at right angles. In its preferred form, the surface of revolution constituting the tank circuit is a section approximating the sector of a circle with the vertex angle located adjacent the vacuum tube involved. Generally speaking, such structure may be said to be doughnut in form. For focussing the electrons there is provided a pair of magnetic lenses each constituted by a leakage field surrounding the envelope of a vacuum tube. Such a vacuum tube and associated tank circuit is generally disclosed in my application Serial No. 296,045, filed September 22, 1939, now United States Patent No. 2,350,907, granted June 6, 1944, to which reference is herein made. It should be understood, however, that this type of tube and tank circuit is merely given by way of illustration since the principles of the invention are equally applicable to any other beam type tube which can be used for my purposes. It should also be understood that other types of tank circuits can be used, as for example a concentric line tank.

In accordance with one embodiment of the invention relating to an oscillator circuit, in order to obtain regeneration there is provided a feed back circuit between the output and the input, and means are provided for varying the potential on the accelerating electrodes of the tubes in order to affect the transit time of the electron stream. Thus by varying the accelerator electrode potential, I am able to vary the velocity of the electrons in the electron stream through the tube and thus vary the phase relation between the output and input currents. Consequently, as the relative phase of the currents fed back from the

output circuit to the input circuit is changed, the operating frequency is changed to a value which will bring the regenerative voltage in phase with the tank voltage. The sensitiveness of the oscillator frequency to accelerator potential change may be increased by lengthening the distance from the control electrode to the output gap of the tank circuit or by employing lower potentials and lower electron velocities. Further, this sensitiveness may also be increased by employing less selective oscillator circuits.

The vacuum tube of the present invention, when employed as an oscillator, finds a wide field of use in wide band frequency modulation. When used for this purpose, the frequency change of the oscillator may be made to be substantially proportional to the potential change for a small range with a small change in amplitude of the output from the oscillator. For a wider frequency range, suitable compensating circuits may be employed to make the frequency change substantially proportional to the potential change, also with a small change in amplitude over this range. Of course, where an accessory amplitude limiter is employed with the oscillator of the present invention, this limiter will replace the amplitude compensator circuits and obviously the amplitude of output of the system will be constant over any desired range of frequencies.

A brief discussion of the principles underlying the oscillator embodiment of the invention follows: It is known that in an electron oscillator where oscillations are the result of an amplifier feeding back sufficient energy to the control element to exceed the losses, the energy fed back from the output to the input or control element must be in correct phase to maintain oscillations. In an electron device of the beam type with which the present invention is primarily concerned, the transit time of the electrons is appreciable, and the following factors enter into a determination of the frequency of oscillation.

(*a*) The constants of the tuned output circuit involving L, C and P which respectively refer to the inductance, the capacitance and the power factor reciprocal of Q.
(*b*) The transit time of electrons.
(*c*) The constants of the tuned input and feed back circuit, here again involving L, C and P.

The frequency of the oscillator can be varied by varying either one or more of the factors (*a*), (*b*) or (*c*). The varying of the L, C or P for modulation purposes over the frequency range of zero into megacycles in order to achieve one of the results of the present invention has been found in practice to be difficult. Varying the transit time in accordance with the invention achieves the desired result in a much simpler and more efficient manner. Since this transit time is determined by the length of the electron path and the voltage accelerating the electrons, it is proposed, in accordance with the invention, to vary the electron velocity and thus change the transit time by varying the accelerating voltage in accordance with any desired type of signal modulation. By increasing the accelerator voltage by a given amount, the transit time is decreased according to the law that the electron velocity is proportional to the square root of the voltage applied to the accelerator electrode. In order to obtain a maximum change in frequency for a given change in moduation voltage, it is desired, in accordance with the invention, to have a minimum resultant change in phase in the input and feed back tuned circuits for a given change in frequency, and for this reason the Q of the input and feed back circuits (reciprocal of power factor) is made as low as practical and the Q of the output resonator (tank circuit) is reduced to a value which will give the desired frequency change.

Another embodiment of the invention comprises a phase modulator which differs from the frequency modulator described above in that the feed back circuit is absent and a source of constant frequency oscillations is supplied to the control element.

Another embodiment of the invention comprises an amplitude modulator in the form of a regenerative repeater. This modulator employs the feed back feature present in the frequency modulator embodiment of the present invention and requires the application of a source of constant frequency oscillations to the control element.

A more detailed description of the invention follows, accompanied by a drawing wherein:

Fig. 1 illustrates a variable frequency oscillator or frequency modulator in accordance with one embodiment of the invention;

Fig. 2 illustrates a phase modulator in accordance with another embodiment of the invention;

Fig. 3 illustrates an amplitude modulator in accordance with a still further embodiment of the invention; and

Fig. 4 illustrates another embodiment of the invention in the form of a variable frequency oscillator or frequency modulator.

Referring to Fig. 1 in more detail, there is shown an electron discharge device oscillator circuit comprising a vacuum tube structure (generally of the so-called inductive output type) consisting of an evacuated glass envelope 1 containing within it a cathode 2, a heater 3, a grid 4, ring-like accelerator electrodes 5, 5 and collector electrode 6 and a suppressor 7. The heater 3 is supplied with energy from a suitable alternating current source, as shown, through choke coils 8. Connected to the cathode 2 and grid 4 is the input tuning circuit 9, which includes a variable condenser 10. The collector electrode 6 for gathering the electrons traversing the length of the glass envelope 1 is shown to be cup-shaped in form, although, if desired, it may be hemispherical, conical or of other suitable shape. Centrally located within the interior of the collector 6 there is provided a rod-like suppressor electrode 7 for gathering secondary electrons which may emanate from 6. The suppressor electrode 7 may take any suitable form according to the design of the collector electrode 6. Accelerator electrodes 5, 5 are narrow in width, and are connected together and connected to a suitable source of modulating voltage 30. Condenser 31 is a by-pass condenser to ground. Source of modulating voltage 30 may comprise speech waves, any suitable variable frequency, a space wave keying system, or an on-off keying system.

Surrounding the exterior of the glass envelope 1 and located intermediate the two accelerator electrodes 5, 5 there is provided the tank circuit 12 (i. e., a tuned circuit) in the form of a surface of revolution whose central plane is perpendicular to the electron beam emanating from cathode 2. This tank circuit is sometimes referred to as a cavity resonator, and, it should be noted, is symmetrically arranged around the glass enve-

lope 1. In order to obtain a desired high impedance across the gap *a*, *b* of the tank circuit for matching the impedance of the vacuum tube structure, the configuration of tank circuit 12, as shown by a cross-section of the surface of revolution through the axis of revolution in the plane of the drawing, should approximate two equal sectors with their vertices toward the glass envelope 1. The dimension of the tank or resonant cavity circuit 12 as measured from the center of the glass envelope 1 toward the arc of the sector, as indicated in the drawing, is approximately one-quarter of the length of the communication wave corresponding to the resonant frequency, provided that the gap *a*, *b* is not supplied with capacitor discs to change the frequency to a value less than the natural frequency of the resonator. The tank circuit 12 is preferably made of a highly electrical conducting material, such as copper.

For focusing the electron beam there are provided a pair of magnetic lenses in series relation constituted by gaps *c*, *d* and *e*, *f* formed by spaced iron sleeves 14, 15 and 16 which surround the glass envelope 1 and are serially arranged with respect to an iron magnetic path. This magnetic path includes a strip of iron 17 which is placed adjacent to the sides of the upper sector of the tank 12 and which is completed through an iron core 18, in turn surrounded by an electromagnetic field coil or solenoid 19 excited by a direct current source of supply 20.

In order to sustain oscillations, the output coupling coil 21 is here shown coupled back to the tuned input circuit 9 through a feed back transmission line 23, which line is adjustable in electrical length by means of trombone sliders 24, 24. A Lecher wire system 25 is connected to the output coupling coil 21 and one end of the transmission line 23 is slidably connected to this Lecher wire system, as shown, while the other end is inductively coupled to the input circuit 9. A slider 26 bridged across the conductors of the Lecher wire system 25 functions to tune the output circuit.

The operation of the oscillator will now be given. The grid bias on electrode 4 is produced by the conventional grid leak 13. The accelerator electrodes 5, 5 are maintained at a given positive bias. The electrons immediately after passing through the apertures of grid 4 will tend to flow toward the interior surface of the first accelerator electrode 5 due to the positive potential on this electrode. In order to prevent the electrons from impinging on this accelerator electrode there is provided a magnetic lens *c*, *d* which, by virtue of the leakage field thereacross, focuses the electrons toward the axis of the vacuum tube. As the electrons approach the gap *a*, *b*, there is a tendency toward dispersion, and it is for this reason that the additional magnetic lens *e*, *f* is required to maintain the beam in the axis of the tube beyond the second accelerator 5, after which the electrons will be gathered up by the collector electrode 6 which is at a suitable positive potential relative to the cathode. Groups of electrons or pulses formed by grid excitation due to the feed back circuit, traverse the gap *a*, *b* and induce high frequency currents between the points *a*, *b*.

The voltage induced at the gap *a*, *b* of the resonator 12 will in turn induce a current in the resonator which through the output coupling loop 21 causes a resultant feed back E. M. F. through the transmission line 23 and the input circuit 9, 10 to the grid 4. If this feed back is sufficient to overcome the losses, oscillations will result.



The frequency of the oscillations will be such as to cause the feed back voltage to be of a phase that will augment the energy in the resonator 12. The establishment of this correct phase will be effected by an automatic adjustment of transit time and phase relations of resonator and feed back circuits. This frequency of oscillation, when there is no moduation, will represent the mean value of carrier frequency. When there is modulation voltage applied by source 30, there will be either an increase or a decrease of accelerator voltage, depending upon the modulation. This variation in the modulating voltage and consequent variation in the accelerator voltage, which in turn will affect the transit time of the electrons in the stream, will change the phase of the feed back energy proportionately. This change in phase will cause a change in the frequency of oscillations due to the inherent tendency of an oscillator to maintain proper phase relation between feed-back and induced voltage.

In practice, the Q of the input circuit 9, 10, as well as the transmission line 23 and the coupling loop 21, 25, is made as low as practicable so that the phase shift therein will be a minimum for a given change in frequency, and the Q of the resonator 12 is chosen for the particular deviation in frequency required. The dimensions and position of loop 21 are adjusted so that the effective Q of the resonator is low enough to accommodate the frequency deviation desired. As a practical matter, each time the feed back or load coupling is changed, it may be necessary to adjust the tuning of the output circuit. Another means for adjusting the effective Q of the resonator is by adjusting the positions of the taps on line 25 extending to the utilization circuit. Any less value of Q for the resonator will result in an undesirable and unnecessary decrease in efficiency. In practice, it is desired that the Q of the resonator be sufficiently low to permit frequency modulation over a desired range of frequencies with relatively small changes in amplitude over said range. If desired, the loop 21 may be replaced by any suitable coupling element or elements, such as an open dipole, whose dimensions and position also control the effective Q of the resonator.

In one embodiment actually tried out in practice, the average frequency or carrier was 480 megacycles and the oscillator was varied over a range of plus and minus 2½ megacycles about this mean frequency of 480 megacycles. The average voltage applied to the accelerating electrodes was 2500 volts positive, and the voltage applied to the collector electrode was 1200 volts positive. Although these values of voltage were employed in connection with an experimental model successfully constructed to demonstrate the principles involved, it should be distinctly understood that these values are merely illustrative and that as electron tubes become commercially available and the transit time and relative distances of the electrodes are changed from those encountered during the demonstration, that more useful values will result.

The phase modulator and amplitude modulating embodiments shown in Figs. 2 and 3 respectively, have been considerably simplified in order to show only the essential elements of the tube structure necessary for an understanding of the principles involved. The electron focusing elements and the envelope of the vacuum tube have not been shown in Figs. 2 and 3 in order to simplify the drawing. Those elements of these fig-

ures which are the same or equivalent to the elements shown in Fig. 1 are represented by the same reference numerals.

In Fig. 2 there is shown a constant source of high frequency currents 32 for applying between the cathode 2 and grid 4 a voltage to modulate the density of the beam of electrons emanating from the cathode. This beam of electrons which is modulated by the high frequency wave impressed by source 32 on the grid 4 tranverses the gap *a*, *b* of the resonator 12 before impinging on the positively charged collector electrode 6, and excites the resonator 12 by induction in the manner now known in the art. The accelerator electrodes 5, 5 are connected together and coupled to a suitable source of modulating voltage 30, the latter impressing the alternating current voltage upon the electrodes 5, 5 for causing either an increase or decrease of the accelerator voltage depending upon the modulation. As in the case of Fig. 1 described above, this variation of modulating voltage with the consequent variation in the accelerator voltage will affect the transit time of the electrons in the stream and thus change the relative phase of the input voltage on grid 4 with respect to the induced voltage in the resonator. Coupling loop 21 is used to derive an output current whose phase continuously varies in accordance with the modulating voltage. Since it is desired to have as little amplitude modulation as possible over the desired range of frequencies, the Q of the resonator 12 should be reduced to the lowest practical value. This reduction of the Q of the resonator is predicated upon not having an amplitude limiter stage following this phase modulator.

Fig. 3 shows an amplitude modulated system employing a regenerative feed back circuit 23' extending from the output loop 21 back to the input circuit 2, 4. Here again there is provided the constant source of high frequency waves 32 for exciting the grid 4. In the operation of this circuit the regeneration adjustment is set to prevent oscillations within the range of modulation. The increase or decrease of the accelerator voltage on the electrodes 5. 5 caused by the application of modulating voltage from 30 will cause a change in the phase between the voltage on grid 4 and the voltage induced in the resonator 12. This phase change in turn causes a corresponding change in the regeneration resulting in a variation in the amplitude of the output voltage. In order to have a minimum phase modulation coincident with amplitude modulation, a high Q is chosen for the resonator 12. This will in turn give high efficiency. The Q of the feed back circuit 23' may be any value that is convenient.

In the operation of the circuit of Figs. 1, 2 and 3, the velocity of the electrons in the stream throughout the length of the beam (the useful part of the stream) is substantially constant, except for such deceleration as is caused by the energy taken by the resonator 12. The same potentials on both accelerator electrodes 5, 5 insures this desired constant velocity condition. There is a minimum electric field in the beam in the space between the accelerator electrodes (substantially electric field free space), and it can be said, in effect, that the electric field of the tank 12 is superimposed on this minimum field in order to decelerate the electrons. The particular embodiments of the invention shown herein make no use of velocity modulation, as is commonly known in the art, for the purpose of obtaining high frequency feed back by grouping or bunching the electrons.

In the design of the electron discharge device circuits of Figs. 1, 2 and 3, it may be advisable to operate the system with the resonator 12 at the same average potential as the accelerator electrodes 5, 5. This is done in order to prevent any potential gradients affecting the electron beam between the two accelerator electrodes 5, 5. Where a single ended circuit constituting a coaxial line is employed for an input or an output circuit, it is necessary to prevent the application of the direct current voltage on the resonator to the grounded outer conductor, and a condenser is used for this purpose. This condenser is made to have low impedance to radio frequency currents in order to by-pass the same to ground. Since the accelerator electrodes are subjected to a modulation potential, the resonator in this instance would be isolated from these electrodes by a choke and/or resistor effective for the modulation frequencies.

Fig. 4 shows the principles of the invention applied to a frequency modulated transmitter. This figure is identical with Fig. 1, except for the following features: (1) Fig. 4 employs only one accelerator electrode 5, and (2) the cavity resonator 12 is maintained at the same average potential as the accelerator electrode. The effective Q of cavity 12 is adjusted by adjusting the dimensions and location of loop 21, or by adjustment of the load taps on line 25, to be sufficiently low so that frequency modulation is obtained over a desired range of frequencies with relatively little change in amplitude over these same frequencies.

It should be understood that the invention is not limited to the precise embodiments shown in the drawing and described in the specification, since various modifications may be made without departing from the spirit and scope of the invention. As an illustration, the principles of the invention are applicable to a regenerative amplifier where it is desired to change the degree of regeneration at any frequency varying from zero into the range of megacycles. Further, the output coupling loop 21 can be replaced by any suitable coupling arrangement, either capacitive, inductive or conductive. Moreover, the result of the invention can be obtained by modulating only the accelerator adjacent the cathode, as well as by modulating both accelerators. It will thus be obvious that it is possible to design the tube in which there is only present the accelerator adjacent to the cathode. The number of accelerator electrodes used in addition to the one adjacent to the cathode depends upon the refinement of the tube design.

The term "angular velocity" used in the appended claims is deemed to include both frequency modulation and phase modulation phenomena.

What is claimed is:

1. In an electron discharge device having a pair of electrodes between which an electron stream passes, and a single tuned circuit physically located between said pair of electrodes and in energy coupling relation to said stream, the method of operation which includes biasing said pair of electrodes positively and to the same degree, and varying said bias in accordance with a continuously variable frequency wave, whereby the time of transit of the electrons in the space between said electrodes is varied with a consequent continuous change in the relative

phase of the voltage induced in said tuned circuit.

2. In an electron beam tube having a cathode, an input electrode having a voltage impressed thereon, and a single output tank circuit adapted to be excited inductively by the passage of a stream of electrons emanating from said cathode, and an electron accelerator electrode positioned between said input electrode and said output tank and maintained at a positive direct current potential relative to said cathode, the method of operation which includes varying the effective bias potential on said accelerator electrode in a continuous manner in accordance with a variable audio frequency wave to thereby vary the time of transit of electrons in said stream and the phase relation between the input voltage and the induced voltage in the tank.

3. In an electron beam regenerative tube having a cathode, a control electrode, a source of constant frequency oscillations coupled between said control electrode and cathode, an output circuit adapted to be excited inductively by the passage of a stream of electrons emanating from said cathode, and a feed back circuit between said output circuit and said control electrode, the method of operation which includes varying the phase relation between the voltage induced in said output circuit and the voltage fed back to said control electrode by varying the transit time of the electrons in said stream.

4. In an electron discharge device modulation system including a source of signal modulations and a pair of electrodes between which an electron stream passes, a direct connection of substantially zero impedance for all modulating frequencies coupling said pair of electrodes together, a tank circuit having a gap located between said pair of electrodes and across which gap said electron stream passes, said tank being arranged to be inductively excited by the passage of the electrons across said gap, the method of operation which includes varying the density of the electrons in said stream prior to the passage of said electrons past the first of said pair of electrodes, and varying in accordance with signal modulations the electron transit time between said pair of electrodes.

5. In an electron discharge device modulation system including a source of signal modulations and a pair of electrodes between which an electron stream passes, a direct connection of substantially zero impedance for all modulating frequencies coupling said pair of electrodes together, a tank circuit having a gap located between said pair of electrodes and across which gap said electron stream passes, said tank being arranged to be inductively excited by the passage of electrons across the gap, the method of operation which includes modulating the density of the electrons in said stream at a constant high frequency rate prior to the passage of said electrons past the first of said pair of electrodes, and varying in accordance with signal modulations the electron transit time between said pair of electrodes.

6. An electron discharge device circuit including means for projecting a stream of electrons, a tuned circuit adapted to be excited by the passage of the electrons in said stream and having a gap adjacent the stream of electrons whereby said tuned circuit absorbs energy from said stream, accelerating electrodes located on both sides of said gap and maintained at the same positive potential, and means for varying the voltage on said accelerator electrodes between certain limits in accordance with an undulatory wave, whereby the transit time of the electrons in said stream is caused to change.

7. An electron discharge device circuit including a tank circuit in the form of a surface of revolution having a gap, a source of electrons for projecting a stream of electrons across said gap for inducing a voltage in said tank circuit, accelerating electrodes located on both sides of said gap and maintained at a positive potential relative to said source and to the same degree, and means for varying the voltage on said accelerator electrodes between certain limits in accordance with variable electrical waves, whereby the transit time of the electrons in said stream is caused to change.

8. An electron discharge device circuit including a tank circuit in the form of a surface of revolution having a gap in the center thereof, a cathode for projecting a stream of electrons across sad gap at right angles to the central plane of said surface for exciting said tank circuit, focussing means for said electrons, accelerator electrodes on both sides of said gap, a source of unidirectional potential for maintaining said accelerator electrodes at a positive potential relative to said cathode and to the same degree, a source of alternating current having a range of modulating frequencies and connected to said accelerator electrodes whereby the potential on said accelerator electrodes is varied in accordance with the modulation with a consequent change in the transit time of the electrons in said stream.

9. An electron discharge device having a cathode, and a pair of spaced positively biased electrodes, said positively biased electrodes being separated solely by etheric space and maintained at the same positive potential, a tank circuit having an aperture located between said electrodes and adapted to be excited by the passage of electrons through said aperture, a connection between said positively biased electrodes, means for directing electrons from said cathode past said positively biased electrodes in succession with a velocity which is substantially constant throughout the distance between said positively biased electrodes, and a connection from said positively biased electrodes to a source of variable wave modulating voltage, whereby the transit time of the electrons varies in accordance with variation of said modulating voltage.

10. An electron discharge device circuit including a tank circuit in the form of a surface of revolution having a gap, a source of electrons for projecting a stream of electrons across said gap for inducing a voltage in said tank circuit, accelating electrodes located on both sides of said gap and maintained at the same positive potential, a control element located between said source of electrons and the first of said accelerator electrodes, a constant source of high frequency oscillations connected between said control element and said source of electrons, and means for varying the voltage on said accelerator electrodes in accordance with signal modulation whereby the transit time of the electrons in said stream is caused to change.

11. An electron discharge device circuit including a tank circuit in the form of a surface of revolution having a gap, a source of electrons for projecting a stream of electrons across said gap for inducing a voltage in said tank circuit, accelerating electrodes located on both sides of said gap and maintained at the same positive poten-

tial, a control element located between said source of electrons and the first of said accelerator electrodes, a constant source of high frequency oscillations connected between said control element and said source of electrons, a feed back circuit extending from said tank circuit to said control element, and means for varying the voltage on the accelerating electrodes in accordance with signal modulations, whereby the transit time of the electrons in said stream is caused to change.

12. An electron discharge device circuit including a tank circuit in the form of a surface of revolution having a gap, a source of electrons for projecting a stream of electrons across said gap for inducing a voltage in said tank circuit, accelerating electrodes located on both sides of said gap and maintained at the same positive potential, a control element located between said source of electrons and the first of said accelerator electrodes, a feed back circuit extending from said tank circuit to said control element, and means for varying the voltage on said accelerator electrodes in accordance with signal modulation, whereby the transit time of the electrons in said stream is caused to change.

13. An electron discharge device circuit including means for projecting a stream of electrons, a tuned circuit adapted to be excited by the passage of the electrons in said stream and having an element adjacent the stream of electrons, whereby said tuned circuit absorbs energy from said stream, accelerating electrodes located on both sides of said element and maintained at the same positive potential, a control electrode located between said means and the first of said accelerator electrodes, a feed back circuit extending from said tuned circuit to said control electrode, and a modulating source of variable frequency waves connected to said accelerating electrodes for varying the accelerator voltage in dependence upon the modulation, with a consequent variation in the transit time of the electrons.

14. A modulator system for use at very high frequencies comprising an electron discharge device circuit including means for projecting a stream of electrons, a tuned circuit adapted to be excited by the passage of the electrons in said stream and having an element adjacent the stream of electrons whereby said tuned circuit absorbs energy from said stream, accelerating electrodes located on both sides of said element and maintained at the same positive potential, a control electrode located between said means and the first of said accelerator electrodes, a feed back circuit extending from said tuned circuit to said control electrode, and a modulating source of variable frequency waves connected to said accelerating electrodes for varying the accelerator voltage in dependence upon the modulation frequency.

15. Apparatus in accordance with claim 14, characterized in this that said system is a frequency modulation system.

16. An amplitude modulation system in accordance with claim 14, characterized in this that a constant source of high frequency oscillations is connected between said control electrode and said means for projecting a stream of electrons.

17. A phase modulator comprising an electron discharge device circuit including means for projecting a stream of electrons, a tuned circuit adapted to be excited by the passage of the electrons in said stream and having an element adjacent the stream of electrons whereby said tuned circuit absorbs energy from said stream, accelerating electrodes located on opposite sides of said element and maintained at the same positive potential, a control electrode located between said means and the first of said accelerator electrodes, a constant frequency source connected to said control electrode, and a source of modulating voltage coupled to said accelerating electrodes.

18. In an electron discharge device having a cathode, an input control electrode, and an output tank circuit adapted to be excited inductively by the passage of a stream of electrons emanating from said cathode, the method of operation which includes producing constant high frequency oscillations, impressing said constant frequency oscillations between said control electrode and said cathode, and subjecting the electrons between said control electrode and said tank to a varying electric field in accordance with signal modulations.

19. In an electron discharge device having a cathode, an input control electrode, and an output tank circuit adapted to be excited inductively by the passage of a stream of electrons emanating from said cathode, the method of operation which includes impressing constant frequency oscillations between said control electrode and said cathode, also feeding back energy from said tank circuit to said control electrode, and subjecting the electrons between said control electrode and said tank to a varying electric field in accordance with signal modulations.

20. An electron discharge device circuit including means for projecting a modulated stream of electrons, a tuned circuit adapted to be excited by the passage of said modulated stream and having an aperture adjacent the stream of electrons whereby said tuned circuit absorbs energy from said stream, an accelerating electrode located between said aperture and said means, means for maintaining said accelerating electrode at a positive potential, and means for varying the potential on said accelerator electrode in accordance with variable frequency signal modulations, whereby the transit time of the electrons in said stream is caused to change.

21. An electron discharge device circuit including a cathode for supplying a stream of electrons, a cavity resonator having a gap therein located in the path of travel of said electrons, whereby said stream of electrons and said resonator are in energy coupling relation, first and second electron permeable electrodes located between said gap and said cathode, a source of alternating current coupled to said first electrode, a source of unidirectional potential for maintaining said second electrode at a positive potential relative to said cathode, and means for varying the potential on said second electrode in accordance with signal modulations, whereby the transit time of the electrons in said stream is caused to change.

22. An electron discharge device circuit including a cathode for supplying a stream of electrons, a cavity resonator surrounding a portion of the path of travel of said stream, said resonator having apertures in both sides thereof to enable said electrons to pass through said resonator, whereby said stream of electrons and said resonator are in coupling relation to each other, first and second electron permeable electrodes located between said cathode and the first of the apertures of said resonator to be traversed by said electrons, a source of alternating

current coupled to said first electrode, a source of unidirectional potential for maintaining said second electrode at a positive potential relative to said cathode, and means for varying the potential on said second electrode in accordance with signal modulations, whereby the transit time of the electrons in said stream is caused to change.

23. An electron discharge device circuit including a cathode for supplying a stream of electrons, a cavity resonator surrounding a portion of the path of travel of said stream, said cavity resonator being in the form of a surface of revolution with the central plane thereof substantially at right angles to the path of travel of said stream, said resonator having apertures in both sides thereof to enable said electrons to pass through said resonator, whereby said stream of electrons and said resonator are in coupling relation to each other, first and second electron permeable electrodes located between said cathode and the first of the apertures of said resonator to be traversed by said electrons, means for impressing an alternating potential on said first electrode, a source of unidirectional potential for maintaining said second electrode at a positive potential relative to said cathode, and means for varying the potential on said second electrode in accordance with signal modulations, whereby the transit time of the electrons in said stream is caused to change.

24. In an electron beam tube having a cathode, an input electrode having a voltage impressed thereon, and a tuned circuit in inductive coupling relation to the stream of electrons emanating from said cathode, and an accelerator electrode positioned between said input circuit and said tuned circuit and maintained at a positive direct current potential, the method of operation which includes varying the effective potential on said accelerator electrode in accordance with an audio frequency wave to thereby vary the time of transit of the electrons in said stream and the phase relation between the input voltage and the induced voltage in the tuned circuit.

25. In an evacuated electron discharge device circuit, means for supplying a stream of electrons, a cavity resonator surrounding a portion of the path of travel of said stream, said cavity resonator being in the form of a surface of revolution with the central plane thereof substantially at right angles to the path of travel of said stream, said resonator having apertures in both sides thereof to enable said electrons to pass through said resonator, whereby said stream of electrons and said resonator are in coupling relation to each other, an accelerating electrode located between said means and the first of the apertures of said resonator to be traversed by said electrons, means for maintaining said electrode at a positive potential relative to said electron supplying means, a source of speech waves coupled to said electrode for varying the potential on said electrode, whereby the transit time of the electrons in said stream is caused to change, a control grid located between said accelerating electrode and said first means, and a source of high frequency current coupled to said control grid.

26. In an electron discharge device oscillator system having a pair of electrodes between which an electron stream passes and a single tuned circuit physically located between said pair of electrodes and in energy coupling relation to said stream, the method of producing a high frequency carrier of a frequency determined over a certain band by the amplitude of a controlling voltage which includes biasing said pair of electrodes positively, and varying the relative phase of the voltage induced in said tuned circuit by simultaneously varying between certain limits and in continuous manner the bias on said pair of electrodes in accordance with variable frequency signal modulations.



27. In an electron discharge device oscillator system having a pair of electrodes between which an electron stream passes and a tuned circuit located between said pair of electrodes and in energy coupling relation to said stream, the method of producing a high frequency carrier of a frequency determined over a certain band by the amplitude of a controlling voltage which includes biasing said pair of electrodes positively, and varying the relative phase of the voltage induced in said tuned circuit by simultaneously varying between certain limits and in continuous manner the bias on said pair of electrodes in accordance with variable frequency signal modulations and to the same degree.

28. A phase modulator comprising an electron discharge device circuit including means for projecting a stream of electrons, a tuned circuit adapted to be excited by the passage of the electrons in said stream and having an element adjacent the stream of electrons whereby said tuned circuit absorbs energy from said stream, accelerating electrodes located on both sides of said element and maintained at the same positive potential, a control electrode located between said means and the first of said accelerator electrodes, a constant frequency source connected to said control electrode, and a source of variable frequency modulating voltage coupled to said accelerating electrodes.

29. An electron discharge device system for operation over a range of frequencies comprising means for projecting a stream of electrons, a cavity resonator of relatively low Q having a gap and adapted to be excited by the passage of electrons in said stream across said gap, an electron accelerator electrode positioned between said means and said resonator, a source of unidirectional potential for maintaining said accelerator electrode at a potential which is positive relative to said means, and means for varying the transit time of said electrons in accordance with signal voltages, a load coupled to said resonator by a coupling element in the interior of said resonator, the degree of coupling between said resonator and said load being such as to provide a desired effective Q of the resonator which permits modulation over said range of frequencies with relatively small change in amplitude.

30. An electron discharge device system for operation over a range of frequencies comprising an electron emitting cathode, a cavity resonator of relatively low Q having a gap and adapted to be excited by the passage across said gap of electrons emitted by said cathode, an electron accelerator electrode positioned between said cathode and the gap of said resonator, an electron collector electrode on the side of said gap remote from said cathode, a source of unidirectional potential for maintaining said accelerator electrode at a potential which is positive relative to said means, and means for varying the transit time of said electrons in accordance with signal voltages, a load coupled to said resonator by a coupling element in the interior of said resonator, the degree of coupling between said resonator and said load being such as to

provide a desired effective Q of the resonator which permits modulation over said range of frequencies with relatively small changes in amplitude, the Q of said coupling element being made relatively low so that the phase shift therein will be a minimum for a given change in frequency, the Q of said resonator being only sufficiently low to accommodate the frequency deviation desired.

31. A frequency modulation generating system comprising an electron discharge device circuit including an electron emitting cathode, a cavity resonator having a gap and adapted to be excited by the passage of electrons across said gap, an electron accelerator electrode positioned between said cathode and said gap, means for maintaining said accelerator electrode at a positive potential relative to said cathode, means for varying the transit time of the electrons in accordance with signal voltages, whereby frequency modulated waves are generated, said resonator having a Q which is sufficiently low to permit frequency modulation over a desired frequency range with relatively small changes in amplitude over said range.

32. An angular velocity system comprising an electron discharge device circuit including an electron emitting cathode, a cavity resonator having a gap and adapted to be excited by the passage across said gap of electrons emitted by said cathode, an electron accelerator electrode positioned between said cathode and gap, means for maintaining both said resonator and said accelerator at the same average potential relative to said cathode, means for varying the transit time of the electrons in accordance with signal voltages, whereby angular velocity modulated waves are generated, said resonator having a Q which is sufficiently low to permit angular velocity modulation over a desired range with relatively small changes in amplitude over said range.

33. An electron discharge device system comprising means for projecting a stream of electrons, a cavity resonator having a gap and adapted to be excited by the passage of electrons in said stream across said gap, an electron accelerator electrode positioned between said means and said resonator, means for maintaining said accelerator electrode at a positive potential, means for varying the transit time of said electrons in accordance with signal voltages, a load coupled to said resonator by means of a coupling element in the interior of said resonator, the dimensions and position of said coupling element being such as to give a desired effective Q for said resonator, and means for varying the Q of said resonator.

34. A frequency modulation generating system comprising an electron discharge device circuit including an electron emitting cathode, a cavity resonator having a gap and adapted to be excited by the passage of electrons across said gap, an electron accelerator electrode positioned between said cathode and said gap, an electron permeable electrode positioned between said cathode and said accelerator electrode, means for maintaining said accelerator electrode at a positive potential relative to said cathode, means for varying the transit time of the electrons in accordance with signal voltages, whereby frequency modulated waves are generated, said resonator having a Q which is sufficiently low to permit frequency modulation over a desired frequency range with relatively small changes in amplitude over said range, and a feed back circuit of relatively low Q from said cavity resonator to said electron permeable electrode.

35. High frequency apparatus comprising a cavity resonator having a gap, an electron discharge system for producing a flow of electrons across said gap, said discharge system comprising cathode, a single control grid, accelerating and anode electrodes arranged in the order named, a circuit connected between said control grid and cathode for varying the electron flow from said cathode and across said gap in a manner so as to cause high frequency excitation of said cavity, a source of signal modulating voltages connected to said accelerating electrode and said cathode, so as to subject said accelerating electrode to a modulating potential with respect to said cathode, and an output circuit coupled to the space in said cavity resonator to enable the derivation therefrom of modulated high frequency oscillations.

36. Apparatus as defined in claim 35, characterized by the fact that a coupling circuit is provided coupling the space in said cavity to the control grid and the cathode electrodes of said system.

37. Apparatus for producing frequency modulated waves comprising a cavity resonator having a gap, an electron discharge system for producing a flow of electrons across said gap, said system comprising cathode, a single control grid, accelerating and anode electrodes arranged in the order named, a circuit coupling said cavity resonator to the control grid and cathode of said system, a circuit for suitably polarizing said anode with respect to said cathode, a circuit connected to said accelerating electrode and cathode for subjecting said accelerating electrode to a variable voltage with respect to said cathode so as to produce frequency modulated waves in said cavity resonator, and an output circuit coupled to said cavity resonator.

38. High frequency apparatus comprising a cavity resonator having a gap, an electron discharge system for producing a flow of electrons across said gap, said discharge system comprising cathode, a single control grid, accelerating and anode electrodes arranged in the order named, circuits for subjecting said electrodes to suitable operating potentials with respect to each other, a circuit connected between said control grid and cathode for varying the electron flow from said cathode and across said gap in a manner so as to cause high frequency excitation of said cavity, a source of modulating voltages connected to said cathode and accelerating electrode, and an output circuit coupled to the space in said cavity resonator to enable the derivation therefrom of modulated high frequency oscillations.

39. Apparatus as defined in claim 38, characterized by the fact that a coupling circuit is provided coupling the space in said cavity to the control grid and the cathode electrodes of said system.

40. Apparatus for producing frequency modulated waves comprising a cavity resonator having a gap, an electron discharge system for producing a flow of electrons across said gap, said system comprising cathode, a single control grid, accelerating and anode electrodes arranged in the order named, a two-conductor circuit coupling the space within said cavity to the control grid and cathode of said system, a circuit for suitably polarizing said anode with respect to said cathode, a circuit connected to said accel-

erating electrode and cathode for subjecting said accelerating electrode to a variable voltage with respect to said cathode so as to produce frequency modulated waves in said cavity resonator, and an output circuit coupled to said cavity resonator.

41. Apparatus as defined in claim 40, characterized by the fact that a high frequency parallel tuned circuit is connected between said grid and cathode and being further characterized by the fact that said two-conductor circuit is inductively coupled to said tuned circuit.

42. High frequency apparatus comprising a cavity resonator having a gap, an electron discharge system for producing a flow of electrons across said gap whereby said cavity resonator is excited at high frequencies, said discharge system comprising cathode, a single control grid, accelerating and anode electrodes arranged in the order named, a circuit connected between said control grid and cathode, a transmission line regeneratively coupling said circuit to said resonator, a source of signal modulating voltages, a circuit connecting said source of modulating voltages to said cathodes and another of said electrodes, whereby the transit time of electrons across said gap is varied, and an output circuit coupled to the space in said cavity resonator to enable the derivation therefrom of modulated high frequency oscillations.

43. Apparatus for producing frequency modulated waves comprising a cavity resonator having a gap, an electron discharge system for producing a flow of electrons across said gap, said system comprising cathode, a single control grid, accelerating and anode electrodes arranged in the order named, a circuit regeneratively coupling said cavity resonator to the control grid and cathode of said system, a circuit for suitably polarizing said anode with respect to said cathode, and a modulation circuit connected to said cathode and another electrode of said system for varying the transit time of electrons across said gap, whereby frequency modulation of the waves set up in said cavity resonator occurs, and an output circuit coupled to said cavity resonator for transmitting said frequency modulated waves.

44. Apparatus as defined in claim 43, characterized by the fact that a high frequency tuned circuit is connected between said grid and cathode and being further characterized by the fact that said coupling circuit couples said tuned circuit to the space within said cavity.

45. Apparatus for producing modulated waves comprising a cavity resonator having a gap, an electron discharge system for producing a flow of electrons across said gap, said system comprising cathode, a single control grid, accelerating and anode electrodes arranged in the order named, a source of high frequency oscillations connected to said grid and cathode electrodes, a circuit coupling the space within said cavity to the control grid and cathode of said system, a circuit for suitably polarizing said anode with respect to said cathode, a circuit connected to said accelerating electrode and cathode for subjecting said accelerating electrode to a variable voltage with respect to said cathode so as to produce modulated waves in said cavity resonator and an output circuit coupled to said cavity resonator.

46. Apparatus as defined in claim 45, characterized by the fact that a high frequency tuned circuit is connected between said grid and cathode and being further characterized by the fact that said circuit which couples the space within said cavity to the control grid and cathode includes a transmission line which is coupled to said tuned circuit.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

| Number | Name | Date |
|---|---|---|
| 2,257,795 | Gray | Oct. 7, 1941 |
| 2,280,824 | Hansen | Apr. 28, 1942 |

OTHER REFERENCES

Journal of Applied Physics, vol. 10, May 1939, pp. 321–327. Copy in Library.