

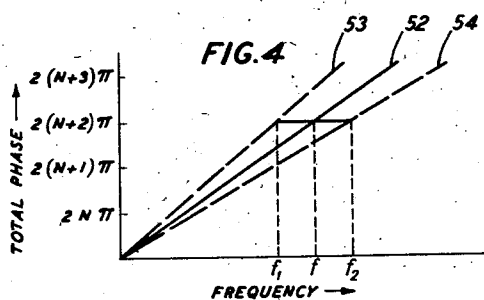
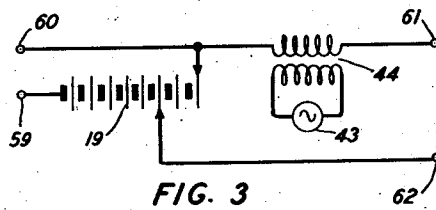
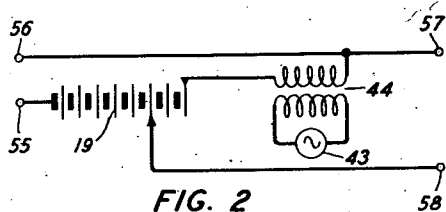
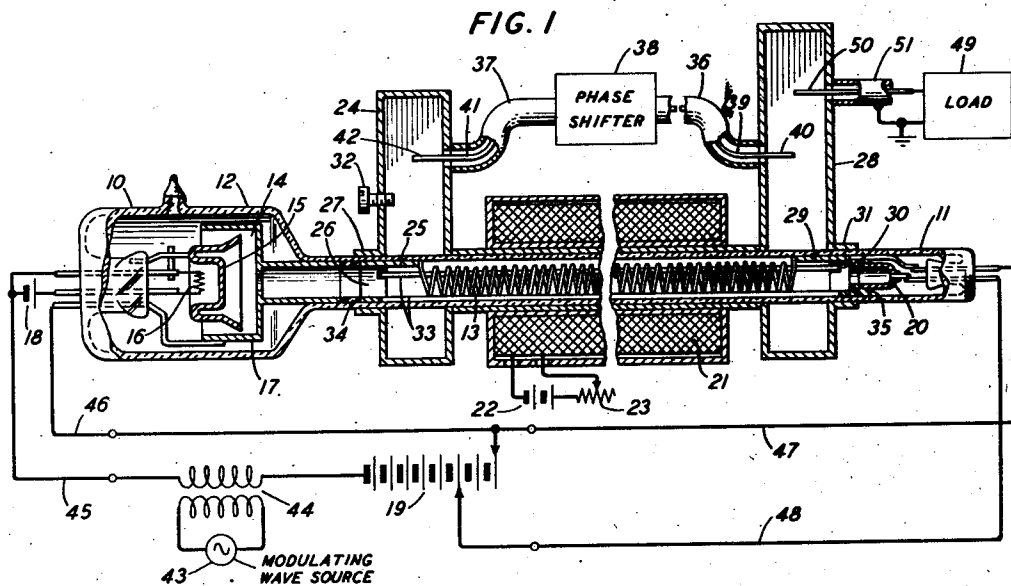
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L. M. FIELD

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MODULATED OSCILLATOR

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MODULATED OSCILLATOR

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16 Claims. (Cl. 332-7)

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This invention relates to signaling means and more particularly to means for the generation of frequency modulated electrical waves.

It is an object of the invention to provide new and improved methods of and means for producing electrical waves having frequency variations in accordance with modulating signals.

It is another object of the invention to provide apparatus methods of and means for utilizing traveling wave amplifying devices for the generation and modulation of high frequency electrical waves.

There have been proposed electron beam amplifying devices wherein amplification is achieved by the interaction between the electron stream and a pure traveling wave, that is, a wave which progresses continuously in a single direction without reflection, along an extended path. Such amplifying devices include a wave guide disposed along the path of the electron stream, the wave guide having an organization such that the traveling wave has electric field components in the direction of the electron stream and there is substantial equality between the speed of propagation of the wave in the direction of the stream and the speed of the electrons in the electron stream. The electron stream then reacts on the electric field of the traveling wave and the electric field reacts on the electron stream in a manner such that the wave increases in amplitude as it progresses along the path. Amplifying devices of this nature have been termed traveling wave amplifiers and have been described, for example, in copending application Serial No. 640,597, filed January 11, 1946 by J. R. Pierce and copending application Serial No. 704,858, filed October 22, 1946 by J. R. Pierce.

There are disclosed in copending application Serial No. 64,309, filed December 9, 1948, by L. M. Field, circuit arrangements whereby traveling wave amplifying devices may be utilized for the generation of high frequency oscillations by utilizing a high frequency energy feedback path between the output end and the input end of the wave guide incorporated in the device. A traveling wave amplifier may then be used for the generation of stable high frequency oscillations whose frequency is primarily determined by the effective electrical length of the loop circuit formed by the wave guide of the device and the feed-back path.

In a wave amplifying device of the character described, the wave propagated along the wave guide of the amplifying device as an increasing wave has a phase velocity which, in the absence of an electron stream, is dependent upon the configuration and electrical characteristics of the wave guide. However, in the presence of an electron stream the phase velocity of the traveling wave is also dependent upon the velocity of the

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electrons of the electron stream. Under such conditions, while the phase velocity of the propagated wave is different from the velocity of the electrons, the phase velocity of the wave is increased when the velocity of the electrons is increased and conversely the phase velocity of the wave is decreased when the velocity of the electrons is decreased.

The present invention contemplates circuit arrangements whereby the effect upon the phase velocity of the wave produced by changing the electron velocity may be utilized in a feed-back oscillator to provide an improved means for the generation of electrical waves whose frequency is modulated in accordance with arbitrary signals representing speech or other intelligence to be impressed upon the generated waves. Generically, the invention may be embodied in a form such that the potential gradients along the path of the electron stream of a traveling wave amplifier are varied in accordance with the modulating signals to produce an electron velocity variation and a consequent phase variation of the wave traveling along the wave guide incorporated in the amplifying device. There is thus produced an effective change in the electrical length of the loop circuit whereby the frequency of the generated waves is varied in accordance with the modulating signals. More particularly, as applied to the structure described in the application Serial No. 704,858 by J. R. Pierce to which reference has been made, the variable potential gradient may preferably be obtained by varying the potential of the helix, which serves as the wave guide, with respect to the potential of the electron source or cathode. Alternatively the modulating potentials may be utilized to vary the potential of either the focussing electrode of the electron gun or the collector anode with respect to the potential of the cathode. Other possible embodiments of the invention are pointed out in connection with the detailed description of the invention.

The features of this invention are pointed out with particularity in the appended claims. The invention itself may be better understood by reference to the following detailed description taken in connection with the accompanying drawings in which:

Fig. 1 illustrates an embodiment of the invention utilizing the preferred form of amplifying device;

Figs. 2 and 3 illustrate alternative circuit arrangements useful in connection with the embodiment of Fig. 1; and

Fig. 4 is a graph useful in explaining the principles of operation of the circuits of the invention.

Referring now to Fig. 1, there is shown an illustrative embodiment of the circuit of the invention employing a traveling wave amplifying device

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adapted for use at hyper and ultra-high frequencies. The arrangement shown comprises an electron beam tube 10 including an evacuated envelope having an elongated portion 11 and an enlarged electron-gun-containing portion 12. The envelope is constituted of a low loss insulating material such as quartz or glass.

The discharge device 10 is provided with a source of electrons together with means for forming the electrons from the source into a concentrated stream directed axially through an elongated helix 13 disposed within the elongated portion 11 of the envelope. The illustrative combination includes a known type of electron gun 14 comprising a cathode 15, a heater 16, and a focussing electrode 17. The heater 16 is supplied with energy from a source 18 and, together with the cathode 15, is connected to the negative pole of a high potential source 19. The focussing electrode 17 is biased to a suitable potential by the high potential source 19 and is of a configuration which provides field patterns adapted to accelerate and focus electrons from the cathode 15 into a concentrated stream. The electron stream so formed moves along an axial path through the helix 13 to a collector anode 20, the helix and the collector anode being maintained at suitable positive potentials by the source 19. The electron stream is further concentrated and guided along the axial path by a magnetic field formed by a coil 21 which is energized by a source 22 through a rheostat 23. The strong magnetic field serves also to prevent the deviation of the electron stream from the desired path by outside magnetic influences.

The elongated helix 13 serves as a wave transmission path or wave guide along which high frequency waves may be propagated to interact with the electron stream flowing therethrough. In order to perform this function the dimensions of the helix must be such that the waves will be propagated in a mode having electric field components in the direction of the electron stream and at a speed along the axis of the helix of an order to which the electron stream may be accelerated by the use of moderate voltages. For accelerating voltages in the order of 1,500 to 2,000 volts, the helix may be wound with several turns per wavelength along the axis. The interaction between the electron stream and the traveling wave is cumulative and to insure an adequate interaction, the axial length of the helix may be of the order of thirty to forty wavelengths.

There are provided wave paths external to the amplifying device 10 for coupling waves or impulses to be amplified to the helix 13 and for transferring to load or other utilization circuits the amplified wave appearing at the output end of the helix. At the input end of the helix 13, an input circuit or wave path is conventionally represented as a wave guide 24 of rectangular cross-section. The amplifying device 10 is inserted transversely through the input wave guide 24, coupling between the guide and the helix 13 being achieved by means of an input coupling strip 25 conductively connected to the input end of the helix. There is provided a cylindrical metallic section 26 which supports the input coupling strip 25 and cooperates with a cylindrical metallic section 27 attached to the input wave guide 24 to effectively form an open circuited coaxial transmission line which has an electrical length in the order of one-fourth of the wavelength of the waves to be amplified. The trans-

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mission line thus formed acts as a low impedance path across the opening in the wall of the wave guide through which the envelope 11 is inserted and as a low impedance support point for the coupling strip 25. Similarly, at the output end of the helix the amplifying device 10 is inserted transversely through an output wave guide 28. An output coupling strip 29 is conductively connected to the helix 13 and is supported by a cylindrical metallic section 30 which cooperates with an external metallic section 31 attached to the output wave guide 28. In general, the couplings between the helix 13 and the input and output wave guides 24 and 28 may be proportioned in accordance with the considerations set forth in application Serial No. 705,181, filed October 23, 1946 by W. W. Mumford for optimum response over a wide range of operating frequencies. Thus the pitch of the turns on the helix 13 may be gradually increased over several turns at each end to assist in matching the impedances at the couplings over a wide band of frequencies. Necessary tuning of the external wave paths may be achieved by means such as a tuning screw 32 illustratively shown in connection with the input wave guide 24.

The helix 13 is supported by a series (e. g. three or four) of non-conductive ceramic rods 33, one only being shown, which are disposed between the helix and the envelope 11 and which also cooperate with ceramic spacers 34 and 35 to maintain a longitudinal spaced relation between the focussing electrode 17, the input coupling strip support section 26, the output coupling strip support section 30, and the collector anode 20. The ceramic rods 33 are coated with a wave dissipative material in order to dissipate waves traveling along the helix 13 in a direction opposite to that of the electron stream, the dissipative material and the rods being organized in accordance with the considerations set forth in application Serial No. 704,198, filed October 22, 1946, now United States Patent 2,575,383, dated November 20, 1951 by L. M. Field.

A high frequency energy feedback path is provided between the output wave guide 28 and the input wave guide 24 to form a feedback oscillator circuit in accordance with the considerations set forth in the previously referenced application Serial No. 64,309, filed December 9, 1948 by L. M. Field. The high frequency energy feedback path is conventionally represented as sections 36 and 37 of coaxial transmission line coupled through a known type of phase shifter 38, and extending between the output wave guide 28 and the input wave guide 24. An inner conductor 39 of the transmission line 36 is extended into the interior of the output wave guide 28 to form a coupling probe 40 while an inner conductor 41 of the transmission line 37 is extended into the interior of the input wave guide 24 to form a coupling probe 42. Thus, high frequency fields in the output circuit formed by the wave guide 28 will be communicated, at least in part, through the high frequency energy feedback path to set up corresponding fields in the input circuit formed by the wave guide 24. The energy in the input wave guide 24 is then imparted to the helix 13 to be amplified by interaction with the electron stream and to produce continuous electrical oscillations.

The phase shifter 38 is included in the high frequency energy feedback path to provide a representation of a necessary functional element of the feedback oscillator illustrated, although the phase shifter need not necessarily be present as a

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separate entity in a practical embodiment of the oscillator. The necessary phase shift is determined by the frequency of operation desired and may be achieved in accordance with the considerations set forth in the above referenced application by L. M. Field.

There is provided in accordance with the invention a source of modulating waves or signals conventionally represented as an alternating current generator 43. The source of signals may supply variable potentials or currents of a single frequency, or more commonly, a complex signal having a spectrum including many components such as is customarily utilized in the transmission of speech or visible images. Signals derived from the source 43 are applied through a coupling means, conventionally represented as a transformer 44, connected between the conductor 45 and the potential source 19, thus effecting a series connection between the cathode 15 and the potential source. The focussing electrode 17, the helix 13, and the collector anode 20 are connected to positive poles of the potential source 19 by means of conductors 46, 47, and 48 respectively, so that the potentials of each, while fixed with respect to the others, are simultaneously varied with respect to the cathode 15 in accordance with the amplitude variations of the modulating signals. The resulting variation of the potential gradients along the path of the electron stream thus produce electron velocity variations in the electron stream and, as will be seen from the subsequent discussion, variations in the frequency of the electrical oscillations appearing in the output wave guide 28. The modulated signals are imparted to a load 49 by means conventionally represented as an output coupling probe 50 and a transmission line 51.

The manner of operation of the circuits of the invention may be most readily understood while having in mind the pertinent operational aspects of the traveling wave amplifying devices used in those circuits. Briefly, the helix 13 of the illustrative device 10 of Fig. 1 acts as a wave guide for waves of proper frequencies, the waves being propagated along the turns of the helix in a mode such that the electrical field associated with the traveling wave has components in the direction of the electron stream. By reason of the fact that the wave travels along the circumference of the helix, the axial velocity of the wave is such that there is substantial equality between the speed of the electrons in the electron stream and the speed of propagation of the wave. Under such conditions the interaction between the electron stream and the wave increases the amplitude of the wave as it progresses along the helix.

A wave, in traveling over the helix from the input coupling strip 25 to the output coupling strip 29, will, in the absence of the electron stream, undergo a change in phase determined solely by the geometry and electrical characteristics of the helical wave transmission path. However, in view of the electrodynamic aspects of the wave as it propagates along the helix in the presence of the electron stream, the total phase shift of the wave in traversing the helix in the presence of the electron stream is also dependent upon the velocity of the electrons. Thus for every electron stream velocity as determined by the potentials applied to the focusing electrode 17, the helix 13, and the collector anode 20, there corresponds a value of phase shift experienced by a wave of a particular frequency in

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traversing the helix. Further, the total phase shift of the wave in traversing the helix will be a linear function of frequency, at least over restricted ranges of frequencies.

The principles of operation of the feedback oscillator of Fig. 1 have been described in detail in the L. M. Field application to which reference has previously been made. For the present purpose it may suffice to say that waves of proper frequencies, which may originate as random impulses, may successively traverse the loop formed by the helix 13, the output wave guide 28, the high frequency energy feedback path comprising the transmission lines 36 and 37 and the phase shifter 38, and the input wave guide 24. The amplitude of such waves is increased for each successive passage around the loop, the waves forming continuous oscillations which reach a limiting amplitude dependent upon the voltage and current characteristics of the amplifying device.

The waves which are built up into continuous oscillations are waves of a frequency such that they undergo a total phase shift which is an integral multiple of 2π radians in traversing the loop from a starting point such as the output coupling strip 29, through the output wave guide 28, the high frequency energy feedback path, the input wave guide 24, the helix 13, and back to the starting point. This phase shift may be termed the "loop phase shift" as distinct from the phase shift through the helix alone, which may be termed the "helix phase shift" utilizing the input and output coupling strips 25 and 29 as points of reference.

Since the loop phase shift and frequency of oscillation are related in an essentially linear fashion, it will now be seen that as the loop phase shift is changed by changing the electrical length of the loop the frequency will change correspondingly. This will be made more clear from a consideration of Fig. 4 where the functional relationships between the phase shift around the loop, plotted as an ordinate, and the frequency, plotted as an abscissa are set forth in graphic fashion. The solid curve 52 indicates the loop phase shift as a straight line or linear function of frequency, this representation being correct for at least limited ranges of frequency variation, the slope of the curve being determined by the total phase shift around the loop. The points along the ordinate corresponding to phase shifts of integral multiples of 2π radians then determine the possible frequencies or modes at which oscillation may take place, the phase shift for $2(N+2)\pi$ radians being arbitrarily selected as corresponding to a frequency f , which may be termed the "carrier frequency."

In accordance with the invention, variations of carrier frequency corresponding to the variations of the modulating signals are achieved by varying the velocity of the electron stream of the amplifying device 10. It will be apparent that, since the total loop phase shift must remain constant (i. e. for a given mode of oscillation) and since the phase shift of waves traversing the helix is a function of the frequency of the wave, as the velocity of the electron stream is varied the frequency of oscillation must also vary in order that the loop phase shift remain constant. Thus for oscillations corresponding to a loop phase shift of $2(N+2)\pi$ radians, the oscillation frequency is varied between the limiting frequencies f_1 and f_2 , the limiting variations indicated by the lines 53 and 54 being determined by the amplitude of the

modulating signal. It will be apparent that by choosing any one of the various modes of oscillation, the frequency change due to modulation may be determined over wide limits. Further, by suitable determination of the phase shift introduced by the external loop, as by adjustment of the phase shifter 38, both the carrier frequency and the frequency change due to modulation may be varied over wide limits in any given mode of oscillation.

Proceeding now to alternative embodiments of the invention, Figs. 2 and 3 illustrate alternative circuit arrangements whereby the electron stream velocity may be varied in accordance with the amplitude variations of the modulating signals. In order to utilize the circuit of Fig. 2, the sources of Fig. 1 may be replaced by those of Fig. 2 by connecting terminal 55 to conductor 45; terminal 56 to conductor 46; terminal 57 to conductor 47; and terminal 58 to conductor 48. The signal source 43 and the coupling transformer 44 are thus connected only between the potential source 19 and the focussing electrode 17 and the helix 13. Hence only the potentials of the helix and the focussing electrode, with respect to that of the cathode, are varied in accordance with the modulating signals.

The circuit of Fig. 3 may be utilized in the arrangement of Fig. 1 by connecting terminal 59 to conductor 45; terminal 60 to conductor 46; terminal 61 to conductor 47; and terminal 62 to conductor 48. The signal source 43 and the coupling means 44 are then connected only between the potential source 19 and the helix 13. Thus the potentials of the focussing electrode 17 and the collector anode 20 remain fixed while only the potential of the helix 13 is varied in accordance with the modulating signals.

It is to be understood that the invention is not to be limited to the embodiments described above, since by the very nature of the art many alternative circuits and structures are feasible within the spirit and scope of the invention.

What is claimed is:

1. In oscillation apparatus, in combination, a traveling wave amplifying device including a wave transmission path comprising a conductor in the form of an elongated helix, a source of electrons, and means for forming electrons from said source into a concentrated stream traveling at a suitable velocity lengthwise of and in the field region of said helix, a high frequency energy feedback path connected between an output and an input end of said helical wave transmission path whereby the generation of high frequency electrical oscillations is achieved, a source of modulating signals, and means for varying the velocity of the electrons of the said electron stream in accordance with the variations of the said modulating signals.

2. A frequency modulated oscillation apparatus comprising a traveling wave amplifier, a high frequency energy feedback path connected between an output end and an input end of said traveling wave amplifier whereby high frequency electrical oscillations may be generated, a source of modulating signals, and means responsive to the signals from said source for varying the frequency of said oscillations in accordance with the variations of the said modulating signals.

3. Oscillation apparatus comprising a traveling wave amplifier, a high frequency energy feedback path connected between an output end and an input end of said traveling wave amplifier whereby high frequency electrical oscillations

may be generated, a source of modulating signals, means responsive to the signals from said source for varying the frequency of said oscillations in accordance with the variations of the said modulating signals, and a load coupled to the output end of the said traveling wave amplifier for utilizing the modulated oscillations so produced.

4. In combination, a wave amplifying device comprising a source of electrons, means for forming electrons from said source into a stream along an extended path, and a wave guide for propagating waves along the path in a mode such that the waves have electric field components in the direction of the electron stream and a velocity of the same order as the velocity of the electrons of the electron stream, the said wave guide having an input end and an output end, means for coupling energy from said output end to said input end of said wave guide to form a feedback path for the generation of carrier oscillations, a source of modulating signals, and means responsive to the signals from said source for varying the velocity of the electrons of the said electron stream whereby the carrier oscillations are modulated in accordance with signals from said source.

5. In combination, a wave amplifying device comprising a source of electrons, means for forming electrons from said source into a stream along an extended path, and a wave guide for propagating waves along the path in a mode such that the waves have electric field components in the direction of the electron stream and a velocity of the same order as the velocity of the electrons of the electron stream, the said wave guide having an input end and an output end, means for coupling energy from said output end to said input end of said wave guide to form a feedback path for the generation of carrier oscillations, a source of modulating signals, means responsive to the signals from said source for varying the velocity of the electrons of the said electron stream, and a load coupled to the output end of the said wave guide for utilizing the modulated oscillations so produced.

6. Oscillation apparatus comprising a traveling wave amplifier, a high frequency energy feedback path connected between an output end and an input end of said traveling wave amplifier whereby high frequency electrical oscillations may be generated, a source of modulating signals, means responsive to the signals from said source for varying the frequency of said oscillations in accordance with the variations of the said modulating signals, and means connected in said high frequency energy feedback path for varying the effective electrical length of the path.

7. In combination, a wave amplifying device comprising a source of electrons, means for forming electrons from said source into a stream along an extended path, and a wave guide for propagating waves along the path in a mode such that the waves have electric field components in the direction of the electron stream and a velocity of the same order as the velocity of the electrons of the said electron stream, the said wave guide having an input end and an output end, means for coupling energy from said output end to said input end of said wave guide to form a feedback path for the generation of electrical oscillations, a source of modulating signals, means responsive to the signals from said source for varying the velocity of the electrons of the said electron stream whereby the said oscillations are modulated in accordance with the signals from said source, and a phase shifter connected in said

feedback path whereby the frequency of the said oscillations may be varied at will.

8. In combination, a wave amplifying device comprising a conductor in the form of an elongated helix, said helix having an input end and an output end, a source of electrons, electrode means for focussing electrons from said source into a stream traveling lengthwise of and in the field region of said helix, a collector electrode, a potential source having a negative pole connected to the said source of electrons and positive poles connected to the said helix, the said focussing means and the said collector electrode for establishing a potential gradient along the path of the said electron stream, means for coupling high frequency energy from the said output end to the said input end of the said helix so as to form an oscillation generator, a source of modulating signals, and means for varying the velocity of the electrons of the said electron stream in accordance with the variations of said modulating signals.

9. The invention in accordance with claim 8, said velocity varying means comprising means connecting said modulating signal source between said electron source and said potential source.

10. The invention in accordance with claim 8, said velocity varying means comprising means for simultaneously varying the potential of the said focussing electrode and the said helix in accordance with the variations of the said modulating signals.

11. The invention in accordance with claim 8, said velocity varying means comprising means for varying the potential of the said helix in accordance with the variations of the said modulating signals.

12. A frequency modulated oscillation apparatus comprising a traveling wave amplifier, a high frequency energy feedback path connected between an input end and an output end of said traveling wave amplifier whereby high frequency electrical oscillations may be generated, a source of modulating signals, and means responsive to the signals from said source for varying the frequency of said oscillations in accordance with the variations in the amplitude of said modulating signals.

13. A frequency modulated oscillation apparatus of the traveling wave amplifier type in which a stream of electrons is directed along a distributed wave transmission circuit in coupling relation thereto at a velocity substantially equal to the velocity of wave propagation along the circuit, and in which amplified wave energy is fed back to an input portion of said circuit to achieve generation of high frequency electrical oscillations including a source of modulating signals and means responsive to the signals from said source for varying the velocity of said electron stream in accordance with the variations in the amplitude of the modulating signals, whereby the frequency of said oscillations is varied in accordance therewith.

14. A frequency modulated oscillation apparatus of the traveling wave amplifier type which includes a distributed wave transmission circuit, means for directing a stream of electrons along said transmission circuit in coupling relation thereto at a velocity substantially equal to the velocity of wave propagation along the circuit, and means for feeding back amplified wave energy to an input portion of said circuit to achieve generation of high frequency electrical oscillations,

a source of modulating signals and means responsive to the signals from said source for varying the velocity of said electron stream in accordance with the variations in the amplitude of the modulating signals, whereby the frequency of said oscillations is varied in accordance therewith.

15. A frequency modulated oscillation apparatus comprising a distributed wave transmission circuit, a source of electrons, means comprising a direct current potential source for producing a unidirectional electric field in the region of the cathode and the wave transmission circuit to form electrons from said source into a stream traveling along said circuit at a velocity substantially equal to the velocity of wave propagation along the circuit, whereby an electromagnetic wave traveling along the circuit in the direction of the electron stream is amplified, feedback means for transferring amplified electromagnetic wave energy from a portion of the circuit remote from the electron source to a portion of the circuit nearer to the electron source whereby the generation of high frequency electrical oscillations is achieved, a source of variable potential modulating signals, and means responsive to the modulating signals for varying the said unidirectional electric field and thereby the velocity of the electron stream in accordance with the variations in amplitude of the modulating signals, whereby the frequency of said oscillations is similarly varied.

16. A frequency modulated oscillation apparatus of the traveling wave amplifier type in which a stream of electrons is directed along a distributed wave transmission circuit in coupling relation thereto at a predetermined velocity, and in which amplified wave energy is fed back from one portion of said circuit to another to achieve generation of high frequency oscillations, including a source of modulating signals and means to vary the velocity of wave transmission along said circuit under the control of the modulating signals whereby to signal-modulate the frequency of oscillation, said wave velocity variation means comprising said source and means coupled thereto to vary the velocity of said electron stream over a range of velocities within which said coupling relation obtains, in accordance with the variations in amplitude of the modulating signals.

LESTER M. FIELD.

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