July 15, 1952 L. M. FIELD 2,603,772

MODULATION SYSTEM

Filed April 6, 1948

FIG. 1

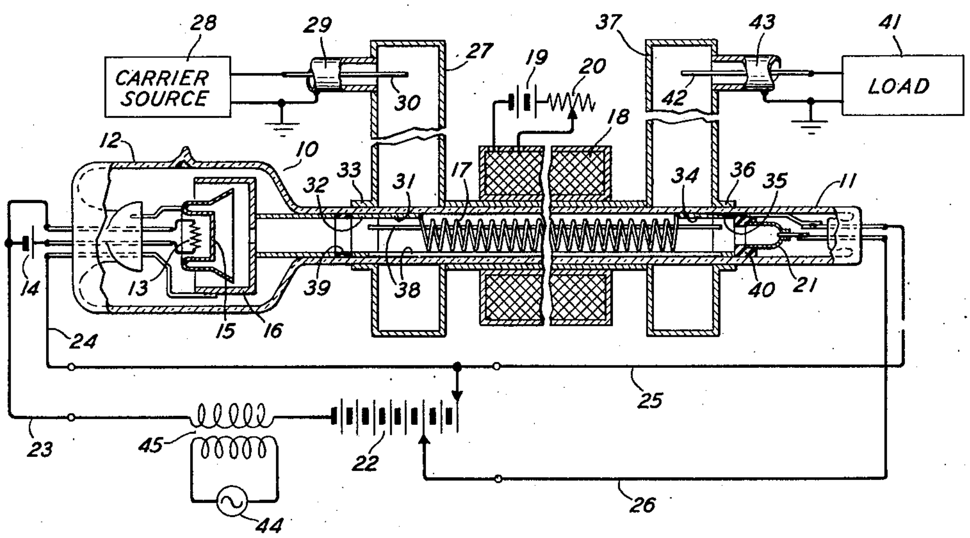


FIG. 2

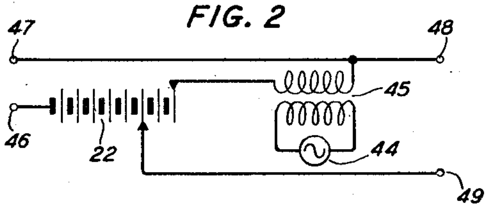
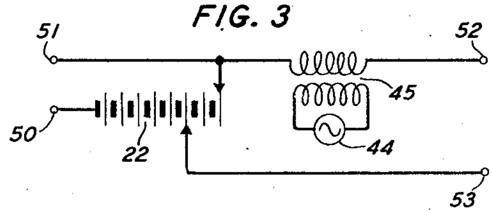


FIG. 3



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MODULATION SYSTEM

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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 modulating the phase or frequency of a high frequency carrier wave in accordance with a signal.

It is an object of the invention to provide new and improved methods of and means for modulating high frequency waves.

It is another object of the invention to provide apparatus for the simultaneous amplification and modulation of high frequency waves.

Copending application Serial No. 704,858, filed October 22, 1946 by J. R. Pierce describes an electronic amplifying apparatus for high frequencies in which the transmission path of the wave to be amplified is incorporated into the amplifying apparatus. The traveling wave follows a path such that the associated electric field may be traversed by an electron stream having a velocity of the same order of magnitude as that at which the traveling wave moves through the amplifying apparatus. Under such conditions the electron stream reacts on the electric field and the electric field reacts on the electron stream in such a manner that the wave traveling along the path in the same direction as the electron stream increases in amplitude with distance while a wave traveling in a direction opposite to the stream is little affected by the presence of the electrons. Thus, the device acts as an amplifier for waves traveling in the same direction as the electron stream.

In a wave amplifying device of the character described, the wave propagated along the transmission path as an increasing wave has a phase velocity which, in the absence of an electron stream, is dependent upon the physical configuration and characteristics of the transmission path. However, in the present of an electron stream, the phase velocity of the traveling wave is also dependent upon the velocity of the electrons of the electron stream. Thus, while under such conditions 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 to provide an improved means for the phase modulation of very high frequency waves. In one embodiment of the invention the potential gradients along the

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path of the electron steam are varied in accordance with the modulating potentials to produce an electron velocity variation and a consequent phase variation of the wave to be modulated. More particularly, as applied to the preferred structure described in the J. R. Pierce application 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 transmission path, 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 a preferred form of amplifying device; and

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

Referring now particularly to Fig. 1, there is shown an illustrative embodiment of a discharge device adapted to be used as an amplifier for ultra-high frequencies. The arrangement shown comprises an electron beam tube 10 including an evacuated envelope having an elongated portion 11. This portion, which is of uniform diameter along its length, connects with an enlarged electrode 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 means such as a known type of electron gun for producing an electron beam. The combination shown comprises a heater 13, which is supplied with energy by a source 14, a cathode 15 connected to the circuit of the heater 13, and a focussing electrode 16 having a configuration which provides field patterns suitable to accelerate and focus the electron stream when the electrode is biased to a suitable potential. The electron stream is further concentrated and guided along an axial path within the space surrounded by a helix 17 by a magnetic field formed by a coil 18 which is energized by a source 19 through a rheostat 20. The strong magnetic field formed by the coil 18 serves also to prevent the deviation of the electron stream from the desired path by an outside magnetic influence. An anode 21 serves to collect the electrons arriving at the end of the envelope 11.

In the operation of the device, the focussing electrode 16 and the helix 17 are maintained at a potential of the order of 1,500 to 2,000 volts above that of the cathode 15 by a potential source conventionally represented as a battery 22. A conductor 23 serves to connect the negative pole of the potential source 22 to the cathode 15 while a conductor 24 serves to connect a positive pole to the focussing anode 16 and a conductor 25 connects the positive pole to the helix 17. The collector anode 21 is connected through a conductor 26 to apply a positive potential somewhat lower than that of the helix for the purpose of decelerating the electron stream before it strikes the anode. This is by no means essential to the operation of the device and the collector may be maintained at a potential higher than that of the helix.

The portions of the device just described are related only to the generation of a stream of electrons and guiding them through the envelope. The transmission elements which make up the high frequency portion of the device serve to introduce the high frequency waves to be amplified into the envelope, provide a path along which the waves may travel to interact with the electron stream and to transfer the amplified waves to the output circuits associated with the device. The device is normally intended for the uniform amplification of a wide band of high frequency waves at wavelengths in the centimeter range and the high frequency transmission elements of the device must necessarily have dimensions suitable for use at the particular wavelength to be amplified. Since the band width of the waves to be amplified may well be of the order of several hundred megacycles, the expressions "wavelength to be amplified" or "carrier frequency" will be understood to denote the wavelength or the frequency at the center of the band.

The elongated helix 17 serves as a conductive path along which the waves to be amplified are propagated in order that they may react with the electron stream flowing therethrough. In order to perform this function, the dimensions of the helix must be such that the linear velocity at which a wave traveling along the circumference of the helix advances along the axis is of some value 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 which may have a length of the order of thirty or forty wavelengths of the wave to be amplified.

There are provided wave guide paths external to the amplifying device for conducting to the device the waves to be amplified and the amplified waves to a transmission or load circuit. At the input end of the helix 16 an incoming wave path conventionally represented as a wave guide 27 of rectangular cross-section is coupled to a source 28 of carrier waves. The coupling is represented as a coaxial transmission line 29 and a probe 30, but may be of any known type suitable for use at the frequencies at which the device is to be used. Where it is intended that the amplifying arrangement, as used with the present invention, be useful over a wide band of frequencies with a minimum of adjustment the coupling may be of the type described in application Serial No. 585,096 filed March 27, 1945, now U. S. Patent No. 2,527,146, dated October 24, 1950, by W. W. Mumford or in United States Patent No. 2,408,032 issued September 24, 1946 to A. C. Beck. The amplifying device is inserted transversely through the input wave guide 27, coupling between the input wave guide and the helix 17 being achieved by means of an input coupling strip 31 connected to the helix 17. There is provided a cylindrical metallic section 32 which supports the input coupling strip 31 and cooperates with a cylindrical metallic section 33 attached to the input wave guide 27 to effectively form an open-circuited transmission line which has an electrical length of one-fourth of the wavelength of the waves to be amplified. The transmission 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 31. At the output end of the helix 17, an output coupling strip 34 is supported by a cylindrical section 35 which cooperates with a section 36 of an output wave guide 37 in an arrangement similar to that at the input end of the helix. The helix 17 is supported by a series of non-conductive ceramic rods 38 which are disposed between the helix and the envelope 11. The ceramic rods 38 also cooperate with ceramic spacers 39 and 40 to maintain a longitudinal spaced relation between the focussing electrode 16, the input coupling strip support section 32, the output coupling strip support section 35 and the anode 21. The output wave guide 37 is coupled to a load circuit 41 by means of a probe 42 and a transmission line 43.

In the operation of the device, the input wave guide 27 is excited so as to produce a mode of wave propagation having an electric field parallel to the input coupling strip 31. A corresponding wave is thus generated along the coupling strip and imparted to the helix 17. The wave then travels along the circumference of the helix at a speed approximating that of light, but at a linear velocity along the axis of the tube which is smaller in proportion to the ratio of the distance between turns to the circumference per turn. The initial interaction between the traveling wave and the electron stream is very slight, the wave serving initially only to produce waves of charge density and velocity in the electron stream. However, as the wave and the electron stream travel along the axis of the helix and a wave is established in the electron stream, a condition is established in which the wave travels a little slower than the electrons forming the modulated electron stream and the electrons impart energy to the wave in a manner which increases the amplitude of the wave at a rapidly increasing rate. The wave reaches a maximum amplitude at the output end of the helix and is transferred to the output wave guide 37 by means of the output coupling strip 34.

Referring again to Fig. 1, there is provided in accordance with the invention a source of modulating signals conventionally represented as an alternating current generator 44. The source of signals may supply variable potentials or currents of a single frequency, or, more commonly, a complex spectrum having many components such as is customarily utilized in the transmission of speech or visible images. Signals derived from the source 44 are applied through a coupling means, conventionally represented as a transformer **45**, so that the signal source is effectively connected in series with the potential source **22** and the cathode **15**. Thus the potentials of the focussing electrode **16**, the helix **17**, and the collector anode **21**, while fixed with respect to each other, are simultaneously varied in accordance with the amplitude variations of the modulating signals with respect to the cathode **15**. The resulting variation of the potential gradients along the path of the electron stream thus produces electron velocity variations and consequent phase variations of the wave traveling along the helix **17**.

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 **46** to conductor **23**; terminal **47** to conductor **24**; terminal **48** to conductor **25**; and terminal **49** to conductor **26**. The signal source **44** and the coupling transformer **45** are thus connected only between the potential source **22** and the focussing electrode **16** and the helix **17**. Hence, only the potentials of the helix and the focussing electrode are varied with respect to that of the cathode.

The circuit of Fig. 3 may be utilized with the device of Fig. 1 by connecting terminal **50** to conductor **23**; terminal **51** to conductor **24**; terminal **52** to conductor **25**; and terminal **53** to conductor **26**. The signal source **44** and the coupling means **45** are then connected only between the potential source **22** and the helix **17**. Thus the potentials of the cathode **15**, the focussing electrode **16**, and the collector anode **21** remain fixed while only the potential of the helix **17** is varied in accordance with the modulating signals. The circuit of Fig. 3 possesses the advantage that for modulating signals of relatively high frequency the electron transit time from the focussing electrode **16** to the helix **17** is somewhat smaller than the transit time from the cathode **15** to the focussing electrode **16**.

The manner of operation of the present invention will be more readily apparent from a further consideration of the theory of operation of the amplifying device of Fig. 1. In such a device the wave which is propagated along the transmission path within the device, in this case along the helix **16**, as a wave of increasing amplitude has both electromagnetic and electrodynamic aspects. That is, the traveling waves embody not only electric and magnetic fields but also fluctuations in the charge density and velocity of the electron stream. Thus, while in the absence of the electron stream the phase velocity of a wave propagated along the transmission path is dependent only upon the characteristics of the transmission path, in the presence of an electron stream the phase velocity of an increasing wave is also dependent upon the velocity of the electrons.

The total phase shift of the high frequency wave in passing through the amplifying device may be expressed as follows:

$$\varphi=\varphi_1+\frac{\omega L}{V_p}$$

where φ is the total shift in phase taken between the input coupling means and the output coupling means; φ_1 is the phase of the increasing wave at the input end of the helix or other wave transmission path taken with respect to the wave at the input coupling means; ω is the angular velocity of the high frequency wave; L is the length of the wave transmission path along which the interaction between the wave and the electron stream takes place; and V_p is the phase velocity of the increasing wave along the transmission path. Now, if the velocity of the electrons is varied, the change in phase may be found by taking the differential of the above expression. Thus:

$$d\varphi=\left(\frac{d\varphi_1}{dV_o}-\frac{\omega L}{V_p^2}\frac{dV_p}{dV_o}\right)dV_o$$

where V_o is the beam velocity expressed in terms of voltage; $d\varphi$ is the change in phase of the high frequency traveling wave; and dV_o is the change in beam velocity.

It will be seen that since only the second term of the latter equation is dependent upon the length of the transmission path, that term will predominate when the equation is applied to practical devices in which the length of the transmission path is in the order of thirty to forty wavelengths. Hence, it will be seen that the total phase change of the wave in traveling over the wave transmission path will decrease with an increase in beam velocity and increase with a decrease in beam velocity.

It is to be understood that while the invention has been illustrated and described in terms of application to an amplifying device incorporating a helical wave transmission path in the interests of simplicity, many other forms of structure may serve as equivalents in the application of the invention. It is also to be understood that the illustrated and described means for varying the electron velocity of the amplifying device are those most preferable from the standpoint of simplicity when used in connection with the illustrated structures and are in no wise intended as a limitation upon the scope of the present invention.

It is further to be understood that the term "phase modulation" as here used is intended as a generic term.

What is claimed is:

1. In a modulator, in combination, a high frequency wave amplifying device comprising a conductor in the form of an elongated helix, means for coupling an input wave source to said device, a source of electrons, means for forming electrons from said source into a concentrated stream traveling lengthwise of and in the field region of said helix, a source of low frequency modulating signals, and means for varying the velocity of the electrons of said stream in their forward travel in said helix in accordance with the amplitude variations of the said modulating signals.

2. The invention in accordance with claim 1, said velocity varying means comprising means for varying the potential between said electron source and said stream forming means in accordance with the variations of the said modulating signals.

3. The invention in accordance with claim 1, said velocity varying means comprising means for varying the potential between said electron steam forming means and the said helix.

4. In combination, a wave amplifying device comprising a conductor in the form of an elongated helix, a source of high frequency waves to be modulated coupled to an input end of said helix, means for producing a concentrated

stream of electrons traveling lengthwise of and in the field region of said helix, a source of low frequency modulating signals, and means for varying the velocity of the electrons of said stream in their forward travel in said helix in accordance with the amplitude variations of the said modulating signals whereby waves traveling over said helix are phase modulated in accordance with the modulating signals from said source.

5. The invention in accordance with claim 4, said velocity varying means comprising means for varying the potential between said helix and said electron stream producing means in accordance with the said modulating signals.

6. A modulating apparatus for high frequency waves which comprises a source of electrons, electrode means for focussing electrons from said source into a concentrated stream along an extended path, a collector electrode for the said electron stream, wave transmission means for propagating high frequency waves to be modulated along the path of the said electron stream and at the same order of velocity as the electrons of the said electron stream, a potential source connected between the said source of electrons and the remaining electrodes for establishing a potential gradient along the path of the electron stream, a source of low frequency modulating signals, and means for varying the velocity of electrons of the said stream in their forward travel along said path in the region of said wave propagation in accordance with the variations of the said modulating signals.

7. The invention in accordance with claim 6, said velocity varying means comprising means connecting said modulating signal source between said electron source and said potential source.

8. The invention in accordance with claim 6, said velocity varying means comprising means for varying the potential of the said focussing electrode in accordance with the variations of the said modulating signals.

9. The invention in accordance with claim 6, said velocity varying means comprising means for varying the potential of the said wave transmission means in accordance with the variations of the said modulating signals.

10. In a modulation system, a discharge device comprising an evacuated envelope, means within said envelope for producing an electron beam, wave transmission means disposed along the path of the said beam and so predesigned as to permit propagation of high frequency electrical waves thereover in the direction of propagation of said beam, means to impress high frequency waves to be modulated upon an input end of said wave transmission means, a source of low frequency modulating signals, and means responsive to said signals for varying the velocity of the electrons of the said beam in their forward travel along said path in the region of said wave propagation.

11. In combination, a source of high frequency electrical waves, means for forming a concentrated stream of electrons along an extended path, means for propagating the waves from said source along the path of said electron stream in such a manner as to cause an increase in the amplitude of the said waves, a source of low frequency modulating signals, and means for varying the velocities of electrons of the said stream in their forward travel along said path in the region of said wave propagation in accordance with the modulating signals from the said source.

12. In apparatus in which amplification of high frequency waves is achieved through interaction between an electron stream and a high frequency electric field associated with the waves to be amplified over an extended distance along the transmission path of the wave, the method of modulation of the wave to be amplified which comprises the variation of the velocity of electrons of the electron stream in their forward travel in the region of said interaction in accordance with the amplitude of a low frequency modulating signal.

13. A device for modulating the frequency of a high frequency electromagnetic wave in accordance with a low frequency modulating signal comprising means for propagating said wave to be modulated and its associated electric field along an extended path at a velocity within the range of practical electron velocities, means for projecting a stream of electrons along said path in said field in the direction of travel of the field at a velocity substantially the same as the velocity of the field and means for varying the velocity of projection of the electron stream along the path in said direction in said field in accordance with variations in the said low frequency modulating signal, whereby the high frequency wave becomes frequency modulated in accordance with the modulating signal during its propagation along the path.

14. The method of modulating the frequency of a high frequency electromagnetic wave in accordance with a low frequency modulating signal which comprises propagating said wave to be modulated and its associated electric field along an extended path at a velocity within the range of practical electron velocities, projecting a stream of electrons along said path in said field in the direction of travel of the field at a velocity substantially the same as the velocity of the field and varying the velocity of projection of the electron stream along the path in said direction in said field in accordance with the variations of said modulating signal.

15. In a modulator, in combination, a wave amplifying device comprising a conductor in the form of an elongated helix, means for coupling an input wave source to said device, a source of electrons, means for forming electrons from said source into a concentrated stream traveling lengthwise of and in the field region of said helix, a source of modulating signals, and means for varying the velocity of the electrons of said stream in accordance with the amplitude variations of the said modulating signals, said velocity varying means comprising means for varying the potential between said electron stream forming means and the said helix.

16. In combination, a wave amplifying device comprising a conductor in the form of an elongated helix, a source of high frequency waves to be modulated coupled to an input end of said helix, means for producing a concentrated stream of electrons traveling lengthwise of and in the field region of said helix, a source of modulating signals, and means for varying the velocity of the electrons of said stream in accordance with the amplitude variations of the said modulating signals whereby waves traveling over said helix are phase modulated in accordance with the modulating signals from said source, said velocity varying means comprising means for

varying the potential between said helix and said electron stream producing means in accordance with the said modulating signals.

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REFERENCES CITED

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

UNITED STATES PATENTS

Number	Name	Date
2,233,779	Fritz	Mar. 4, 1941
2,239,677	Jobst	Apr. 29, 1941
2,254,036	Gray	Aug. 26, 1941
2,276,247	Hahn	Mar. 10, 1942
2,300,052	Lindenblad	Oct. 27, 1942
2,409,608	Anderson	Oct. 22, 1946
2,521,760	Starr	Sept. 12, 1950

OTHER REFERENCES

Article: "Traveling Wave Tubes" by J. R. Pierce et al., proceeding of the I. R. E., February 1947, pages 108–111, vol. 35, No. 2.