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MODULATION SYSTEM

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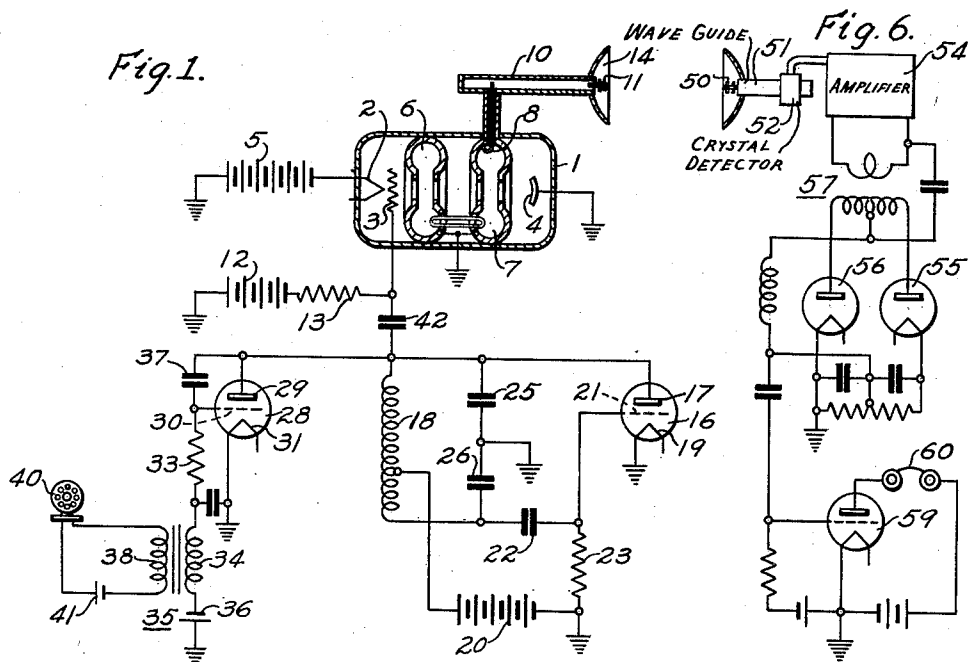


Fig. 2.

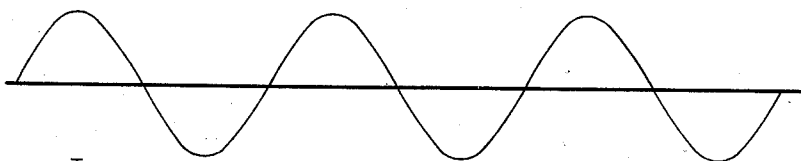


Fig. 3.

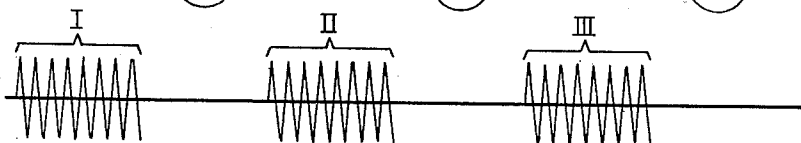


Fig. 4.

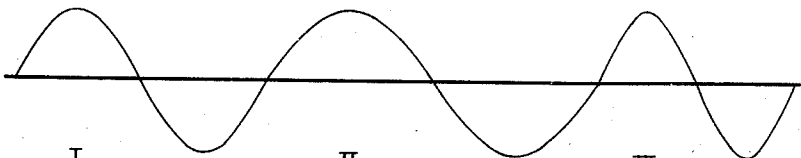
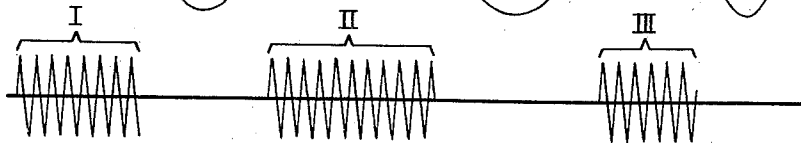


Fig. 5.



WITNESSES:

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MODULATION SYSTEM

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1

This invention relates to communication systems and more particularly to systems employing ultra-high-frequency carrier waves.

With the event of new techniques in producing ultra-high-frequency energy of relatively high power, various problems arose in utilizing this energy for communication purposes and particularly for voice frequency transmission. The major problem concerns the modulation of ultra-high-frequency energy in such manner that the modulation signal may be transmitted without appreciable distortion. In speaking of ultra-high-frequency currents, it is understood that the energy transmitted has a frequency in the neighborhood of 500 megacycles up to several thousand megacycles. At these frequencies, various operational difficulties have been encountered in view of the critical conditions existing in the apparatus producing such high-frequency currents as well as in the transmission thereof at a distance with satisfactory efficiency.

As a source for ultra-high-frequency currents, vacuum tubes have been developed which form a complete oscillating system and operate on the electron velocity principal. As an example, tubes of this type are described in United States Patent 2,242,275 to R. H. Varian, issued May 20, 1941. They are also referred to as electrical converters which produce oscillations by using an electron beam by means of space-resonant devices which form highly efficient tank circuits for the oscillator. The electrons are alternately accelerated and decelerated at the frequency of oscillation, and ultimately the energy of the electron beam is converted into electromagnetic field energy.

The present invention discloses a method and means for modulating the ultra-high-frequency energy produced by tubes of the character above described. While it is particularly advantageous for modulation of the output energy of electron velocity actuated tubes, it may also be applied to oscillators of various kinds operating on the magnetron principle or of the vacuum tube feedback type.

The primary object of the invention is to provide a modulation system which is adaptable to control the source of ultra-high-frequency energy in such manner that the transmitted wave shall be modified in accordance with the intelligence to be transmitted and be of such form that it can be demodulated by simple well-known receiving systems.

A particular feature of the invention is that the modulation system requires relatively small pow-

2

er for efficient modulation of ultra-high-frequency energy of relatively high power without introducing distortion of the carrier frequency.

Other features and advantages will be apparent from the following description of the invention pointed out in particularity by the appended claims and taken in connection with the accompanying drawing in which:

Figure 1 shows a schematic circuit arrangement of the modulation system applied to an ultra-high-frequency transmitter in the form of an electron velocity actuated type tube.

Figs. 2, 3, 4 and 5 illustrate by means of curves the frequency relations of the carrier and modulation frequencies, and the characteristic of the resultant high-frequency energy transmitted.

Fig. 6 shows a simple schematic circuit of a suitable receiver for the communication system herein described.

In any modulation system in connection with high frequency energy, the difficulties for undistorted transmission of the carrier wave reside in the particular characteristics of the vacuum tubes which necessarily play an important part in all high-frequency apparatus. The modulation characteristic of vacuum tubes is seldom a straight line, and when the operating voltage applied to certain electrodes of the tube is varied in accordance with a modulating signal, the radio frequency output does not follow the magnitude changes in exact proportion with the variations due to modulation. Particularly is this true in connection with the electron velocity actuated type tubes above referred to, since their characteristics do not allow direct application of a modulation signal to any of the vacuum tube elements. When such a tube is modulated by impressing a sinusoidal potential between its anode and cathode, the output of the tube will have an envelope of squared or stepped wave form. While the distortion encountered in modulating such tubes is of no consequence when the tube is used for telegraphic communication, it prevents the use of the tube in modulation systems for telephonic communication. The present system about to be described provides a method of modulating tubes which are characterized by a non-linear relation between radio frequency output and modulation signal input.

Referring to Fig. 1, the source of ultra-high-frequency energy is schematically indicated by the electron velocity actuated tube 1. The invention does not concern the particular form of the source of ultra-high-frequency energy, and the tube 1 is chosen here merely by way of ex-

ample. Those skilled in the art are familiar with the various types of tubes now available for generating ultra-high frequencies, and no comprehensive discussion of the principles of operation of such tubes is believed to be necessary here. The principal elements of the tube 1 include the cathode 2, the control grid 3 and the anode 4. In order to simplify the illustration, the operating potentials for energization of the various components of the system are shown here by batteries. It is, of course, understood that any suitable power supply may replace these batteries which are merely symbols of operating voltage sources. The battery 5 provides the high voltage required between cathode and anode of the tube 1. It is assumed that the cathode is suitably energized to have the required temperature for electron emission. The oscillating circuit within the tube includes the space-resonant devices 6 and 7 which are excited by the beam of electrons projected from the cathode 2 to the anode 4. The ultra-high-frequency energy is conducted from a coupling loop 8 terminating in the space resonator 7, and is conducted by means of the wave guide 9 to a suitable radiator 11 located in a reflector 14. The control electrode 3 is provided with the required operating potential from the voltage source shown here by the battery 12 through a grid load resistor 13. The description so far given was directed solely to the source of ultra-high-frequency energy which is part of the communication system. This source is shown to be a particular type of vacuum tube, and it is assumed that the operating elements of this tube are suitably proportioned and the operating voltages are so distributed that the tube 1 will operate to generate an ultra-high-frequency wave which can be effectively radiated through space. It is to be noted for a thorough understanding of the modulation system herein disclosed that the operating characteristic of the tube 1 is such that the grid electrode 3 is effective for controlling the operation of the tube in such manner that within certain values of grid potential the tube will function as an oscillator and at a discrete value it will cease to function as such. In other words, the operation of the tube may be intermittent depending upon the particular value of operating potential applied to its control grid 3.

The modulation circuit comprises a vacuum tube 16 in a conventional oscillator circuit for producing high-frequency oscillations. The anode 17 thereof connects through a portion of the inductance 18 to the cathode 19 including the operating voltage source shown here by the battery 20. The grid electrode 21 is coupled through a portion of the inductance 18 by means of the condenser 22 and returns through a suitable leak resistor 23 to the cathode 19. Condensers 25 and 26 in series are effectively connected across the terminals of the inductance 18, the junction point of the condensers 25 and 26 being returned to the cathode 19. The inductance 18 together with the condensers 25 and 26 form a frequency determining circuit for the oscillator tube 16. The frequency of its operation is determined by the particular value assigned to the inductance 18 and the condensers 25 and 26. Connected to the oscillator circuit 16 is the modulator tube 28 having an anode 29, a control electrode 30 and a cathode 31. The anode 29 connects directly to the anode 17 of the oscillator tube 16 and thereby receives operating potential for its anode circuit from the same voltage source, namely, the bat-

tery 20. The cathode 31 is similarly connected to ground as is the cathode 19 of the tube 16. The grid 30 returns to the cathode through the resistor 33 and the secondary winding 34 of the modulation input transformer 35. A suitable source of grid bias potential is included in the circuit and is represented here by the battery 36. The grid circuit is coupled to the anode circuit by means of the condenser 37. By virtue of this connection, there is formed a quadrature circuit whereby the grid electrode 30 is supplied with energy from the plate circuit through a resistance capacity network. The grid voltage appearing will be effectively at a 90° phase shift with respect to the plate voltage. The anode resistance of the tube 28 represents also a parallel load for the tank circuit of the oscillator. A circuit of this type is also known as an electronic reactance circuit, the effective reactance value of which may be controlled by varying the bias potential of the grid 30, which, in turn, will vary the effective reactance of the vacuum tube 28. This will react on the oscillator circuit in effect acting as a variable inductance or capacity in shunt with the tank circuit. The variation in the grid bias for control purposes is obtained by the modulation signal which is applied to the primary winding 38 of the transformer 35 from the microphone 40 which alters the current flow through this winding from the battery 41.

The operation of reactance circuits are well known in the art and have been described in great detail in the Proceedings of I. R. E., volume 23, by Travis. For the purpose of explaining the operation of the modulation system, it should be understood that the frequency of the oscillator 16 may be varied within a certain band of frequencies by variations of grid potential of the control tube 28. Variation is effected by the signalling current produced by the microphone 40 in the secondary winding 34 of the transformer 35. The frequency of the oscillator will undergo a deviation in proportion to the intensity of the signalling currents and this deviation will occur at a rate of the signal frequency. In order that the oscillator frequency shall control the generation or transmission of ultra-high frequency, a coupling is provided between the oscillator output and the control grid 3 of the tube 1 by means of the condenser 42. In this manner the output voltage of the oscillator is applied, and utilized to vary the potential of the grid 3 and trigger the action of the ultra-high-frequency generator tube 1 as will be described in connection with the operation of the modulation system.

The communication system so far described included the transmitting portion which has the following basic components: (1) a generator of ultra-high-frequency radiation; (2) a source of high-frequency energy adapted to control the operation of the generator; and (3) a control circuit for the high-frequency oscillator to vary the oscillation frequency thereof in accordance with variations of a modulating signal which is impressed on the modulation circuit. The operation of the transmitting circuit will be better understood by reference to the curves of Figs. 2, 3, 4 and 5. The sine wave of Fig. 2 shows the output of the oscillator tube 16 and the curves of Fig. 3 illustrate a sine wave of much higher frequency, namely the output of the ultra-high-frequency transmitter emitted from the radiator 11. The two curves just mentioned show the condition of signal transmission when there is no modulation of the transmitter, that is, when the

microphone 40 is not energized. Figs. 4 and 5 show curves similar to those of 2 and 3, respectively, illustrating the oscillator output with frequency variations of the oscillator within a predetermined band of frequencies, and the corresponding wave trains emitted by the radiator 11.

In connection with the operation of the transmitting system, it should be borne in mind that the ultra-high-frequency generator tube 1 can be controlled as to its operation in such manner that at and below a critical positive potential with respect to its cathode the grid electrode 3 will function to cease operation entirely of the tube 1. Under such conditions no oscillations are generated consequently no transmission takes place, whereas, above this critical potential in the opposite sense and therebeyond, the grid 3 will not impede the electron beam and the tube 1 will generate ultra-high-frequency energy which will be radiated in the form of a carrier wave by the radiator 11. The output voltage of the oscillator tube 16 is calculated to be of such value that at one half-cycle of its operation the voltage impressed on the grid 3 will be subtractive from the bias voltage of the battery 12 to such an extent that cut-off point is reached and the tube 1 will cease to function. On the positive half-cycle of the output wave of the tube 16, on the other hand, normal operation of the tube 1 will be obtained. The frequency of the oscillator tube 16 is chosen to be a suitable value lower than the ultra-high-frequency transmitted. The particular value of the frequency chosen will depend largely on practical consideration as to receiver design since it is one of the salient features of the system that conventional receiver circuits may be used.

For practical purposes the following relation may be chosen as an example. Let us assume that the tube 1 will generate a 3000-megacycle carrier frequency. The frequency of the oscillator tube 16 may be two megacycles per second in the absence of a modulation signal. If the oscillator 16 is operating, a voltage of two megacycles frequency will appear on the grid 3 of the ultra-high generator tube 1. This will cause the latter to start and stop its oscillations at the rate of two megacycles per second. Therefore, the output of the ultra-high-frequency generator 1 will consist of a groups of 3000 megacycles radio frequency oscillations each group being approximately of a $\frac{1}{4}$ microsecond duration followed by a period of equal duration when the generator tube 1 will not operate. In other words, there will be two million such groups of oscillations each second. Referring to Fig. 2, it is seen that at the positive half-cycle of the output voltage of the oscillator 16 there is a corresponding group I of ultra-high-frequency waves shown in Fig. 3. At the negative half-cycle of the output wave of Fig. 2, the oscillations of the generator tube 1 will cease and no energy is radiated at all. This is repeated at each succeeding half-cycle of the oscillator frequency, resulting in groups of wave trains radiated. The succeeding groups I, II, and III of ultra-high-frequency radiation shown in Fig. 3 intend to convey the idea of successive wave trains. The exact numerical ratio of oscillations for one half-cycle with respect to the control frequency of the oscillator tube 16 is not intended to be shown here in order to make the illustration practical and avoid over crowding of the lines representing each wave train. Knowing the duration of each operating half-cycle, it can easily be

calculated that with a 3000-megacycle carrier frequency, each group of wave trains transmitted will have approximately 833 oscillations at a rate of 3000 megacycles per second.

If a modulation signal is impressed on the transformer 35, the frequency of the oscillator 16 will vary within a band of frequencies. Let us assume that the oscillator frequency will vary between 1.9 to 2.1 megacycles during the modulation cycle. In other words, the frequency modulation of the oscillator 16 will include a 200-kilocycle total shift of frequency. Any variation of the frequency of the oscillator 16 will in turn vary the duration per unit time of the output wave trains of the generator 1. In Fig. 4, the output frequency of the oscillator 16 is shown to vary from the two-megacycle mid frequency to the lower limit of 1.9 megacycles shown by the second output wave to 2.1 megacycles shown by the third output wave. The resultant ultra-high-frequency energy in the first group has a time duration of the positive half-cycle of the two-megacycle control frequency, whereas in the second group the time duration is extended in view of the fact that the positive half-cycle of the control frequency is of a frequency lower than before. The third group illustrates the other limit of the frequency shift showing a group of the shortest duration per unit time corresponding to the positive half-cycle of a 2.1 megacycle control frequency.

The modulation system as described permits operation at ultra-high frequencies by allowing transmission of ultra-high-frequency energy of substantially constant amplitude at a rate which varies in accordance with a predetermined frequency. The latter controlled as to frequency deviation impresses the modulation component on the carrier in the form of varying groups of ultra-high-frequency energy having a basic rate determined by the generator tube 1. Analyzing the output wave, it is found that it contains a component of the fundamental frequency of the control oscillator 16 and that this component is frequency-modulated in accordance with the modulation signal. In order to receive this signal, a simple rectifier may be used the output of which can be amplified by an intermediate frequency amplifier which has a band-width corresponding to the range of frequencies of the modulating signal. The range in accordance with the example herein given would have to be between 1.9 and 2.1 megacycles.

A simple receiving circuit is shown in Fig. 6 comprising the receiving antenna 50, from which the signal is transmitted through a wave guide 51 to a crystal detector 52, shown here in a block diagram form representing any conventional ultra-high-frequency crystal receiver. The output of the crystal 52 is connected through suitable coupling means to a conventional intermediate frequency amplifier 54 shown also by block diagram. The output of the amplifier is impressed on a suitable frequency discriminator circuit illustrated here by the diode tubes 55 and 56 fed by the coupling transformer 57. The output of the discriminator will be a reproduction of the modulation signal impressed on the transformer 35 from the source 40. The signal may be applied to suitable audio frequency amplifiers of which one stage is shown here by the vacuum tube 59 having in its output circuit a telephone receiver 60.

I claim as my invention:

1. In a communication system operating at

7

ultra-high frequencies, a source of ultra-high carrier frequency energy comprising an oscillator of the electron velocity actuated space-resonant type, a source of high frequency energy of a frequency lower than said carrier frequency, means for triggering the action of said oscillator at a rate determined by said source of high frequency energy, means for impressing modulations comprising means for shifting the frequency of said last-mentioned source in accordance with the amplitude of the signal to be transmitted and at a rate of said signal frequency.

2. In a communication system operating at ultra-high frequencies, a source of ultra-high carrier frequency energy comprising an oscillator of the electron velocity actuated space-resonant type, a source of high frequency energy of a frequency lower than said carrier frequency, means for controlling the operation of said oscillator at intervals of unit time determined by the instantaneous frequency of said high frequency source, means for impressing modulations comprising means for shifting the frequency of said last-mentioned source in accordance with the amplitude of the signal to be transmitted and at a rate of said signal frequency.

3. In a communication system operating at ultra-high frequencies, a source of ultra-high carrier frequency energy comprising an oscillator of the electron velocity actuated space-resonant type, a source of high frequency energy of a frequency lower than said carrier frequency, means for controlling the operation of said oscillator at intervals of unit time determined by the semi-cyclic time base of the instantaneous frequency of said high frequency source, means for impressing modulations comprising means for shift-

8

ing the frequency of said last-mentioned source in accordance with the amplitude of the signal to be transmitted and at a rate of said signal frequency.

4. In a modulation system for ultra-high frequency carrier transmission, a source of ultra-high frequency energy in the form of an electron velocity actuated space-resonant type tube having principal operating electrodes and a control electrode effective in controlling the operation of said tube, a second source of high-frequency energy comprising a vacuum tube oscillator, a frequency determining circuit for said oscillator, circuit means for coupling the output of said oscillator to said control electrode, a source of modulation frequency currents, and means for impressing the modulation frequencies of said source upon said frequency determining circuit for effecting variation of frequency of said oscillator.

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