

April 7, 1942.

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2,278,658

FREQUENCY MODULATION

Filed Dec. 6, 1939

5 Sheets-Sheet 1

Fig. 1a

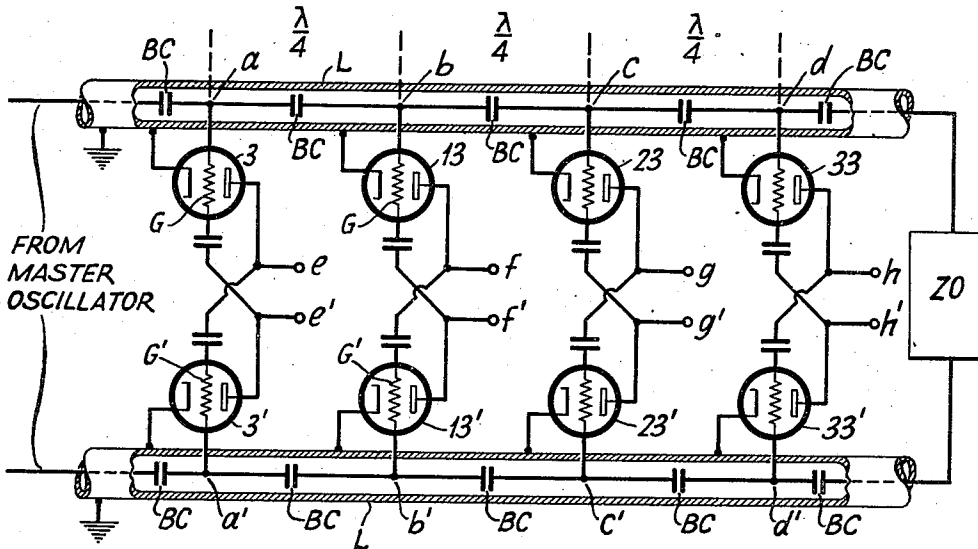


Fig. 1b

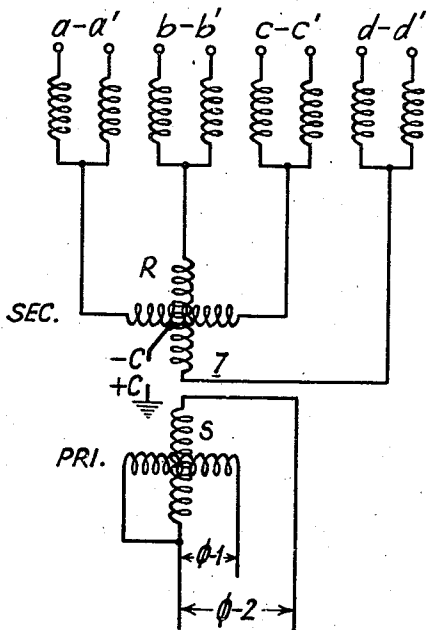
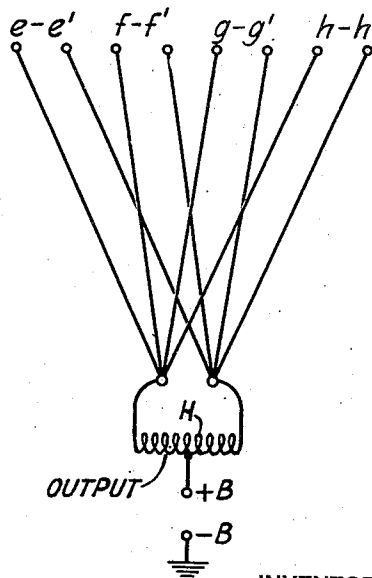


Fig. 1c



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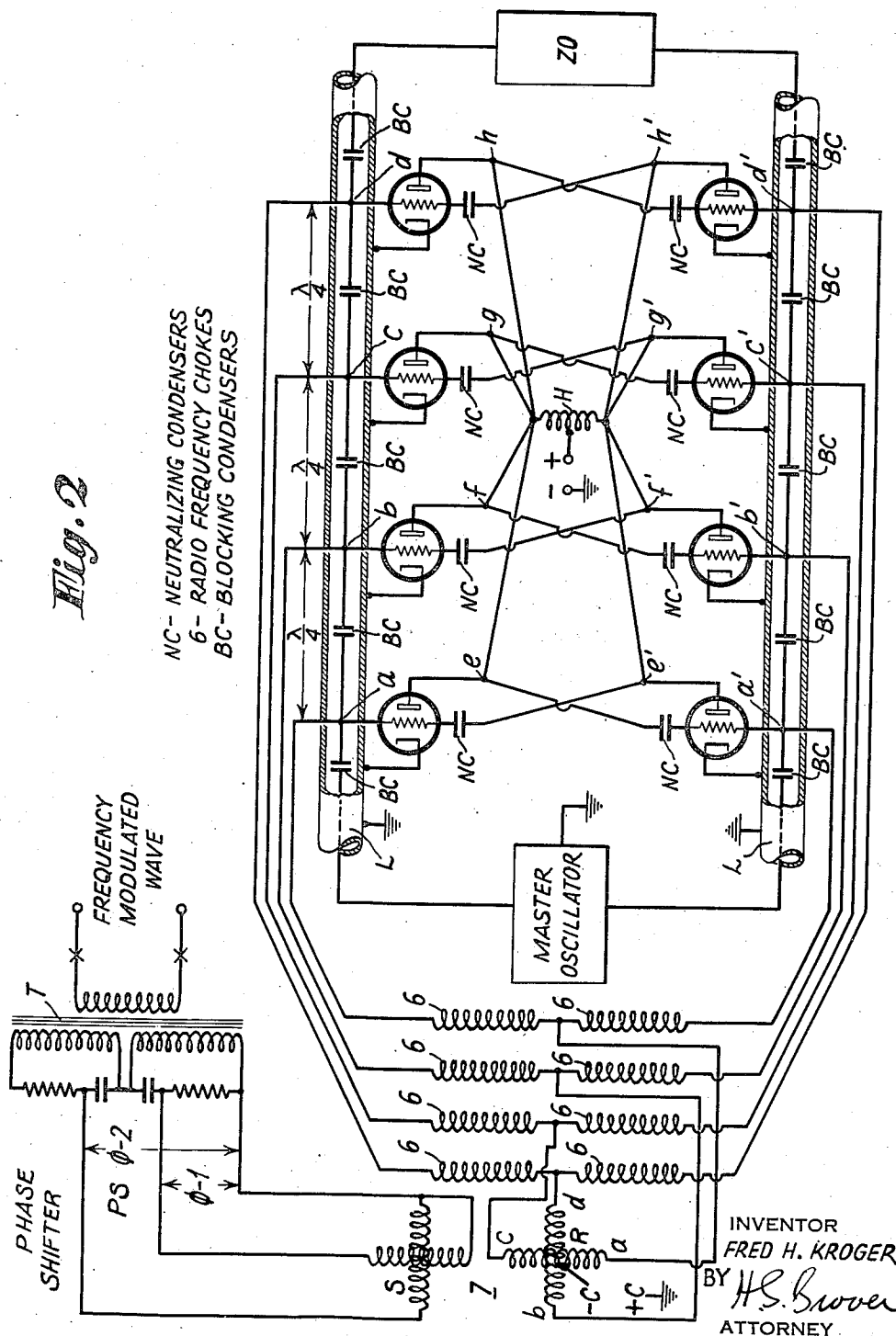
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FREQUENCY MODULATION

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Fig. 2



April 7, 1942.

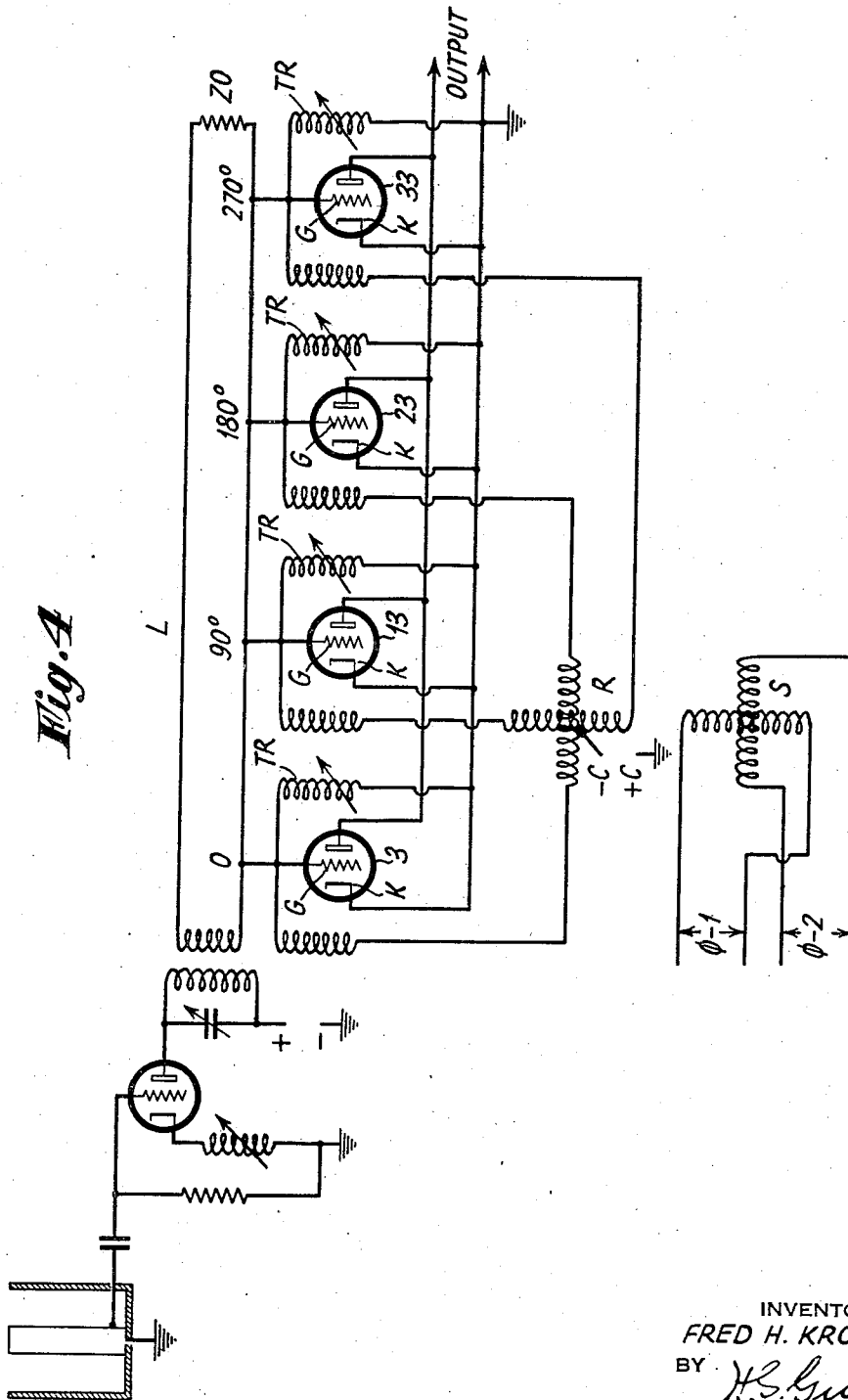
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FREQUENCY MODULATION

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FREQUENCY MODULATION

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Fig. 5

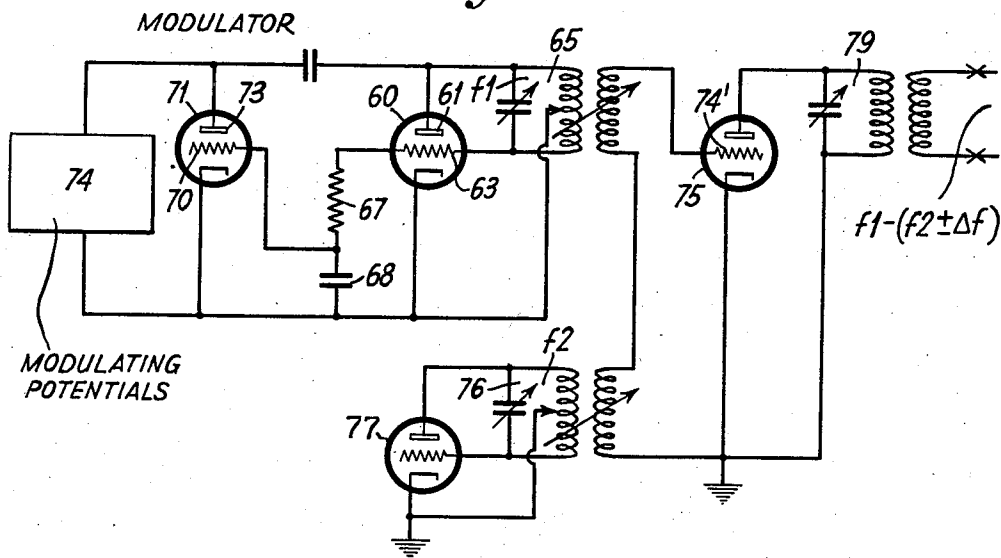
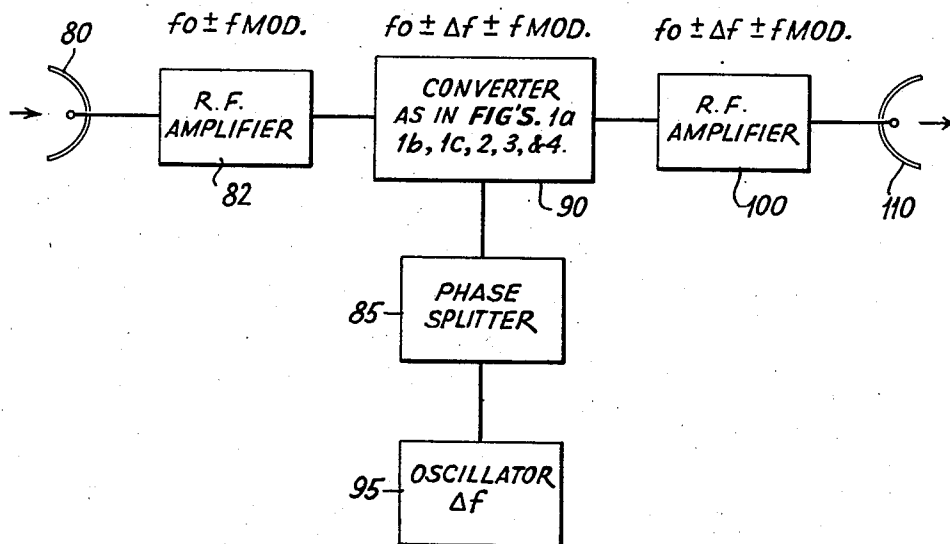


Fig. 6



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2,278,658

FREQUENCY MODULATION

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Application December 6, 1939, Serial No. 307,726

18 Claims. (Cl. 179—171.5)

This application concerns a new and improved method of and means for varying the output frequency of a repeater or amplifier system.

The application also concerns a new and improved modulated wave relaying system by means of which frequency modulated waves of a given average mean frequency have said frequency increased or decreased by any desired fractional amount and are retransmitted.

My application also concerns a new and improved means for modulating wave energy in accordance with signal potentials.

It is well known in the radio art that it is advantageous for certain purposes, such as, for example, for the sake of efficiency, economy of operation, etc., to vary the output frequency of a transmitter of wave energy in accordance with signalling potentials. These signalling potentials may be characterized by a sine function as when a source of tone energy is used for modulation purposes or they may be characterized by a complex function such as occasioned by speech.

In frequency modulation as known in the art, the frequency of a wave is caused to vary about or relative to an average value and it is usually a requisite that the average frequency be as constant in value as possible.

In my new and improved method and means, a high frequency or ultra-high frequency wave of substantially constant frequency is modulated in frequency about or relative to its mean value in accordance with signalling potentials of any nature whatever. A particular application of my invention is modulating or varying a substantially constant wave of any frequency in frequency in a manner characteristic of an extremely wide band of signalling potentials, such as those used, for example, in video or television systems.

In the majority of uses for frequency modulation, it is also generally required that the frequency modulated wave or carrier be of constant amplitude, and my novel method of and means for varying the frequency of the carrier about or relative to a substantially constant frequency includes the necessary elements required to give this constancy of amplitude. As a matter of fact, the amplitude of the wave so varied in accordance with my method and means is inherently maintained at said constant amplitude by said method and means.

A disadvantage inherent in frequency modulators known heretofore is that the mean frequency may not be kept as constant as desired, and these deviations or variations in the mean

frequency introduce in the system extraneous phase or frequency or amplitude modulation which is undesired. Frequency modulation systems of various types are known in the art and my novel method and means makes use of a new and improved frequency modulator in an early stage of the system disclosed here.

In its broadest aspect, my novel method of and means for frequency modulation involves the use of a generated carrier having a very constant value of frequency with means for adding to and/or subtracting cycles from the carrier, thereby obtaining an output of variable frequency. The cycles added to or subtracted from this constant frequency carrier are characteristic of signalling potentials of any type.

The principle used is similar to that occurring in an induction motor with a wound rotor. If 60 cycles is applied to the stator and the rotor is driven backward, the energy derived from the rotor will have a frequency equal to 60 plus KS where S is the R. P. M. and K is a constant. Rotation of the stator in the opposite direction will result in the difference frequency. The same principle and effect is obtained when a railroad engine approaches one, causing the whistle note to be higher than the note to be heard by the engineer, which is in turn higher than the note heard by one from whom the engine is receding. What is happening in both cases is a continuous advancing of phase of output with respect to the generator output. Any means accomplishing this result will give a resultant frequency different from that generated. The principle involved here is also similar to what is known as the Doppler effect.

My invention is applicable to the production of frequency modulated waves for transmission purposes and is especially adaptable to use in relaying frequency modulated waves from point to point.

In describing my invention, reference will be made to the attached drawings wherein:

Figures 1a, 1b, and 1c together illustrate one embodiment of my means for adding cycles to or subtracting cycles from wave energy of a constant frequency. This means has been separated into three figures for purposes of illustration, one purpose being to illustrate that, preferably, certain of the leads and connections in the system are equal in length.

Figure 2 illustrates the arrangement of the prior figures as connected in circuit and adds features not illustrated in the prior figures, such

as a phase splitting circuit, a source of wave energy of constant frequency, etc.

Figures 3 and 4 illustrate modifications of the arrangement of Figures 1 and 2. In Figures 3 and 4 a single line converter or modulator or cycle adding system with single tube stages is shown.

Figure 5 illustrates in detail means for obtaining frequency modulated potentials, particularly adapted to use in circuits such as illustrated in Figures 1, 2, 3 and 4.

In Figure 6 I have shown a relaying system wherein my frequency adding or subtracting means is made use of in a novel modulated signal relaying system.

Referring to Figure 1a, items L comprise a balanced transmission line composed of two coaxial conductors. This transmission line is terminated as shown by an impedance Z0 of a value such that when a substantially constant frequency wave is impressed on the line input from a source such as a master oscillator, not shown, no appreciable standing waves are produced in the line. A plurality of pairs of electron discharge devices 3, 3', 13, 13', 23, 23', 33, 33' have their control grids G, G', connected as shown to spaced points on the inner conductors of the coaxial cables forming the transmission line. These points of connection between the said conductors and the control grids are, as shown, spaced apart a distance equal to $\lambda/4$, where λ is the length of the wave of substantially fixed frequency supplied from the master oscillator, not shown, to the input of the line. The stages 3, 3', 13, 13', etc., are one-way repeaters, such as are obtained by neutralizing the stages by means of neutralizing condensers NC. Obviously, other types of non-reactive stages, such as obtained by the use of screen grid tubes, may be used here. The points of connection between the inner conductors of the coaxial lines and the grids of the tubes are indicated at a, a', b, b', c, c', d, d'.

With a line having similar lumped constants $\lambda/4$ apart, if there are an even number of such elements, their effects on the line will cancel for the input frequency because of the phase inverting effect due to the $\lambda/4$ spacing and thus do not cause reflections or standing waves in the line when the same is matched.

If the amount of standing waves is small, they only slightly effect the relay excitation and since, preferably, saturation excitation is used, the output from the repeaters will be substantially constant in amplitude.

The potentials on the control grids, of tubes 3, 3', 13, 13', etc., are controlled in phase successively in either direction, that is, from right to left or from left to right, depending on the direction of rotation of the applied polyphase modulating potentials. The modulating potentials in this application preferably comprise wave energy of the desired frequency, which may be, for example, an intermediate frequency modulated in frequency in accordance with signalling potentials. These modulating potentials from any source, not shown, are applied in two-phase relation to the stator S of a phase shifting device 7, the rotor R of which is connected as shown to points a, a', b, b', c, c', d, d'. See Figures 1a and 1b. The connections from the rotor R to the points a, a', b, b', and etc., should be electrically equal, and, preferably, as direct as possible.

In the connections shown, the potentials to the stages 3, 3', 13, 13', etc., vary successively in the direction from 3, 3', to 13, 13', etc., or in the

direction from 33, 33', to 23, 23', etc., depending upon the direction of rotation of the field produced by the stator windings S. The anodes of the stages 3, 3', 13, 13', etc., are connected by the leads e, e', f, f', g, g', etc., in phase opposition to an output circuit, such as shown in Figure 1c. These anode connections are electrically equal, as indicated in Figure 1c, and preferably as direct as possible.

In operation the wave energy of substantially constant frequency supplied by the master oscillator to the input of the transmission line travels along said line, due to the matching impedance Z0 at the end thereof. The points a, b, c, and d, on the line are an electrical distance apart of 90°. The grids of the tubes are connected at these points. The two-phase energy is supplied to the stator of the primary of 7 at some frequency less than the frequency of the travelling waves in the transmission line. Assuming proper c bias on the control grids of the tubes 3, 3', 13, 13', etc., causes the tubes to pass energy or amplify energy from the line and supply it to the load circuit in rotation, a complete cycle being passed through for each cycle of the two-phase energy supplied by 7. If the direction of rotation of the two-phase energy is such as to cause the tube 3 to be excited first, travelling left to right we have the effect of travelling away from the energy on the transmission line, and, therefore, the frequency of the inputs and outputs of the plate circuits of the tubes is lower. Conversely, if the direction of rotation of the two-phase energy is such that tube 33 is excited first, and the sequence of excitation is from right to left, we have the effect of travelling toward the energy on the transmission line and the frequency of the outputs of the tubes is increased. For example, if the frequency of the master oscillator is say 1,000,000 cycles and a pure sine wave is supplied to 7 at a frequency of say 10,000 cycles, the tubes will supply to the output circuit a constant frequency of a 1,000,000 cycles plus 10,000 cycles, provided the phase in 7 is such as to excite the tubes successively in a sequence from right to left, and will be 1,000,000 minus 10,000 cycles if the phase is such that the tubes are excited in a sequence from left to right. If the two-phase energy supplied to 7 is now frequency modulated in accordance with signals, the output at H will be $1,000,000 \pm (10,000 \pm \text{the modulating frequency})$.

I do not limit my invention to two-phase operation since three-phase, etc., may be used but two-phase has the advantages mentioned above.

In view of the fact that line L of Figure 1a is terminated by a matching impedance, we may consider the voltage at all points in the line due to the impressed master oscillator voltage as being practically constant throughout the entire length of line. When tube 3 is positive, due to the two-phase current, tube 13 has reached zero from a plus value, tube 23 is highly negative, and tube 33 has reached zero from a negative value. Tubes 3, accordingly, repeat or amplify the carrier wave continuously advanced or retarded in phase in accordance with the controlling two-phase voltage, so that if the modulation frequency is considered a sine wave, the frequency of the output is equal to the frequency of the carrier wave plus or minus the modulation wave, depending on the direction of the rotation of the two-phase currents. A quarter of a cycle later, in the high frequency wave, the grid of tube 13 is highly positive, the grid of tube 3 has ap-

proached zero from the plus side, the grid of tube 23 has approached zero from the negative side, and the grid of tube 33 is highly negative. The tube 13 now passes current. This cycle is repeated for the remaining tubes. Thus, since the output circuits of the tubes are in parallel, the energy delivered will be the resultant of the energies of the four tubes and summed up will have a frequency which is the sum or difference of the carrier and modulation frequency. If the modulating potentials are frequency modulated; that is, is a sine wave, the modulation increment is added or subtracted.

By using the modulating potentials differentially, the variations can be made relative to the master oscillator frequency rather than relative to a frequency separated from the master oscillator frequency by a frequency which is the mean frequency of the frequency modulated modulating potentials.

More complete circuit connections have been shown in Figure 2 wherein numerals and letters corresponding to those used in Figures 1a, 1b, 1c are used to designate corresponding parts. Blocking condensers BC are interposed in the line to isolate the accelerating potentials supplied from 7 to points a, a', b, b', etc., without cutting off the flow of high frequency wave energy in the line. The high frequency wave energy in the line is prevented from reaching the rotor of the transforming means of 7 by radio-frequency choking inductances 6 connected as shown. In Figure 2, I have shown one means, PS for obtaining the frequency modulated two-phase energy supplied to the stator windings of 7. The frequency modulated wave energy is supplied to the primary winding of transformer T, the secondary windings of which supply the phase shifting circuit PS.

A balanced system is preferable in some cases, and in some cases a single line with single tube stages is preferable. The latter arrangements have been illustrated in Figures 3 and 4 which, it is believed, are self-explanatory once the arrangement of Figures 1a, 1b, 1c and Figure 2 is understood. In Figures 3 and 4 the capacities imposed by the tubes on the line L are tuned out by means of tuning reactances TR connected as shown and shunted between the grids G and cathodes K of the tubes. In Figure 3 an oscillator 40, comprising an electron discharge device 41 having its control grid 43 connected to a point on a frequency stabilizing line 42, is used to produce the high frequency oscillations of constant frequency f_0 and supply the same to the line. The grid 43 of the tube 41 is connected to one member of the resonant line 42, while the cathode of tube 41 is connected to the outer member of the resonant line 41. If necessary, the cathode circuit may include a tuning reactance 44. Oscillations are sustained by virtue of the low loss resonance characteristic of the line 42 and of the coupling between the line L and the inner member of 42. Line L in Figure 3, instead of being matched by a resistance at the end absorbing all of the energy, is connected back to supply some feedback. The length of the line is adjusted so that the phase of the feedback energy is proper for regeneration. The output circuit of 41 is tuned by an inductance 45 and condenser. The inductance 45 is coupled to the line L. In case it is not undesirable to waste the energy lost in matching the line L with a resistor Z0, I may utilize an oscillator arrangement of the type illustrated in Figure 4 and the

line L is then damped by an impedance Z0 as in Figures 2 and 4. The arrangement of Figure 4 is otherwise similar to that of Figure 3.

In Figure 3, I have also shown a carrier wave source 50, frequency modulator 51, and a source of signal potentials 52 connected to the phase shifter circuit PS. This frequency modulation system may also represent a system connected to the points marked X of Figure 2.

The operation of Figures 3 and 4 will be understood from the description of the operation of Figure 2 given hereinbefore. In practice the tubes 3, 13, 23, 33, are selected so that they, in effect, load the line L by about 1,000 ohms. The terminating impedance of the line then may be about 100 ohms.

In the prior art, considerable difficulty has been encountered in frequency modulating a transmitter in accordance with a wide band of signalling potentials, such as used in television, video systems, etc. An object of my invention is to overcome this disadvantage, and, in accordance therewith, I have provided a frequency modulating means illustrated in Figure 5 wherein wave energy is modulated through a wide range in accordance with signalling potentials. The frequency modulating system illustrated in Figure 5 is an important feature of my invention, and is utilized to supply to the phase splitting or shifting means modulating potentials such that they can readily be handled by the said phase splitting circuits and then used to add or subtract cycles from the carrier wave supplied by the master oscillator of substantially constant frequency.

In Figure 5, 60 is a high-frequency oscillator tube having an anode 61, and a grid 63 connected in tuned circuit 65 wherein oscillations are produced. Oscillations produced in 60, 61, 63, 65, etc., are impressed by phase shifting circuit 67, 68 on the control grid 70 of a reactance type tube modulator 71. The oscillations on the control grid 70 are due to the action of the phase displacing circuit 67, 68 in phase quadrature with respect to the voltages on the anode 73 of the tube 71. Due to the phase displaced relations of the high-frequency voltages on the grid and anode of the tube 71, the tube 71 simulates a reactance and is as shown in the oscillation generator frequency controlling circuit. Moreover, this reactive effect into which the tube 60 looks is varied in accordance with variations in the impedance of the tube 71 and the impedance of tube 71 is varied by modulating potentials from the source 74. The source 74, as pointed out above, may consist of a wide band of potentials, such as used in television, video, and facsimile, etc. The frequency modulated waves produced in 65 are impressed on the control grid 74' of a converting tube 75. High-frequency oscillations produced in oscillator 77 of conventional type are also impressed on the control grid 75. The output circuit 79 of converter 75 is tuned to a frequency equal to the frequency $f_1 - f_2 + f_\Delta$ where f_1 is the frequency of operation of circuit 65, f_2 is the frequency of operation of circuit 76 and f_Δ is the signal potential frequency. This frequency modulator output can be utilized in the systems described in Figures 1a, 1b, 1c, 2, 3, 4 by connecting the same thereto at the points marked X. In Figures 1a, 1b and 1c a phase splitting circuit is interposed between points X of Figure 5 and the stator windings of 7.

Since the frequency modulator illustrated in Figure 5 involves grid modulation and is oper-

ated at low potential, linear frequency modulation of the output through a wide range of modulating potentials can be obtained. The two phase currents, obtained by impressing the frequency modulator output on phase splitter 7, now varies through a wide range of signal variation but at a point much higher in the frequency spectrum, so that the cycles are added to and subtracted from the carrier wave of constant frequency in a manner to produce an output which varies in frequency substantially in accordance with the wide band of modulation potentials.

The system illustrated in the prior figures for adding or subtracting from a substantially fixed frequency wave, an additional frequency which may be substantially fixed or frequency or phase modulated, may be put to a great number of uses in the radio art. My invention, as illustrated above is particularly applicable to modulated signal wave relaying systems and in Figure 6, I have illustrated a novel modulated wave relaying system utilizing the principles of the system described in the prior figures.

Referring to Figure 6, 80 is a high-frequency wave energy pick-up device of any appropriate type and this device supplies excitation to a radio-frequency amplifier 82 connected as shown with a wave converter arranged in accordance with my preceding disclosure. In Figure 6 the unit 90 is designated as a converter and may include the frequency adding or subtracting circuits of Figures 1a, 1b, 1c, and Figures 2, 3, and 4, modified in some cases as described herein-after. The unit 100 is a radio-frequency amplifier while 110 is a high-frequency wave radiating or transmitting means.

The phase splitter of unit 85 may be of any nature, such as, for example, shown at PS in Figures 2 and 3. The unit 95 involves an oscillator or other means for providing a wave of substantially constant frequency and amplitude which, by means of 85, is converted to phase displaced wave energy and supplied to a means in 90 similar to the phase rotating means 7 to control in sequence the conductivity of the tubes connected at quarter wave space points on the line. That is, when a phase or frequency modulated wave is received at 80 as would be the case assumed here, the oscillations from 95 will not be modulated but will be used to excite the phase splitter and supply the phase displaced oscillations to the phase rotator and from the phase rotator to the relay tubes to control the converter 90 to add to or subtract from the modulated wave supplied to the converter 90 from 82 a fixed fractional frequency. The modulated wave of changed frequency is then amplified in the unit 100 and impressed on the translator 110.

As an example, assume that the modulated wave of mean frequency f_0 is amplified in 82 and impressed on the converter 90. In the converter 90 this modulated wave f_0 plus or minus the modulation frequency has added or subtracted therefrom a frequency Δf equal to the frequency of the oscillations supplied from 95 so that from the output of 90, we obtain oscillations of a frequency $f_0 \pm \Delta f \pm$ the modulation frequency (f , mod.) and this wave is supplied to the radio frequency amplifier 100 for amplification and radiation from the radiator 110. Note again that whether Δf is added to or subtracted from $f_0 \pm f$, mod. depends on the direction of rotation of the 2 phase control frequency Δf .

The advantage of a relay system arranged in

accordance with my invention, as illustrated in Figure 6, is that the frequency of the wave at the input of the relay system is different from the frequency of the wave at the output so that the tendency of reaction between circuits is reduced. Note, however, that two primary frequencies only are involved in the circuits so that the system does not make use of a large number of different frequencies, harmonics of which frequencies might affect other frequencies. An additional feature of the present invention is that the system avoids the use of regeneration, again decreasing the chances of undesired reaction.

Since two primary frequencies only are involved, my relay is adapted to relay systems wherein a great number of stations are used.

An important feature of my invention is that in converting the modulated wave to a different frequency for amplification and transmission, I do not make use of heterodyning or detecting actions. The action in my relay system is pure relaying or amplification. That is, although a frequency is added or subtracted from the incoming frequency, there is no beating action nor is there a detecting action.

What is claimed is:

1. In a wave length modulation system in combination, a source of wave energy to be modulated, a transmission line, wherein travelling waves are set up, connected to said source, a plurality of impedances connected to spaced points on said line, a source of wave energy modulated in frequency by modulating potentials, and means for varying said impedances in accordance with phase differentiated voltages characteristic of said modulated wave energy.

2. A system as recited in claim 1 wherein said line has an electrical length greater than one-half wave length of the wave energy to be modulated, and said points are substantially equally spaced along said line.

3. A system as recited in claim 1 wherein said line is at least a wave length long and said points are substantially one-quarter wave length apart along said line.

4. A system as recited in claim 1 wherein there are an even number of said impedances which include similar reactances, and said points are spaced substantially one-quarter wave length of said wave energy to be modulated, whereby the reactive effects of said impedances on said line are inverted by said one-quarter wave spacing and neutralize.

5. A system as recited in claim 1 wherein there are an even number of said impedances each of which comprises the space between electrodes of an electron discharge device, and said points are spaced by substantially one-quarter wave length of the wave energy to be modulated.

6. A system as recited in claim 1 wherein said impedances each comprise an electron discharge device having electrodes coupled to said line and electrodes coupled to said source of modulated wave energy.

7. In a system for changing the frequency of wave energy substantially by a precise amount, a first source of wave energy, an output circuit, a line connected to said source, said line having a character such that travelling waves are established in said line, a plurality of relays connected to said line at points thereon separated by substantially equal electrical amounts, means connecting the outputs of said relays to said output circuit, and means for controlling the out-

puts of the relay devices in substantially time sequence at a frequency related to the increment by which the frequency of said wave energy is to be changed.

8. A system as recited in claim 7 wherein said relays are separated by one-quarter wave lengths of said wave energy.

9. In a system for changing the frequency of wave energy substantially by a precise amount, a first source of wave energy, an output circuit, a line connected to said source, an impedance equal to the surge impedance of the line terminating said line so that travelling waves are established in said line, a plurality of relays connected to said line at points thereon separated by substantially equal electrical amounts, means connecting the outputs of said relays to said output circuit, and means for controlling the outputs of the relay devices substantially in time sequence at a frequency related to the increment by which the frequency of said wave energy is to be changed.

10. A system as recited in claim 9 wherein said relays are separated by one-quarter wave lengths of said wave energy.

11. In a system for changing the frequency of wave energy substantially by a precise mean amount and adding frequency modulations to the energy of changed frequency, a first source of wave energy, an output circuit, a line connected to said source, said line being of a nature such that travelling waves are established in said line, a plurality of relays connected to said line at points thereon separated by substantially equal electrical amounts, means connecting the outputs of said relays to said output circuit, and means for controlling the outputs of the relay devices in time sequence by frequency modulated waves of a mean frequency related to the increment by which the frequency of said wave energy is to be changed.

12. In a system for changing the frequency of wave energy substantially by a precise amount, a source of wave energy, an output circuit, a line connected to said source of wave energy, said line being of a nature such that travelling waves are established in said line, a plurality of electron discharge devices connected to said line at points thereon separated by substantially equal electrical amounts, means connecting the outputs of said devices to said output circuit, and means for controlling the conductivity of said devices in sequence at a frequency related to the frequency by which the frequency of said wave energy is to be changed.

13. A system as recited in claim 12 wherein said discharge devices comprise even numbers of pairs of devices and wherein said pairs of de-

vices are separated by one-quarter wave lengths of said wave energy.

14. In a system for changing the frequency of wave energy substantially by a precise amount, a source of wave energy, an output circuit, a pair of transmission lines connected to said source of wave energy, said transmission lines having set up therein travelling waves, pairs of relay devices each having input and output electrodes, means connecting the input electrodes in push-pull relation between points on the respective lines separated substantially by quarter wave lengths of said wave energy, means for connecting all of the output electrodes in push-pull relation to said output circuit, and means for controlling the impedances of said pairs of devices in phase opposition substantially in time sequence at a frequency related to the increment by which the frequency of said wave energy is to be changed.

15. In a wavelength modulation system in combination, a source of wave energy to be modulated, a source of wave energy modulated in frequency by modulating potentials, an electrical circuit coupled to one of said sources whereby wave energy is fed from said one of said sources to said circuit and wave energy set up therein, a plurality of impedances connected to electrically spaced points on said circuit, and means for varying said impedances in accordance with phase differentiated voltages characteristic of wave energy from the other of said sources.

16. A system as recited in claim 15 wherein said impedances each comprise an electron discharge device having electrodes coupled to said circuit and electrodes coupled to said other of said sources.

17. In a modulation system, a source of wave energy, an output circuit, a circuit coupled to said source of wave energy whereby wave energy is fed from said source to said last named circuit, and wave energy set up in said last named circuit, a plurality of electron discharge devices connected to said last named circuit at points thereon separated by substantially equal electrical amounts, means connecting the outputs of said devices to said output circuit, and means for controlling the conductivity of said devices in sequence at a frequency related to the frequency by which the frequency of said wave energy is to be changed.

18. A system as recited in claim 17 wherein said discharge devices comprise even numbers of pairs of devices and wherein said pairs of devices are electrically spaced on said circuit by one quarter wave lengths of said wave energy.

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