

April 14, 1942.

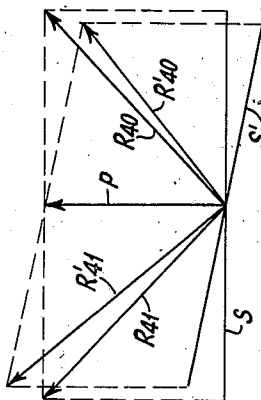
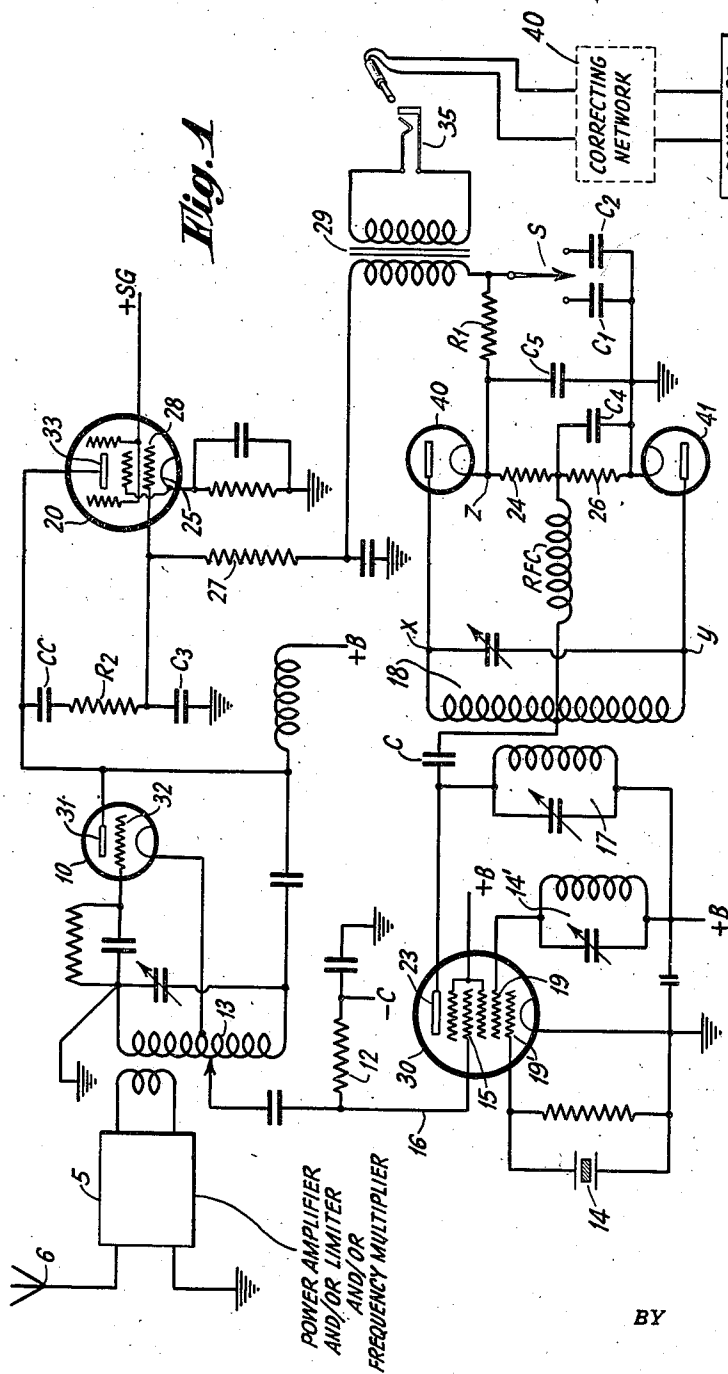
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2,279,659

FREQUENCY MODULATOR

Filed April 13, 1937

2 Sheets-Sheet 1



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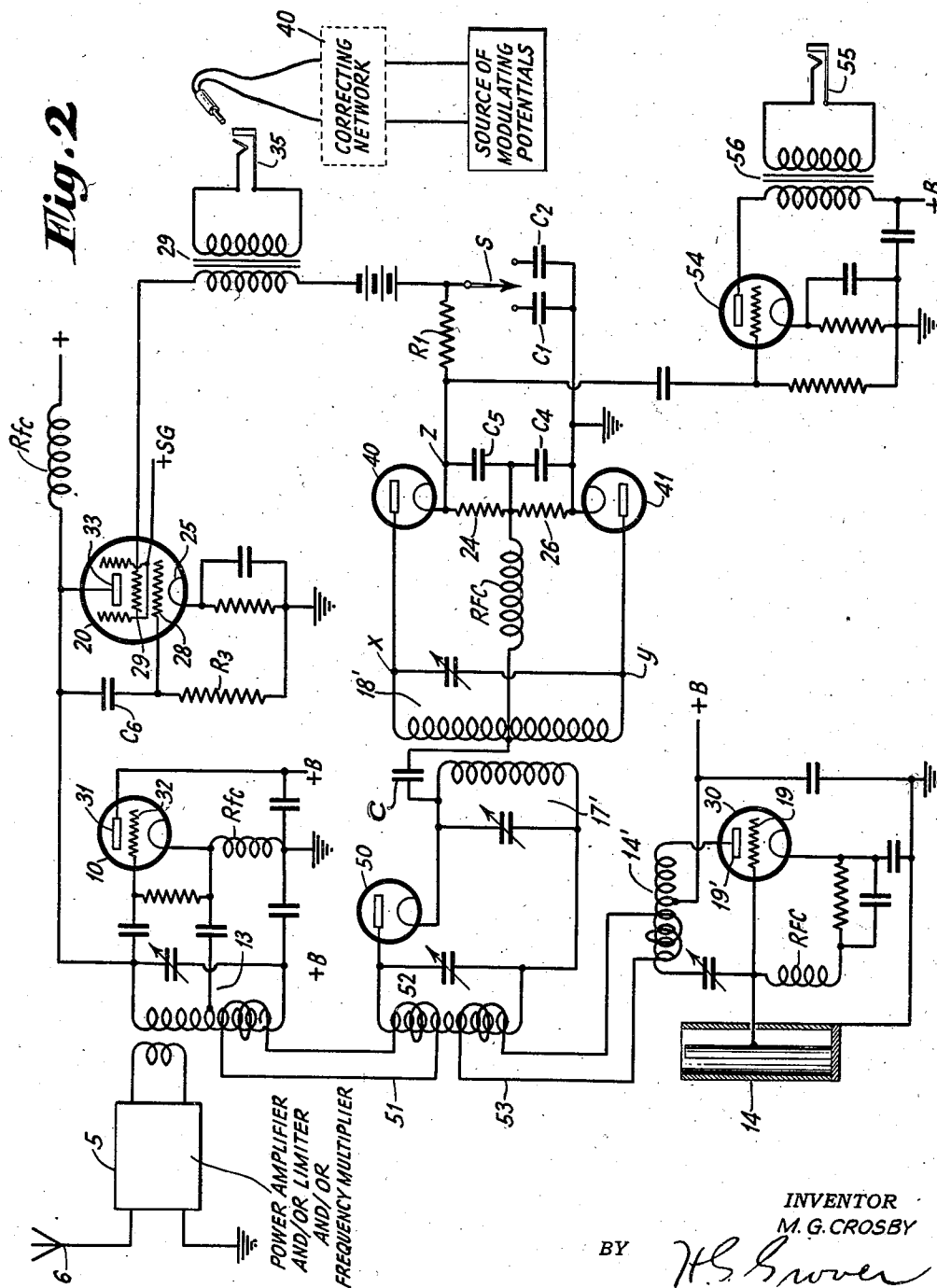
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Fig. 2



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FREQUENCY MODULATOR

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Application April 13, 1937, Serial No. 136,578

47 Claims. (Cl. 179—171.5)

This invention discloses a type of frequency modulator wherein a high degree of stability is maintained by the use of automatic frequency control. The same controlling means is used for automatically controlling the mean frequency of the modulation as is used to produce the frequency modulation. In this way a simple frequency modulator with a high degree of stability is obtained without the necessity of a high degree of frequency multiplication.

In the prior art of generating frequency modulation, one method used to obtain frequency modulation without sacrificing stability has been the use of phase modulation with correction or modification of the audio frequency modulating potentials and the use of a high degree of frequency multiplication. Since the amount of phase modulation which may be obtained in a phase modulator is effectively a very small amount of frequency modulation, a high degree of frequency multiplication is necessary to obtain frequency modulation by a phase modulation and multiplication method. Also, the audio correction necessary to correct the phase modulation to frequency modulation involves the use of correction circuits which necessitates additional amplification to make up for the losses induced by the correction circuits.

When the ordinary oscillator, utilizing tuned circuits, is frequency modulated, in order to obtain a high degree of frequency modulation without encountering inertia or fly-wheel effects, the tuned circuit of the oscillator must be damped or constructed with high losses so that the frequency may be modulated at a high rate without distortion to the higher modulation frequencies. When this damping is applied to the oscillator tuned circuit, or when low Q circuits are used for the tuned circuit, the stability of the mean frequency of the oscillator is reduced in accordance with the reduction in Q of the tuned circuit. Thus, the required damping of the tuned circuit loosens up the stability of the mean frequency so that when the oscillator is frequency modulated, the degree of modulation is dependent upon the degree of stability present. Hence, mean frequency instability is attendant to a high degree of frequency modulation.

My frequency modulator utilizes automatic frequency control of a frequency modulated oscillator to insure a high degree of stability for slow frequency variations or drift but its stability is loosened for frequency variations at signal frequency. In this manner I provide a simple frequency modulated oscillator with stability

comparable to a crystal controlled oscillator and yet the frequency of the oscillator can be varied over a wide range of frequencies linearly in accordance with modulating potentials. Due to the wide frequency modulation which can be obtained in the modulated oscillator less frequency multiplication is required to produce a high degree of frequency modulation.

In the frequency modulator of this invention automatic frequency control is used to hold the mean frequency of the modulated oscillator at a fixed position. The oscillator energy is heterodyned to an intermediate frequency by means of a crystal oscillator whose stability is very high. This intermediate frequency is passed through frequency discriminating circuits and rectified so that the rectified energy may be used to vary an element voltage of a reactance tube connected to the tuned circuit of the modulated oscillator. Thus, mean frequency variations of the oscillator are converted to energy which operates a reactance in the said oscillator circuit in a manner to compensate for said mean frequency variation tendencies. These frequency variation tendencies occur at rates which are slow compared to modulation frequencies ordinarily used for signalling. Hence, signalling frequencies may also be applied to an element voltage of the reactance tube which will modulate the frequency of the oscillator but which will not be compensated by the automatic frequency control circuits due to time constant circuits placed in the automatic frequency controlling circuits.

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

Figures 1 and 2 each show a frequency modulator circuit wherein the mean frequency of the oscillator is maintained constant and wherein the frequency of the oscillator is modulated in accordance with signals or other controlling potentials; while

Figure 3 is a vector diagram illustrating the manner in which the frequency controlling potentials are obtained.

Figure 1 shows a specific embodiment of the principle employed in this invention. Tube 10 is the oscillator tube, tube 20 is the reactance tube, tube 30 is the frequency converter tube and tubes 40 and 41 are diodes which have been shown as separate tubes but may be enclosed in a single envelope. The oscillator 10 having tuned circuit 13 is of the grounded grid type and has its output coupled to power amplifier 5 and through 5 to antenna 6. Unit 5 may also contain amplitude limiters and frequency multipliers. Part of the

energy from the oscillator circuit 13 is fed to one of the grids, say 15, of pentagrid converter tube 30 by means of lead 16. Grid leak 12 furnishes bias for the grid 15. Tube 30 also includes oscillation generator elements 19, and 19' connected by piezo-electric crystal 14 and tuned circuit 14' to the cathode and operated in a well known manner to produce oscillations of a frequency determined by 14 and 14'. Preferably the circuit 14' is tuned to be inductively reactive to the oscillations produced. The oscillations produced are impressed on or modulate the electron stream of the tube 30 and reach the shielded anode 23 by way of the electron stream only. Crystal 14, in conjunction with anode tuned circuit 14', oscillates at a frequency differing from the frequency of tuned circuit 13 by a frequency difference equal to an intermediate frequency. Thus, the electron stream of tube 30 is controlled by oscillations produced in 30 and by oscillations from 10. The transformer consisting of primary and secondary windings 17 and 18 is tuned to the said intermediate frequency. The mid-tap of the secondary 18 of this transformer is connected through a by-pass and coupling condenser C to the high intermediate frequency potential side of the primary winding 17 of the transformer. Thus, the voltage applied to each of the diodes 40 and 41 is the combination of the voltage applied to the high potential end of primary winding 17 and the voltage induced by winding 17 in the secondary winding 18. The transformer 17, 18 forms a retard circuit so that the voltage fed to the diodes 40 and 41 is a combination or resultant of a retarded voltage and an unretarded voltage. Thus, this coupling forms a frequency modulation sloping filter in the manner described in the Crosby United States application #618,154 filed June 20, 1932, Patent No. 2,229,640, January 28, 1941. In the arrangement of the said Crosby application the retarded voltage is combined with the unretarded voltage by means of coupling tubes. In the circuit of Figure 1 of this disclosure, coupling tubes are dispensed with and the retarded voltage appearing at the transformer secondary 18 is combined directly with the unretarded voltage appearing at its primary 17 and supplied to 18 through coupling condenser C. The energy from the frequency discriminating transformer 17 and 18 is differentially rectified by diodes 40 and 41. The rectified energy appears in resistors 24 and 26 and a voltage characteristic thereof is passed through time constant elements R_1C_1 , or R_1C_2 , depending on the position of switch S, and thence through transformer secondary 29 and through grid leak 27 to the grid of the reactance tube 20.

The operation of the frequency discriminating circuit comprising the intermediate frequency transformer 17 and 18 and the direct coupling C to produce a potential of a value characteristic of the extent of deviation of the mean intermediate frequency from its correct value and of a polarity characteristic of the direction of said deviation from said correct value will now be described. The differential direct current potentials produced in 24 and 26 whose magnitude and polarity are determined by the amount and sign, respectively, of the difference between the applied frequency in 17 and the induced frequency in 18 is obtained by rectifying action of 40 and 41. As is known, a 90° phase relation exists between the primary voltage in 17 and the secondary voltage in 18 where 17 and 18 are loosely coupled and both tuned. This phase relation changes as the ap-

plied frequency varies. Thus, if the primary and secondary voltages are added vectorially, the absolute magnitude of the resultant vector will be greater on one side of resonance than on the other. The potentials at the ends of the inductance of 18, i. e., at X and Y are 180° out of phase because the center point is connected to the primary 17. Thus two potentials may be produced, one maximizing above and one maximizing below the center or resonant frequency. These voltages are applied to the rectifiers 40 and 41.

In Figure 3 let P represent the primary voltage supplied by C to the anodes of 40 and 41. Let S represent the voltage induced in 18 and assume that the correct intermediate frequency is set up in the primary 17 so that an exact phase quadrature relation is obtained between the primary voltage P and secondary voltage S. Two resultants R_{40} and R_{41} are produced and act through 40 and 41 to produce in 24 and 26 opposite and equal currents and no potential is supplied by 40, 41 to control the reactance tube 20 and in turn the tune of 13. Under this condition the tuning of 13 is adjusted to produce in 10 the frequency desired as the mean frequency of the frequency modulated transmitter.

Now assume that the mean intermediate frequency slowly changes due to shift in frequency of 10. The phase relation between P and S heretofore 90° changes and S takes up a new position as shown at S' in Figure 3. The 180° phase relation between the secondary voltage at points X and Y remains. The vector R'_{41} has become longer while the vector R'_{40} has become shorter. Thus, the voltage on 41 has become greater and that on 40 smaller so that a resultant is produced at 24 and 26 to act through R_1 to retune 13 in a direction to return the intermediate frequency to the correct value. If the mean frequency shifts in the other direction the vector relation of P and S changes and the voltage applied to 40 becomes greater than that applied to 41 and 13 is tuned in the opposite direction. In other words, if the proper mean frequency is applied to 17 equal voltages are applied between X and ground and Y and ground. These voltages are rectified in 40 and 41 and appear in 24 and 26 flowing in opposite directions. The potentials are equal and the net is zero potential between Z and ground. However, when the applied frequency at 17 is incorrect and departs from resonance the frequency discriminating circuit comes into play and the voltages between X and ground and Y and ground are unequal. Unequal drops in 24 and 26 produce a resultant potential at Z which acts on 27. The polarity of this potential depends on direction of frequency departure from center frequency. C_4 and C_5 are of low impedance to the intermediate frequency.

Reactance tube 20 is of the type in which a vacuum tube is converted into a reactance by feeding an out of phase voltage to its grid. Thus, resistor R_2 and condenser C_3 form a phase shifting circuit which shifts the voltage supplied from the anode 31 of 10 to the plate 33 of the reactance tube 20 so that it reaches the grid 28 of tube 20 with a 90° phase lag. The value of R_2 is made high as compared to the reactance of C_3 for the frequency used so that the current through the circuit is largely resistive and is in phase with the voltage. However, the voltage drop through C_3 will lead the current by substantially 90° and the desired phase relation

necessary to produce the reactive effect in 20 is obtained.

The control tube 20 acts to vary the oscillator frequency and this variation may be thought of as if due to a variation in capacity, or of an inductance. The total oscillator circuit reactance may be considered to consist of two parts. That part physically present as in the variable tuning condenser and the tuning coil of circuit 13, and that part reflected by the control circuit of tube 20. The latter is a function of the intermediate frequency carrier frequency supplied by 17 and 18, and its magnitude varies with the shift from the intermediate frequency mid-band frequency. It will be noted that the plate of control tube 20 is coupled into the high potential side of the tank circuit, and that the grid of the control tube is excited by a voltage which is 90° out of phase with that appearing across the tank circuit. The plate current in the control tube is then likewise out of phase with the tank voltage, and accordingly, the control tube 20 looks like a reactance to the tank circuit. A similar reactance tube has been described in Travis United States application #4,793 filed February 4, 1935, and in Travis United States application #19,563, filed May 3, 1935. New and improved reactance tubes have been described in my United States application #209,919 filed May 25, 1938, Patent No. 2,250,095, July 22, 1941.

The sign of the reactance presented to the tank circuit by the control tube depends upon the nature of the impedance across which is developed a voltage to be fed to the input electrodes of the control tube. The magnitude of the reflected reactance depends upon the automatic frequency control bias impressed upon the control grid of control tube 20, as this varies the mutual conductance, and proportionately the magnitude of the plate current, of the control tube. In Figure 1 there is shown one method of obtaining the out-of-phase excitation for the grid of the control tube, and it will be noted that this is accomplished by taking the voltage across condenser C_3 in series with resistance R_2 coupled with the tank coil 13 and anode 31. The effect of this arrangement is to produce an inductive effect across the circuit. As the plate current of tube 20 is decreased the shunting effect of the reflected inductance is decreased and the effective inductance of the circuit 13 will therefore increase. This results in a rise of oscillator frequency. When the plate current to 20 increases the effective reactance supplied to circuit 13 increases and the frequency of the produced oscillations falls.

The reactance of the tube 20 between its plate 30 and cathode 25 is connected as shown in shunt to the anode 31 and grid 32 of oscillation generator 10 or effectively in shunt to the frequency determining circuit 13. The gain of tube 20 controls the reactance between its electrodes. The gain of tube 20 is controlled by the potential on 28 and this potential is determined in value by the deviation of the intermediate frequency from resonance of transformer 17, 18, while the polarity of the potential supplied by 40, 41, and R_1 to 27 and 28 depends on the direction of deviation of the intermediate frequency from said point of resonance.

When the frequency of the oscillator 10 varies a given amount the intermediate frequency appearing in the plate circuit of tube 30 will vary the same number of cycles since the crystal oscil-

lator has a high degree of stability and will not vary appreciably. This change in frequency is converted into a change in voltage appearing across the diode resistors 24 and 26 by means of the frequency discriminating transformer 17, 18 and the direct coupling C. After passing through either one of the time constant circuits R_1C_1 or R_1C_2 the energy is passed to the grid 28 of the reactance tube so that the reactance in the plate of tube 20 is changed by an amount sufficient to compensate for the change in frequency of the oscillator. Thus, the mean frequency of the oscillator is automatically held to its selected mean frequency at a stability dependent upon the stability of the crystal oscillator 20 and of the frequency discriminating circuits C, 17, and 18.

Signal modulation may be applied through jack 35 and transformer 29 to the grid 28 of the reactance tube 20 to vary the tuning of the oscillator 10 and, in turn, the frequency of the oscillator 10. Since this signalling voltage will alternate at a rate which is too great to be passed by time constant circuit R_1C_1 or R_1C_2 , the frequency deviations due to the signalling waves will not be compensated for by the automatic frequency control C and 17 and 18 including the intermediate frequency discrimination circuits. Thus, the oscillator may be varied at a rate corresponding to the signalling frequency but may not be varied at a rate lower than signalling frequencies so that the slow drifts of mean frequency are compensated for without impairing the applied frequency modulation.

The circuit of Figure 2 contains the following additional modifications which may be applied to the invention of the application:

1. The use of a line controlled oscillator 30 for the heterodyning oscillator.
2. The use of a different form of reactance tube 20 for varying the tuning of the modulated oscillator 10.
3. The use of a limiter action (50) to remove unwanted amplitude modulation from the energy applied to the automatic frequency control circuit.
4. The addition of a monitoring circuit to monitor the quality of the frequency modulation.

The line controlled oscillator shown in Figure 2 and comprising tube 30 and its associated circuits including resonant line 14 may employ the principle of stabilizing the frequency of an oscillator as described by Messrs. C. W. Hansell, and P. S. Carter in the Proceedings of the Institute of Radio Engineers, vol. 24, No. 4, April 1926. The title of this article is "Frequency control by low power factor line circuits." No novelty is herein claimed as to the particular type of line controlled oscillator to be used.

The reactance tube 20 of Figure 2 utilizes broadly the method hereinbefore described but differs therefrom in several respects. Here the reactance effect is obtained by applying the feedback voltage from the plate of the reactance tube to its grid. Here however, new and improved results are obtained by a simple arrangement utilizing suppressor grid modulation as described in my United States application #209,919, filed May 25, 1938, Patent No. 2,250,095, July 22, 1941. Elements C_6 and R_3 form the feedback phase shifting circuit by means of which potentials from the anode 33 of tube 20 are supplied to the grid 28 of tube 20 in 90° phase displaced relation relative to the phase of the voltage on 33. The reactance of C_6 is made

large compared to the resistance of R_3 for the frequency used so that current through the circuit is largely determined by the condenser. Since the current is capacitively reactive, it leads the voltage by 90° . The voltage in R_3 will be in phase with the current through C_3R_3 . Consequently, the voltage across R_3 is 90° out of phase with respect to the voltage across C_3R_3 and the required phase relation is obtained. The condenser C_3 may represent the capacity between 33 and 28 or may represent a separate condenser supplementary said capacity. Modulating potentials are applied to the suppressor grid 29.

The detector tube 50 of Figure 2, is separate instead of being included as a part of the pentagrid converter as shown in Figure 1. 50 is a diode so that diode limiting may be utilized at this point in the circuit. Briefly the principle of operation of the diode limiter 50 consists in applying the voltage to be limited at a level which is high compared to the voltage which is applied for heterodyning. Since a diode detector is a linear detector it detects the envelope of the modulated wave applied at its input. The detected output is proportional to the mean voltage of the modulated wave and the percentage of modulation. Thus, $I_h = kEM$, where I_h is the heterodyne output, k a constant of the circuit and tube, E the mean voltage and M the percentage of modulation. When the diode is used as a heterodyne detector, the modulated wave is due to variations in strength of the carrier wave and local oscillator wave which are applied at the input. Hence the strongest of the two voltages is modulated up and down by the addition and subtraction of the weaker. The percentage of modulation is therefore proportional to the ratio between the carrier and local oscillator voltages, or $M = E_o/E_c$ where E_o = oscillator voltage and E_c = carrier voltage in the case where the carrier voltage is the strongest. Since the mean voltage will be equal to E_c , the heterodyned output will be:

$$I_h = kE_c \times \frac{E_o}{E_c} = kE_o$$

Consequently with the carrier voltage stronger than the local oscillator voltage, the heterodyne output is dependent upon the oscillator voltage only. This is the feature which allows the device to be used as a limiter. By using such a detector and adjusting the signal voltage so that it is stronger than the local beating oscillator, the heterodyne output is constant for all values of signal greater than equality with the local oscillator. By varying the strength of the local oscillator the point where limiting begins may be adjusted. Thus, energy of relatively high amplitude from oscillator 10 designated hereinbefore as the carrier is fed from the tuned circuit 13 by means of link coupling 51 to the tuned circuit 52 of the diode detector-limiter 50. Energy from the tank circuit 14' of the line-controlled heterodyning oscillator 30, 14, etc., designated hereinbefore as the local oscillator is fed from circuit 14' to the diode input circuit 52 by means of link coupling 53. The differential transformer 17, 18 and diode detectors 40, 41, are the same as described in Figure 1.

The audio monitoring circuit consisting of amplifier tube 54 feeding through an output transformer 56 to jack 55 is coupled to the diode resistors 24 and 26 at a point preceding the time constant circuit R_1C_1 or C_2 through which the automatic frequency control energy is fed. This

circuit enables the monitoring of the detected frequency modulation which will appear across the diode resistors. This modulation appears at the diode resistors by virtue of the transformer 17, 18 which converts the frequency modulation to amplitude modulation for detection by the diodes 40, 41. Thus, the quality of frequency modulation obtained due to the application of modulation potentials, through jack 35 and transformer 29, may be observed and defects noted.

It will be noted that in Figure 2 oscillator tube 10 utilizes a somewhat different circuit than the oscillator of Figure 1. The oscillator of Figure 2 utilizes a grounded-plate circuit in place of the grounded-grid circuit of Figure 1. Both of these circuits are particularly well adapted to the placing of a reactance tube across the oscillator tuning circuit. Any oscillator circuit with one side of the circuit at radio frequency ground potential would be as well adapted as these two types of circuit. For instance, a Meissner circuit would be so adapted. For a diagram of the Meissner circuit see the book "Radio Engineering" by F. E. Terman, page 228. The "Reversed Feedback" and "Tickler Feedback" circuits on the same page of that book would be likewise suitable.

This type of circuit may be used to produce phase modulation of the type wherein frequency modulation is corrected to phase modulation by the use of a particular value of time constant R_1C_1 or R_1C_2 . Thus, R_1C_1 might be of such a value as would enable the production of frequency modulation, and R_1C_2 might be of such a value as would enable the production of phase modulation. Hence, by switching switch S either phase or frequency modulation may be chosen. The time constant R_1C_2 for phase modulation would be of such a value as to allow the automatic frequency control to partially compensate for the frequency deviations of the lower signaling frequencies. Hence, a frequency deviation would be produced which would be proportional to the audio frequency applied. A frequency modulation with such a proportionality is effectively a phase modulation.

For frequency modulation, the time constant of R_1C_1 would be adjusted to a value which is substantially greater than the period of the lowest modulating frequency. Thus for a lowest modulating frequency of 50 cycles, the time constant would be substantially greater than $\frac{1}{50}$ of a second—a value of about $\frac{1}{5}$ second would be satisfactory. With this value of time constant, R_1C_1 would sufficiently attenuate frequencies higher than about 50 cycles so that only frequency changes having a rate of change less than 50 cycles per second would be allowed to pass from the frequency discriminating detector circuit to the reactance tube. Hence if a modulating potential having a frequency of 50 cycles or higher were applied through transformer 29, the frequency of the oscillator 10 would be modulated in accordance with the potentials and the automatic frequency control action would not oppose the modulating potentials.

In the case of phase modulation production, the time constant of R_1C_2 is adjusted so that the modulating potentials of lower frequency are opposed by the automatic frequency control action. As I have shown in my United States application #618,154 filed June 20, 1932, Patent No. 2,229,640, January 28, 1941, a phase modulated wave is equivalent to a frequency modulated wave whose modulating potentials have been distorted with respect to their frequency characteristic such

that the degree of frequency modulation is proportional to the frequency of the modulating potentials. That is, all that is necessary to produce phase modulation on a frequency modulation transmitter is to add a correction circuit to the modulating potentials such that each modulating frequency is applied with an amplitude proportional to its frequency. Hence, the low frequency modulating potentials must be attenuated with respect to the high frequency modulating potentials or the high frequency modulating potentials increased in amplitude in accordance with their frequency. This may be done with the aid of an audio correction network inserted in the leads supplying the modulating potentials, but it may be also done in the novel manner of the present invention. The method of the present invention is to make the time constant R_1C_2 of such a value that the automatic frequency control action tends to reduce the degree of frequency modulation for the lower frequency modulating potentials. Thus, if R_1C_2 is of such a value that an appreciable amount of 50 cycle energy will be passed by it from the frequency discriminating detectors to the reactance tube, this energy will tend to oppose that applied through transformer 29 and the degree of frequency modulation for that modulation frequency will be reduced. For a higher modulation frequency the attenuating effect of R_1C_2 would be greater so that there would not be as much opposition to the modulating potentials and a greater degree of frequency modulation would result. This sort of characteristic with a degree of frequency modulation which rises as the modulation frequency rises is just what is desired to produce a phase modulation wave. Thus, instead of adjusting for a time constant of $\frac{1}{2}$ second, C_2 would be adjusted to have a reactance at the lowest modulating frequency of about $\frac{1}{2}$ the resistance of R_1 . Such an adjustment would attenuate a modulation frequency of 50 cycles by a ratio of 5:1 and a modulation frequency of 5000 cycles by a ratio of 500:1. The lower modulating frequencies would therefore be attenuated less than the higher modulating frequencies so that the degree of frequency modulation of the lower modulation frequencies would be reduced to a greater extent than that of the higher and a phase modulated wave would result. Various degrees and characteristics of attenuation could be obtained by substituting other elements for R_1C_2 , for instance a resistance in series with a condenser could be substituted for C_2 in order to decrease the rate at which the attenuation increased with frequency. The time constant circuit R_1C_1 or R_1C_2 might also consist of other elements besides resistance and capacity so as to produce the desired correction circuit to correct the frequency modulation into phase modulation. This type of phase modulator would be very advantageous where high degrees of phase modulation are required.

It will be apparent to those skilled in the art that the crystal oscillator energy might be supplied from a separate unit which contained some form of stable oscillator with or without frequency multipliers. A multi-grid tube such as the 6L7 could then be used as the frequency converter in place of the pentagrid converter 30 shown in Figure 1.

In a modification I utilize the principle of inverse feedback to reduce the distortion and still obtain the increased stability which the circuits of this application have. In order to apply in-

verse feedback to transmitters, the procedure employed is to receive some of the energy to be radiated and apply this rectified energy to the audio system at a phase such that the energy fed back opposes the energy applied as modulating potentials. Thus, in the case of the use of inverse feedback on an amplitude modulation transmitter, some of the transmitted energy is rectified and fed back into the audio system with the polarity adjusted so that the feedback and applied modulating potentials oppose. This type of degeneration or inverse feedback has the property of reducing distortion due to non-linearity and also tends to flatten out the frequency characteristic. The principle of inverse feedback has been described by H. S. Black in an article entitled "Stabilized feedback amplifiers" in vol. 53, page 114; January 1934 of *Electrical Engineering* (also in the January 1934 issue of *The Bell System Technical Journal*). A notable use of the principle in a broadcast transmitter is described by Poppele, Cunningham and Kishpaugh in an article entitled, "Design and equipment of a fifty-kilowatt broadcast station for WOR" in the *Proceedings of the I. R. E.*, vol. 24, No. 8, August 1936.

In my application of inverse feedback to a frequency modulation transmitter, I receive some of the energy from the frequency modulated oscillator on a frequency modulation receiver consisting of a frequency discriminating circuit and rectifiers and then feed this rectified energy in series with the modulating potentials at a polarity which opposes the modulating potentials. This procedure increases the required amplitude of the modulation potentials for a given degree of frequency modulation, but this may be compensated for by inserting additional amplification in the modulating potential circuits.

The circuits of Figure 1 and Figure 2 are ideally adapted to the application of inverse feedback. The only change necessary is to eliminate the time constant consisting of R_1 , C_1 or C_2 or else substitute a time constant of such value that it will pass all of the frequencies in the modulation band equally well. The latter adjustment is preferable since the time constant then tends to prevent radio frequency energy from feeding back, but allows the modulating potentials to be fed back without attenuation. With either of these adjustments the detected output of the diodes 40 and 41, therefore, corresponds to the "envelope" of frequency modulations on the energy from 13. Thus, when this detected output is fed back to oppose the applied modulating potentials, inverse feedback is obtained with its accompanying advantages.

The operation of these circuits with their time constant circuits removed, or adjusted so that they do not attenuate the modulating potentials, is in most respects the same as that of the circuits with a higher value of time constant present. The only difference being in the requirement of modulating potentials of higher amplitude. Additional audio frequency amplifiers can be added to the equipment connected at 35 to 29. This requirement would be compensated for by a reduction of distortion with respect to linearity and frequency characteristic. Since it is rather difficult to obtain a frequency deviation which is in exact linear accordance with the modulating potentials, the improvement in this respect is greatly to be desired.

In the phase modulation modification of these circuits, inverse feedback is also used, but the

feedback potentials are attenuated by the time constant circuit in a manner to produce a feedback which converts the frequency modulation into phase modulation. This required a particular value of time constant to produce the proper attenuation of the feedback energy. In the case of frequency modulation, there are two adjustments possible one as previously described where the time constant circuit allows only slow variations to pass and thereby correct for slow drifts in mean frequency, and the other in which the time constant is removed and the feedback potentials are allowed to oppose the modulating potentials, but the modulating potentials are increased a compensating amount.

The second modification concerns the elimination of the step of heterodyning. For instance in the case of Figure 1, tube 30 and its oscillator circuit may be removed and transformer 17, 18 may be tuned to the frequency of oscillator 13, 10 and fed directly by energy from oscillator 10. This arrangement is not as preferable as the heterodyne arrangement since the frequency discriminating circuit operates at a high frequency and the reduced selectivity inherent to the higher frequency will reduce the degree of overall stability obtained. However, the advantages inherent to the inverse feedback are still present and the system also has more flexibility with regard to change of operating frequency. The specific arrangement of the circuit of Figure 1 to eliminate the step of heterodyning is to eliminate tube 30 and all of its associated elements including the primary tuned circuit 17. Tuned circuit 18 is then coupled directly to 13 and condenser C tapped on coil 13 at the same position that lead 16 is tapped at present.

The arrangement of Figure 2 may, in like manner, be modified to employ reversed feedback, mean frequency control and frequency or phase modulation by a tuned radio frequency control receiver reactance tube control modulator etc., by coupling 18' directly to the circuit 13 and directly to circuit 13 by condenser C and removing 50, 51, 53, 17', 14' and 30 and its circuits. In this case the operation is the same as described hereinbefore except that the discriminator circuit comprising C and 18' is operating at a higher frequency and is dimensioned accordingly.

The principle of this invention utilizes inverse feedback for all of its adjustments. The difference between the various adjustments is a matter of adjusting the value of the time constant to control the relative attenuations of the frequencies fed back. There are three possible adjustments:

(1) With a slow time constant of the order of $\frac{1}{2}$ of a second such that the feedback only corrects for slow frequency deviations. This would give a frequency modulation transmitter which would be capable of being frequency modulated at a relatively high rate, but which would automatically reduce frequency deviations or drifts which were of a relatively slow rate, i. e., of a rate lower than that of the lowest modulating frequency. In order to produce phase modulation with this adjustment, an audio correction circuit such as disclosed in my United States application #608,383 filed April 30, 1932, now Patent #2,085,739 dated July 6, 1937, may be inserted in the modulating potentials path as indicated by dotted lines at 40 in Figures 1 and 2, between the modulating potential source and the transmitter.

(2) With a time constant of a value somewhat less than $\frac{1}{2}$ second which would allow the automatic frequency control action to reduce the degree of modulation on the lower modulation frequencies. This adjustment would automatically correct the modulating potentials so that the frequency deviations of the lower modulating frequencies would be reduced and the resulting wave would then be a phase modulated wave and the distorting network 40 may be removed or adjusted to pass all potentials in like manner.

(3) With either no time constant at all or with a value of time constant which would not attenuate any of the modulating frequencies. This would result in a frequency modulation transmitter which required a higher value of modulating potentials than that required for the adjustment of (1), but the stability with respect to frequency drift would still be present, and in addition the linearity of the modulation would be greatly improved. In order to produce a phase modulated wave with this arrangement, the modulating potentials fed to the transmitter would have to have a correction circuit 40 applied which would make their amplitudes proportional to their frequency in the known manner of correcting a frequency modulation transmitter for phase modulation emission as disclosed in my aforesaid application.

I claim:

1. In a wavelength modulation system, a high frequency wave generator the mean frequency of operation of which may vary slowly, means for producing potentials characteristic of slow variations in the mean frequency of operation of said generator, substantially inertialess means connected with said generator and actuated by said potentials and operating without mechanical movement for preventing slow variations in the frequency of operation of said wave generator and means for modulating the length of the wave generated by said generator in accordance with controlling potentials of a frequency greater than said slow variations.

2. In a wavelength modulation system, a wave generator the mean frequency of operation of which may vary slowly, electron discharge tube means for producing potentials characteristic of slow variations in the mean frequency of operation of said generator, additional electron discharge tube means connected with said generator and with said first named electron discharge tube means and actuated by said produced potentials for preventing slow variations of the mean frequency of operation of said wave generator and additional means cooperating with said second electron discharge tube means for modulating the length of the wave generated by said generator in accordance with controlling potentials of a frequency greater than said slow variations.

3. In a wavelength modulation system, a high frequency wave generator the mean frequency of operation of which may vary slowly, means connected with said generator for producing potentials characteristic of the slow variations in the mean frequency of operation thereof, substantially inertialess means operating without mechanical movement coupling said first means to said generator and actuated by said produced potentials for preventing said slow variations of the mean frequency of operation of said wave generator and means for modulating the length of the wave generated by said generator in accordance with controlling potentials of a fre-

quency greater than said slow variations, said two means having a part in common.

4. In a frequency modulation system, a signalling wave generator, an oscillation generator, substantially inertialess means operating without mechanical movement actuated by oscillatory energy from said generators for preventing slow variations of the mean frequency of operation of said signalling wave generator and means for modulating the frequency of said signalling wave generator in accordance with controlling potentials of a frequency greater than said slow variations, said two means having a part in common.

5. In a phase modulation system, a main oscillation generator, an auxiliary oscillation generator, means coupled with both of said generators and actuated by energy produced by said main generator and by said auxiliary generator for preventing slow variations of the frequency of operation of said main generator, means for modulating the frequency of said main generator in accordance with signal potentials of a frequency greater than said slow variations, and means for modifying said signal potentials in accordance with their frequency.

6. In a wavelength modulation system, an oscillation generator of controllable frequency, an oscillation generator of substantially fixed frequency, means for producing potentials characteristic of slow variations of the frequency of said first generator relative to the frequency of said second generator, substantially inertialess means operating without mechanical movement energized by said potentials for controlling the frequency of said first generator to oppose said slow variations, and means for impressing modulating potentials on said second named means for modulating the frequency of said first generator.

7. In a frequency modulation system, an oscillation generator of controllable frequency, an oscillation generator of substantially fixed frequency, means for producing potentials characteristic of slow variations of the frequency of said first generator relative to the frequency of said second generator, substantially inertialess means operating without mechanical movement energized by said potentials for controlling the frequency of said first generator to oppose said slow variations, and means for impressing signalling potentials on said last substantially inertialess named means for controlling the frequency of said first generator at signal frequency.

8. In a phase modulation system, an oscillation generator of controllable frequency, an oscillation generator of substantially fixed frequency, means for producing potentials characteristic of slow variations of the frequency of said first generator relative to the frequency of said second generator, means energized by said potentials for controlling the frequency of said first generator to oppose said slow variations, means for modifying signal potentials in accordance with their frequency, and means for impressing said modified signal potentials on said second named means for controlling the frequency of said first generator.

9. In a frequency modulation system, an electron discharge tube oscillation generator of controllable frequency, an electron discharge tube oscillation generator of substantially fixed frequency, electron discharge tube means for producing potentials characteristic of slow variations of the frequency of said first generator

relative to the frequency of said second generator, a variable electron discharge tube reactance coupled to said first generator and actuated by said produced potentials for controlling the frequency of said first generator to oppose said slow frequency variations, and means for impressing additional controlling potentials on said variable tube reactance for controlling the frequency of said first generator in accordance with signalling potential.

10. The method of phase modulating oscillator energy which includes the steps of, producing oscillator energy of controllable frequency the frequency of which may vary slowly, utilizing said slow variations to produce frequency changes of said oscillator energy which oppose any tendency of said produced oscillatory energy to change slowly in frequency, producing modulating potentials the amplitudes of which vary substantially in accordance with the frequency thereof and producing variations in the frequency of said produced oscillatory energy in accordance with said produced modulating potentials of a frequency greater than said slow changes.

11. In a modulation system, a high frequency oscillator comprising an electron discharge device having its electrodes coupled in oscillation producing circuits, a second high frequency oscillator comprising a second electron discharge tube having electrodes connected in oscillation producing circuits, frequency stabilizing means in the oscillation producing circuits of said last named discharge tube, combining means coupled to both of said circuits, a frequency discriminating circuit coupled with said combining means, a rectifier having input electrodes coupled with said frequency discriminating circuit, said rectifier having output electrodes, a frequency control circuit including an electron discharge tube reactance coupling the output electrodes of said rectifier to said first oscillator, and a source of modulating potentials coupled to said last named coupling.

12. In a modulation system, a high frequency oscillator comprising an electron discharge device having its electrodes coupled in oscillation producing circuits, a second high frequency oscillator comprising a second electron discharge tube having electrodes connected in oscillation producing circuits and having additional electrodes, frequency stabilizing means in the oscillation producing circuits of said last named electron discharge tube, a coupling between one of said additional electrodes and said first named electron discharge device, a frequency discriminating circuit coupled with one of said additional electrodes, a diode rectifier having input electrodes coupled with said frequency discriminating circuit, said diode rectifier having output electrodes, a reactance tube having input and output electrodes coupled by phase shifting reactances to said first named electron discharge device, a coupling between the output electrodes of said diode rectifier and the input electrodes of said reactance tube and a source of modulating potentials coupled to said last named coupling.

13. In a modulation system, a high frequency oscillator comprising an electron discharge device having its electrodes coupled in oscillation producing circuits, a second high frequency oscillator comprising a second electron discharge tube having electrodes connected in oscillation producing circuits and having additional electrodes, frequency stabilizing means in the oscil-

lation producing circuits of said last named discharge tube, a coupling between said additional electrodes and said first named electron discharge device, a frequency discriminating circuit coupled with said additional electrodes, a pair of diode rectifiers having input electrodes coupled with said frequency discriminating circuit, said diode rectifiers having output electrodes, a reactance tube having input and output electrodes coupled by phase shifting reactances to said first named electron discharge device, a coupling between the output electrodes of said diode rectifiers and the input electrodes of said reactance tube, time control elements in said last named coupling, and a source of modulating potentials coupled to said last named coupling.

14. In a modulation system, a first oscillation generator comprising an electron discharge tube having electrodes coupled in oscillation producing circuits, a second oscillation generator comprising an electron discharge tube having electrodes coupled in oscillation producing circuits, frequency stabilizing means in said last named circuits, a rectifier having input and output electrodes coupled in an alternating current input circuit and an alternating current output circuit, a coupling between said alternating input circuit and both of said generators, a frequency discriminating circuit coupled to said output alternating current circuit, a rectifier having input electrodes coupled to said frequency discriminating circuit, said rectifier having output electrodes, a reactance tube having input and output electrodes, phase shifting reactances coupling the input and output electrodes of said reactance tube to said first named oscillation generator, a circuit including time control elements coupling the output electrodes of said rectifier to an electrode in said reactance tube, and means for impressing modulating potentials on said last named circuit.

15. In a modulation system, a first oscillation generator comprising a discharge tube having electrodes coupled in oscillation producing circuits, a second oscillation generator comprising an electron discharge tube having electrodes coupled in oscillation producing circuits, frequency stabilizing means in said last named circuits, an amplitude limiting diode rectifier having input and output electrodes coupled in an alternating current input circuit and an alternating current output circuit, a coupling between said alternating current input circuit and both of said generators, a frequency discriminating circuit coupled to said output alternating current circuit, a pair of diode rectifiers having input electrodes coupled differentially to said frequency discriminating circuit, said diode rectifiers having output electrodes, a reactance tube having input and output electrodes, phase shifting reactances coupling the input and output electrodes of said reactance tube to said first named oscillation generator, a circuit including time control elements coupling the output electrodes of said diode rectifier to an input electrode in said reactance tube, and means for impressing modulating potentials on said last named circuit.

16. In a wavelength modulation system, a main wave generator; an auxiliary wave generator, a variable reactance of the reactance tube type associated with said main generator to control the frequency of operation thereof, means for deriving wave energy from said generators and producing electrical variations characteristic of slow

variations in the frequency of operation of said main generator, means for controlling the reactance of said variable reactance in accordance with said electrical variations for opposing said slow variations of the frequency of operation of said main wave generator, means for modulating the length of the wave generated by said main wave generator in accordance with signalling potentials of a frequency greater than said slow variations, said two means having a part in common, and monitoring means connected with said first named means.

17. In a wavelength modulation system, an oscillation generator of controllable frequency, an oscillation generator of fixed frequency, means for producing potentials characteristic of slow variations of the frequency of said first generator relative to the frequency of said second generator, reactance tube means coupled to said first generator and energized by said potentials for controlling the frequency of said first generator to oppose said slow variations, means for impressing modulating potentials on said last named means for controlling the frequency of said first named generator in accordance with said modulating potentials, and monitoring means coupled with said first means.

18. In a wave length modulation system, an electron discharge device generator having electrodes connected in oscillation generating and wave length controlling circuits, a reactance tube having an anode, a control electrode and a cathode, means coupling said anode and cathode in shunt to a portion of said generator circuits to control the wave length of the oscillations generated, phase displacing circuits coupling the anode and control electrode of said reactance tube to said generator to impress on said control electrode and anode phase displaced oscillatory potentials to produce in said reactance tube a reactive effect between said anode and cathode and in shunt to a portion of said generator circuits, a wave length discriminating circuit coupled with said generator circuits, rectifying means coupled with said discriminating circuit for producing potentials characteristic of slow changes in the wave length of the oscillations generated in said discharge device and circuits, means for controlling the gain of said reactance tube in accordance with said produced potentials to thereby stabilize the operation of said generator, and means for controlling the gain of said reactance tube in accordance with modulating potentials to modulate the wave length of said generated wave.

19. A system as recited in claim 18 wherein said means for controlling the gain of said reactance tube comprises an auxiliary electrode in said reactance tube connected by a circuit including time constant elements to said rectifier.

20. In a wave length modulation system, an electron discharge device having a plurality of electrodes connected in oscillation generating and wave length stabilizing circuits, a reactance tube having an anode, a cathode, a control electrode and an auxiliary electrode, means coupling said anode and cathode with said generator circuits to control the wave length of the oscillations generated, phase displacing circuits coupling the anode and control electrode of said reactance tube to said generator to excite said anode and control electrode by phase displaced oscillating potentials so that a reactive effect is produced between the anode and cathode of said reactance tube and in said oscillation generating

circuits to which said anode and cathode are coupler, a source of modulating potentials, and connections between said source of modulating potentials and the auxiliary electrode and cathode of said reactance tube for impressing modulating potentials on the auxiliary electrode and cathode of said reactance tube to control the gain of said reactance tube in accordance with said modulating potentials to thereby control the reactance of said oscillation generating circuits and the wave length of the oscillations generated in accordance with said modulating potentials.

21. In a wave length modulation system, an electron discharge device having a plurality of electrodes connected in oscillation generating and wave length stabilizing circuits, a source of modulating potentials, a reactance tube having an anode, a cathode and a control electrode, phase displacing means coupling the anode and control electrode of said reactance tube to said generator circuits, means coupling the cathode of said reactance tube to said generator circuits, means coupling said source of modulating potentials to an electrode in said reactance tube to control the gain thereof and thereby modulate the length of the oscillations generated, means coupled with said generator circuits for producing potentials characteristic of said length modulations of said oscillations, and means for impressing said produced potentials on an electrode of said reactance tube to control the gain of said tube in a sense to oppose said aforesaid gain control to thereby improve the linearity of said wave length modulating action.

22. The method of signalling by means of wave energy of carrier frequency and controllable wave length which may vary in mean frequency in an undesired manner slowly, and potentials characteristic of signals, which includes the steps of, producing potentials characteristic of the slow variations in the mean frequency of said wave energy, utilizing said produced potentials to control the mean frequency of said wave energy in a sense to oppose said slow variations modifying the amplitudes of said signal potentials as a function of their frequency, modulating the length of said wave energy in accordance with said modified signal potentials, rectifying the modulated wave energy to produce potentials characteristic of the wave length modulations on said wave energy, and additionally controlling the length of said wave energy in accordance with the nature of said last produced potentials in a sense opposite to said modulating action to improve the linearity of modulation of the length of said wave energy in accordance with said potentials characteristic of signals.

23. In a frequency modulation system a high frequency oscillator comprising an electron discharge device having its electrodes coupled in oscillation producing circuits to produce oscillation the mean frequency of which may vary slowly in an undesired manner, a frequency discriminator circuit having an input and having an output, the characteristic of said discriminator circuit being such that the output thereof varies in accordance with variations in the mean frequency of wave energy applied to the input thereof, means for impressing voltages the frequency of which vary in accordance with said slow variations in the frequency of the oscillations produced in said device on the input of said frequency discriminator circuit, an electron discharge tube having a plurality of electrodes including a cathode, an anode and a control elec-

trode, a coupling between the anode of said tube and said oscillation producing circuits, a phase displacing circuit coupling the control electrode of said tube to said oscillation producing circuits, a coupling between the output of said discriminator circuit and the control electrode of said tube and means for varying the impedance of said tube at signal frequency to thereby modulate the frequency of the oscillations produced at signal frequency.

24. In a frequency modulation system the combination of, means for producing oscillations to be modulated in frequency at signal frequency comprising an electron discharge device having its electrodes coupled in oscillation generating circuits to generate oscillations the length of which may vary slowly in an undesired manner, means for stabilizing the frequency of the oscillations generated in said circuits comprising an electron discharge tube having a plurality of electrodes including a controlling electrode, means coupling two of said electrodes to different points on said oscillation producing circuits, a phase shifting circuit coupling said controlling electrode to a third point on said oscillation producing circuits, a frequency discriminator circuit having an input coupled to said oscillation producing circuits and an output coupled to an electrode in said electron discharge tube, said frequency discriminating circuit having a characteristic such that the voltages at the output thereof vary in accordance with slow changes in the frequency of the oscillations produced in said oscillation producing circuits and means for varying the impedance of said discharge tube at signal frequency to modulate the frequency of the stabilized oscillations.

25. In a frequency modulation system a high frequency oscillator comprising an oscillation circuit in which oscillating electrical voltages the frequency of which may change slowly in an undesired manner are caused to flow, a frequency discriminator circuit having an input and having an output, the characteristic of said discriminator circuit being such that the potential at the output thereof varies in accordance with variations in the mean frequency of oscillatory energy applied to the input thereof, means for impressing voltages the frequency of which vary in accordance with said slow variations in the frequency of the electrical voltages caused to flow in said oscillation circuit on the input of said frequency discriminator circuit, an electron discharge device having a plurality of electrodes including a cathode, and a controlling electrode, a coupling between an electrode of said device and said oscillation circuit, a phase displacing circuit connecting the control electrode of said device to said oscillation circuit, a coupling between the output of said discriminator circuit and an electrode of said device for impressing gain controlling voltages from the output of said discriminator circuit on said last named electrode and means for varying the gain of said device at signal frequency to thereby modulate the frequency of the oscillations produced at signal frequency.

26. In a frequency-modulating system, an oscillation generator having a frequency-determining resonant circuit, means to vary the effective value of one of the reactive components of said circuit in accordance with signal impulses to produce frequency-modulation of the generated oscillations, means for stabilizing the mean frequency of the oscillations comprising a tuned

detector coupled to the resonant circuit and connected to react on the said means to produce frequency-modulation, in such direction as to counteract departures from the mean frequency, and means preventing said stabilizing means from exerting control of the frequency except with respect to relatively slow variations in frequency whereby the stabilizing means does not prevent frequency modulation in accordance with the signal impulses.

27. In a frequency-modulation system, an oscillation generator including a resonant circuit for determining the frequency, a space discharge tube having a plate impedance, means including said tube for varying the tuned impedance of said circuit to vary the frequency in accordance with variations in the plate impedance of said tube, means for controlling the plate impedance of said discharge tube in accordance with signals, and means for independently controlling the plate impedance of said tube in response to slow departure of the frequency from normal.

28. In a frequency-modulating system, an oscillation generator having a resonant circuit for determining the frequency, means comprising a control tube for varying the resonant frequency of said circuit at signal frequency to produce frequency-modulation, and other means including said control tube for counteracting slow departures from normal of the frequency of the generated oscillations.

29. In a frequency modulation system, an oscillation generator, means for controlling the frequency of said generator, a reactance tube connected to said generator, means for varying at signal frequency the effective reactance of said reactance tube whereby to vary the frequency of said oscillation generator at signal frequency, means for utilizing one portion of the oscillations of varied frequency for transmittal, means for reducing the mean frequency of another portion of the frequency varied oscillations of said generator, and means for utilizing the energy of reduced mean frequency for controlling the mean frequency of operation of said oscillation generator.

30. In a frequency modulation system, a tube oscillation generator having an anode, a cathode and a control grid, means for connecting said anode, cathode and control grid to high frequency circuit for producing high frequency oscillations, a reactance tube having an anode, a cathode and a control grid, means connecting the anode of the reactance tube and the anode of the oscillator together, means for feeding oscillations from said oscillator in phase shifted relation to the control grid of said reactance tube, means connecting the cathode of the oscillator to the cathode of the reactance tube, means for varying the voltage across the grid and cathode of the reactance tube at signal frequency for varying the frequency of said oscillations produced by said oscillation generator, means for energizing an antenna with energy derived from one portion of said frequency varied oscillations, means for producing the frequency of another portion of said frequency varied oscillations, and means for utilizing the energy of reduced frequency for controlling the effective or average mean frequency of said oscillation generator.

31. In a wave length modulation system, a circuit wherein substantially constant frequency high frequency wave energy to be modulated flows, high frequency wave energy amplifying and transmitting means coupled to said circuit,

means for modulating the length of the wave energy flowing in said circuit including a reactance tube having an anode, a control electrode, an auxiliary grid, and a cathode, connections coupling said anode and cathode with said first mentioned circuit to control the wave length of the high frequency wave energy flowing therein, a phase displacing network coupling the control electrode of said reactance tube to said first mentioned circuit, a source of waves of signalling frequencies, and connections coupling said last named source to said auxiliary grid and cathode for controlling the gain of said reactance tube with waves from said source at signal frequencies to thereby modulate the length of the wave energy.

32. A transmitter comprising a high frequency generator having a resonant circuit which controls the frequency of operation of said generator, means for varying the resonant frequency of said circuit to vary the frequency of operation of said generator in accordance with modulating waves including, an electron discharge tube having an electron emitting electrode, an electron receiving electrode and an electron flow control electrode, means for impressing voltage from said generator substantially in phase quadrature relation on said electron receiving and electron flow control electrodes respectively, whereby a reactive effect is produced in said tube, means coupling a pair of electrodes of said tube to said resonant circuit to supplement the reactance thereof by said reactive effect, and means for controlling the gain of said tube by modulating potentials to modulate said reactive effect, a substantially constant frequency crystal controlled oscillator, and means responsive to waves derived from said generator and from said crystal controlled oscillator to automatically frequency control said generator.

33. In a transmitter, a wave generator having a resonant circuit, a source of modulating potentials, means to frequency modulate the output of said generator with potentials derived from said source of modulating potentials including, an electron discharge tube having an electron emitting electrode, an electron receiving electrode and an electron flow control electrode, circuits for impressing alternating current from said generator on said electron receiving electrode and on said electron flow control electrode substantially in phase quadrature with respect to the alternating current impressed on said electron receiving electrode, a circuit coupling the impedance between the cathode and electron receiving electrode of said tube to said resonant circuit, connections between said tube and source of modulating potentials for controlling the gain of said tube in accordance with said modulating potentials, a circuit coupled to said generator for radiating a portion of the modulated waves produced by said generator, and means for stabilizing the mean frequency of operation of said generator including a frequency discriminating circuit excited by waves produced by said generator, a rectifier coupled to said discriminating circuit for rectifying waves from said discriminating circuit, a control responsive to the rectified waves for frequency controlling the mean frequency of operation of said generator, and means preventing said stabilizing means from exerting control of the frequency of operation of said generator except with respect to relatively slow variations in frequency whereby the stabilizing means does not prevent frequency

modulation of said generator in accordance with the modulating potentials.

34. A transmitter comprising a generator, a source of modulating potentials, reactance tube means for frequency modulating the output of said generator with waves derived from said source of modulating potentials, means for transmitting a portion of the modulated wave energy derived from said generator, a substantially constant frequency oscillator, means for beating together waves derived from said oscillator and generator, a discriminator circuit, means for feeding beat wave energy to said frequency discriminator, a rectifier coupled to said discriminator, and means including said reactance tube for utilizing the output of said rectifier to control the mean frequency of operation of said generator.

35. In combination, a source of modulating waves, means for amplifying said modulating waves, a high frequency generator having a frequency controlling reactance, an electron discharge tube having an electron emitting electrode, an electron flow control electrode and an electron receiving electrode, circuits including phase displacing elements coupling said generator to said electron flow control electrode and said electron receiving electrodes to supply to said electrodes alternating currents displaced in phase substantially 90 degrees whereby a reactive effect is produced in said tube, circuit means coupling said tube to said reactance to supplement the said reactance, a circuit coupling said amplifying means to said tube for controlling said reactive effect by said amplifying means for varying the frequency of said generator in accordance with said amplified modulating waves, means for transmitting a portion of the output of said generator, a combined oscillator and converter, means for feeding wave energy derived from said generator to said converter, means for feeding the output of said combined oscillator and converter to a frequency discriminator circuit, a rectifier coupled to said discriminator circuit, and means for utilizing the output of said rectifier to control the mean frequency of operation of said generator.

36. A transmitter comprising a regeneratively connected high frequency generator, a source of modulating potentials, a modulation potential amplifier for amplifying said potentials, a reactance tube circuit coupling said amplifier and said generator whereby the output of said generator is varied in frequency in accordance with said modulating potentials, means for feeding a portion of wave energy derived from said generator to a transmitting output circuit, a crystal controlled high frequency oscillator, means to combine wave energy derived from said oscillator and waves derived from said generator to produce waves of varying frequency differing in frequency from the waves generated by said generator, means for feeding said differing frequency waves to a frequency discriminating network, means for rectifying wave energy modified by said discriminating network, and means feeding said rectified wave energy to said reactance tube circuit for controlling the mean frequency of operation of said generator.

37. In a wave length modulation system, an oscillation generator having a wave length determining resonant circuit, a reactance tube coupled to said resonant circuit and controlled by signal potentials to vary the effective value of one of the reactive components of said resonant circuit in accordance with signal potentials to produce wave length modulation of the generated oscillations, and circuit connections for stabilizing the mean wave length of the oscillations generated including a tuned detector coupled to the resonant circuit and connected to the reactance tube to control the said reactance tube to produce wave length modulation of said generator in such a direction as to counteract departures from the mean wave length generated, said circuit connections including said tuned detector connected to said reactance tube also controlling the effective value of one of the reactive components of said resonant circuit in a degenerative sense to improve the linearity of said wave length modulation.

38. In a wave length modulation system, an oscillation generator having a frequency-determining resonant circuit, a reactance tube coupled with said resonant circuit and controlled by signals to vary the effective value of one of the reactive components of said circuit in accordance with signals to produce wave length modulation of the generated oscillations, means and circuit connections for stabilizing the mean frequency of the generated oscillations including a tuned detector coupled to the resonant circuit and connected to said reactance tube to control the same to produce wave length modulation in such a direction as to counteract departures from the mean frequency, said circuit connections also serving for producing potentials which are modified replicas of the signals and for controlling said reactance tube by said last produced potentials in a sense opposite to the control thereof by said signals.

39. In a wave length modulation system, an oscillation generator including a resonant circuit which determines the wave length of the oscillations generated, a space discharge tube having an impedance between two of its electrodes, means including said tube impedance for varying the tuned impedance of said resonant circuit to vary the wave length of the oscillations generated in accordance with variations in the said impedance of said tube, means for controlling the said impedance of said discharge tube in accordance with signals, and means for independently controlling the said impedance of said tube in response to slow departure of the wave length generated from normal and for degeneratively controlling the said impedance of said tube as a function of the modulation envelope.

40. In a wave length modulation system, an oscillation generator having a resonant circuit for determining the wave length of the oscillations generated, other circuits including a control tube for varying the resonant frequency of said resonant circuit at signal frequency to produce wave length modulation of the oscillation generated, and additional circuits including said control tube for counteracting slow departures from normal of the wave length of the generated oscillations for degeneratively controlling said wave length modulation of the oscillations generated as a function of the modulated wave envelope.

41. In a wave length modulation system, an oscillation generator having a wave length determining resonant circuit, a reactance tube excited by voltages derived from said resonant circuit and signal voltages to vary the effective value of one of the reactive components of said circuit in accordance with signal voltages to produce wave length modulation of the generated oscillations.

42. In a wave length modulation system, an oscillation generator having a wave length determining resonant circuit, a reactance tube excited by voltages derived from said resonant circuit and signal voltages to vary the effective value of one of the reactive components of said circuit in accordance with signal voltages to produce wave length modulation of the generated oscillations.

tions, and apparatus for stabilizing the wave length of the oscillations generated including a tuned detector coupled to the resonant circuit and connected to react on the said reactance tube to produce wave length modulation in such a direction as to counteract slow departures from the mean wave length and to apply potentials to said reactance tube which oppose said signal voltages to produce degeneration in said reactance tube to improve the linearity of said wave length modulation.

42. A wave length modulation system comprising in combination, means for generating wave energy to be modulated including an electron discharge device including electrodes connected in wave generating circuits, apparatus for modulating the length of the wave generated by said wave generating circuits including a reactance tube having an anode, a control electrode, an auxiliary grid, and a cathode, connections coupling said anode and cathode with said generating circuits to control the frequency of the waves generated, voltage phase displacing elements coupling the control electrode of said reactance tube to said generating circuits, a circuit coupled with said auxiliary grid for controlling the gain of said reactance tube at signal frequency to thereby modulate the length of the generated waves, and a circuit coupled with said auxiliary grid for impressing thereon potentials which are substantially an inverse copy of the modulation envelope of said modulated wave.

43. A wave length modulation system comprising in combination, apparatus for generating wave energy to be modulated including an electron discharge device having a plurality of electrodes connected in oscillation generating circuits, apparatus for modulating the length of the wave generated by said oscillation generator including a reactance tube having an anode, a control electrode, an auxiliary grid, and a cathode, connections coupling said anode and cathode with said generating circuits to control the frequency of the oscillations generated, phase displacing elements coupling the control electrode of said reactance tube to said generating circuits, a circuit connected with said auxiliary grid for controlling the gain of said reactance tube at signal frequency to thereby modulate the length of the generated waves, and a circuit for impressing potentials on an electrode of said tube which are substantially an inverse copy of the modulation envelope of the said modulated wave.

44. In a wave length modulation system, an oscillation generator including a resonant circuit for determining the frequency of the oscillations generated, an electron discharge device having an output impedance connected in shunt to a portion of said resonant circuit, said electron discharge device having a control grid and an additional grid, means including said control grid for varying the tuned impedance of said circuit to vary the frequency of the oscillations generated in accordance with variations in the output impedance of said device, means including said additional grid electrode of said tube for controlling said output impedance of said device in accordance with signals to thereby modulate the wave length of the oscillations generated, and circuits connected with an electrode of said device for controlling the output impedance of said device in response to slow departures of the frequency

of the oscillations generated from the normal frequency and for varying the output impedance of said device as an inverse function of the modulation envelope of said wave length modulated oscillations.

45. In a frequency modulation system, an oscillation generator of controllable frequency, a reactance tube connected therewith to control the frequency of the oscillations generated thereby, an oscillation generator of substantially fixed frequency, a first circuit for controlling the reactance of said reactance tube at signal frequency to modulate the frequency of the oscillations generated by said first generator at signal frequency, a second circuit for producing potentials characteristic of slow variations and variations at signal frequency of the frequency of said first generator relative to the frequency of said second generator, a third circuit which includes part of said first circuit for controlling the reactance of said reactance tube by said produced potentials for controlling the frequency of said first generator to oppose said slow variations and for controlling the reactance of said reactance tube as an inverse function of the signal modulation on the oscillations generated by said first generator to improve the linearity of said modulation.

46. In a wave length modulation system, means for generating wave energy to be modulated including an electron discharge device having electrodes connected in an oscillation generating circuit, apparatus for modulating the length of the wave generated by said oscillation generator including a reactance tube having an anode, a cathode, a control electrode, and an additional grid-like electrode, connections coupling said anode and cathode with said generating circuit to control the frequency of the oscillations generated, phase displacing elements coupling the control electrode of said reactance tube to said generating circuits, a circuit coupled with said additional grid-like electrode for controlling the gain of said reactance tube at signal frequency to thereby modulate the length of the generated waves, and a circuit coupled with said additional grid-like electrode for impressing potentials thereon which are substantially an inverse copy of the modulation envelope of said modulated wave.

47. In a wave length modulation system, an oscillation generator including a resonant circuit for determining the frequency of the oscillations generated, an electron discharge device having an output impedance coupled in shunt to a portion of said resonant circuit, said electron discharge device having a control grid and an additional grid, means including said control grid for varying the tuned impedance of said circuit to vary the frequency of the oscillations generated in accordance with variations in the output impedance of said device, a modulation circuit coupled to said additional grid electrode of said device for controlling said output impedance of said device in accordance with signals to thereby modulate the wave length of the oscillation generator, and a control circuit coupled with said additional grid for varying the output impedance of said device as an inverse function of the modulation envelope of said wave length modulated oscillations.

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