March 30, 1943. M. G. CROSBY 2,315,050

FREQUENCY MODULATION SYSTEM

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Fig. 3.

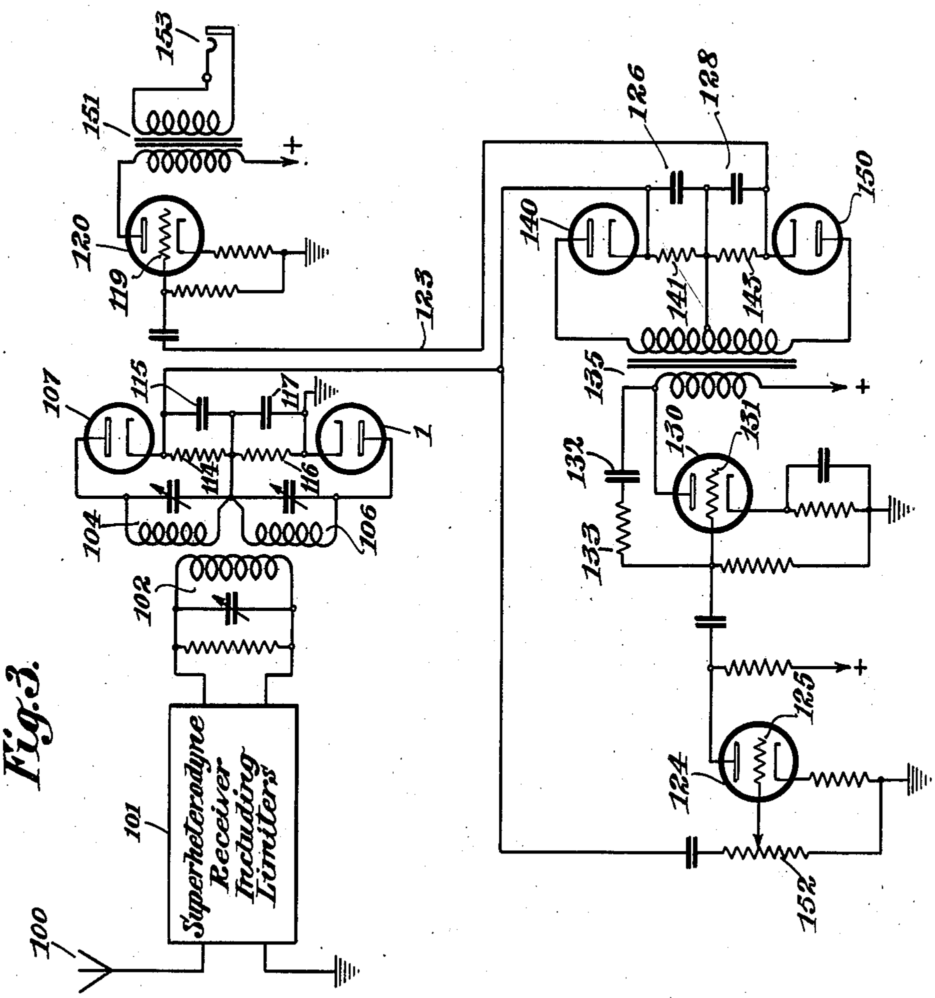
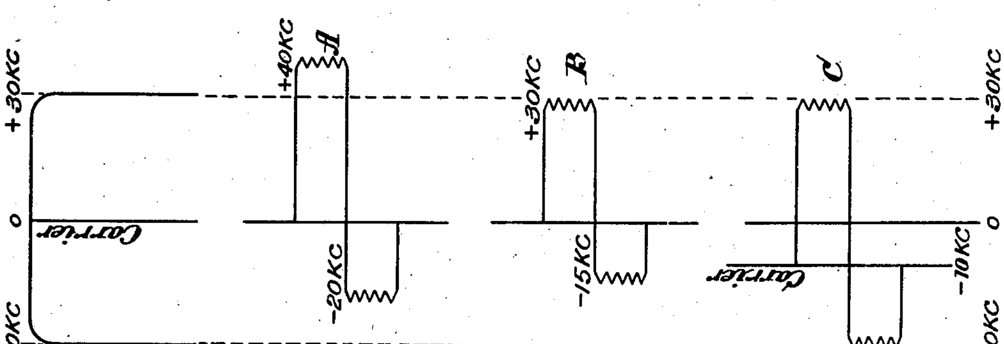


Fig. 1.



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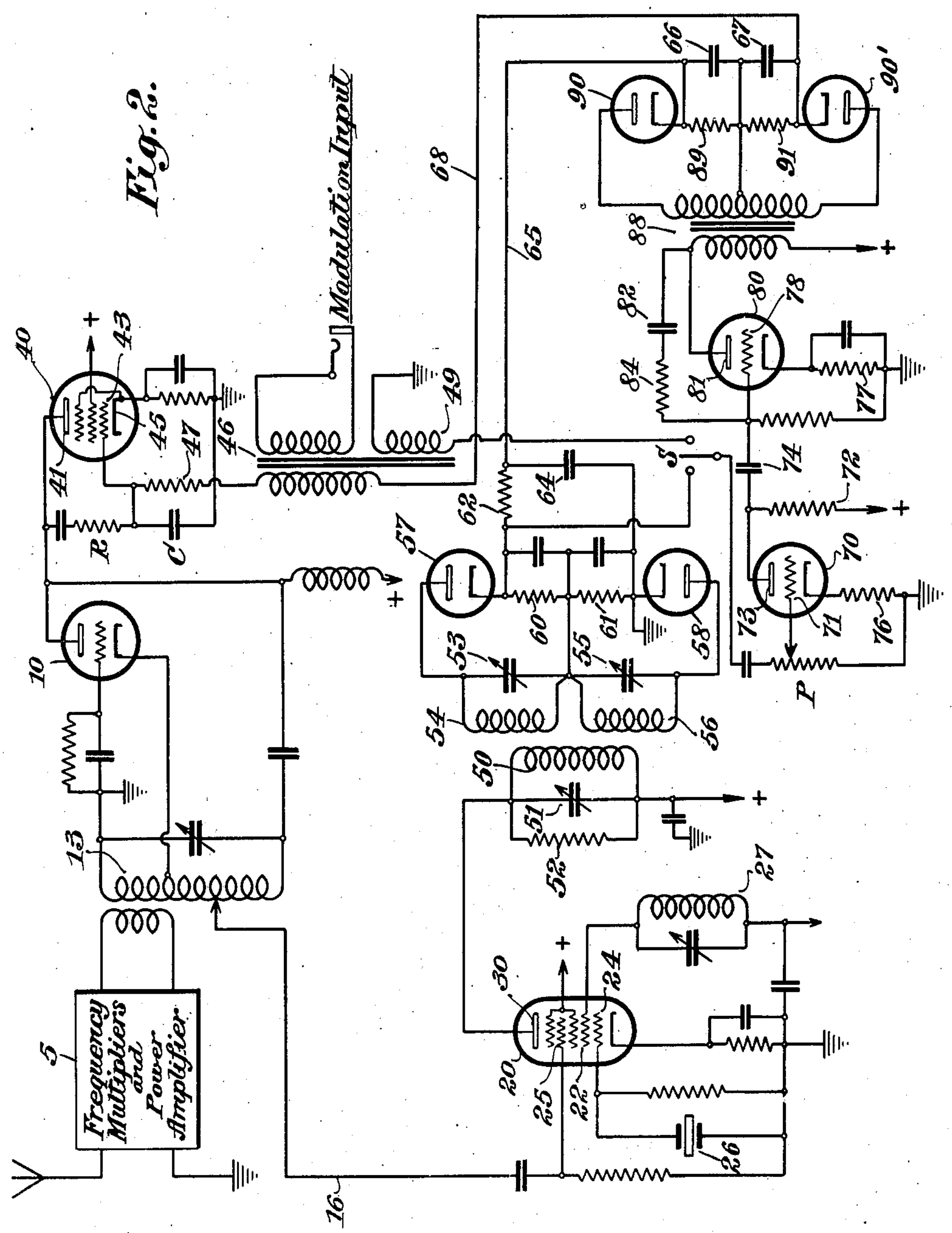

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FREQUENCY MODULATION SYSTEM

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9 Claims. (Cl. 250—6)

This application concerns a method of frequency modulation in which the carrier is given a frequency shift in accordance with the dissymmetry of an unsymmetrical modulating wave. This allows the modulation to properly fill the channel and not exceed the limit on one side of the channel.

The energy content of opposite half cycles of an unsymmetrical speech wave is equal. The wave may be unsymmetrical with respect to peak voltage but symmetrical with respect to energy or average voltage. In order to obtain the greatest amount of frequency modulation possible in an allowable channel, I provide a new and improved method of and means for shifting the carrier or mean frequency of the wave, being modulated in frequency by an unsymmetrical wave, in accordance with the dissymmetry of the peak voltage of the unsymmetrical modulating wave.

The present method and means is not to be confused with automatic frequency control systems such as disclosed in my United States application #136,578 filed April 13, 1937, now U. S. Patent No. 2,279,659, dated April 14, 1942, which prevent slow frequency variations or drifts. In the present application, I have provided means to be used with said prior systems to shift the carrier in accordance with the dissymetry of the peak voltage of the modulating wave. The present application discloses such a system and in this disclosure the term "carrier shift" has been used to designate the action.

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

Fig. 1 comprises graphs A, B and C illustrating the operation of my system; while

Figs. 2 and 3 illustrate two embodiments of my system.

In Hathaway United States Patents #2,158,820 and #2,158,821 a modulating wave of an amplitude modulation system is so poled that said wave, which may for example be, a voice wave which has a dissymmetry with respect to the zero axis of the wave, always modulates the half cycles with the higher peak amplitudes in the upward direction. This allows a gain in percentage of modulation of up to about six decibels since most transmitters are capable of modulation in the upward direction of greater than 100% but are limited to 100% modulation in the downward direction. In these systems disclosed by Hathaway, it is noted that the frequency of the modulated wave is unaffected. The modulation voltages are controlled as to polarity in accordance with their amplitude to use up the allowable modulation to approach 100% modulation.

In my new and improved system the mean frequency of the carrier is shifted in accordance with the dissymmetry of the peak voltages about a mean or zero value. One might say that the present system and automatic frequency control systems are analogous in some respects. However, in accordance with my invention in a frequency modulation system, the carrier is shifted to one side at the transmitter so that the negative and positive peaks of the modulating wave hit the upper and lower frequency deviation limits at the same time.

For instance, suppose we had a voice current with a positive half cycle of 4 peak volts and a negative half cycle of 2 peak volts. Also, let us assume that 3 peak volts deviates the frequency of the frequency modulator the maximum amount which, for purposes of illustration, we will call 30 kilocycles. When this unsymmetrical wave is applied to the modulator, it will deviate the frequency 4/3 times 30 kilcocycles or 40 kilocycles, in one direction, and 2/3 times 30 kilocycles, or 20 kilocycles in the other direction as shown in attached Fig. 1, graph A. Thus, there will be over-modulation in one direction and under-modulation in the other, and to correct this situation, the modulation level should be reduced so that the modulation swings 30 kilcocycles in one direction and 15 kilocycles in the other, as shown in Fig. 1 at B. This reduction corresponds to a loss in modulation level which would impair the received signal-noise ratio.

To eliminate this loss of modulation level, I provide means which shifts the carrier 10 kilocycles to one side when this example of unsymmetrical modulation is applied. This allows the application of the full amplitude of the modulation wave without over-modulation, as shown in Fig. 1 at C. The carrier then takes its position at the −10 kilocycle point in the frequency spectrum so that the positive deviation swings from −10 to +30 kilocycles (or 40 kilocycles) and the negative deviation swings from −10 to −30 (or 20 kilocycles).

A feature of the means for shifting the carrier frequency to one side of the main frequency of the frequency spectrum in which I am operating is a modulation potential relay or amplifier circuit including means for producing a direct-current voltage component characteristic of the non-symmetrical peaks and adding this component to the said modulation potential. This process is in a sense direct-current insertion.

This means for regulating the position of the carrier or mean frequency in the frequency spectrum, wherein I am operating, in accordance with non-symmetry of the modulation potentials about its zero value may be used in various parts of the modulation system. In a preferred embodiment, the carrier or mean frequency controlling means is used at the transmitter. When so used the said relay or amplifier supplies the biased modulation to the modulator of the transmitter to shift the carrier frequency. When the device is used at the receiver it is caused to shift the receiver tuning. Placing my correction device in the receiver may cause the transmitter to exceed its channel limits in order to take advantage of the gain in modulation which may be undesirable in some cases.

In my modulators one of which has been illustrated in Fig. 2 of the drawings, an oscillator 10 has a tuned circuit 13 coupled to frequency multipliers, amplifiers, etc., 5 and by lead 16 to the grid 24 of a mixer tube 20 which also serves as a source of wave energy of substantially fixed frequency. The source of wave energy of substantially fixed frequency may comprise an oscillator tube 20 having its grids 22 and 24 connected with crystal 26 in an oscillation generation circuit. The circuit 27 is tuned to the frequency of the oscillations generated and the generator electrodes are coupled to the anode 30 by the electron stream of the tube.

The frequency of the oscillator 10 is modulated as disclosed in my prior application by a reactance tube 40 having its anode 41 and grid 43 excited by phase quadrature voltages from 10, its anode 41 and cathode 45 in circuit with the reactance of circuit 13 and its gain controlled by modulation potentials from transformer 46 connected by resistance 47 to the grid 43. Frequency modulation of the oscillator 10 is accomplished in a well known manner as described more in detail in my application #136,578 filed April 13, 1937, now U. S. Patent No. 2,279,659, dated April 14, 1942 and application #312,446 filed January 5, 1940, now U. S. Patent No. 2,279,660, dated April 14, 1942.

The modulated carrier is supplied to the grid 25 of tube 20 and is heterodyned to a lower frequency in the tube 20 which serves as an oscillator and mixer tube. The mean frequency variation or drift, and frequency modulation are converted to amplitude variations and detected by means of a discriminator circuit comprising winding 50, condenser 51, resistance 52, and windings 54 and 56 and detector tubes 57 and 58. The detected output potentials are set up across resistances 60 and 61 and comprise variations at signal frequency, and slow variations characteristic of drift in frequency of the intermediate frequency due to any cause whatever. These variations are impressed on time constant elements 62 and 64 and the variations passed thereby are supplied through lead 65, by-pass condensers 66 and 67 and lead 68, the secondary winding of transformer 46 and resistance 47 to the grid 43 of reactance tube 40.

In operation, oscillations are produced in tube 10. These oscillations are modulated in frequency by means of reactance tube 40. R and C form the phase shifter for the reactance tube to provide the phase quadrature relation between the alternating-current voltages on the anode 41 and grid 43. The mean frequency of operation of the oscillator, that is the carrier, is stabilized by means of the AFC system comprising oscillator and converter tube 20 with the discriminator including elements 50 to 56 and diode rectifiers 57 and 58. Part of the oscillator energy is fed to the signal grid 25 of pentagrid converter tube 20. The converter tube has crystal 26 and tuned circuit 27 in its oscillator circuit so that the frequency modulated energy is heterodyned to a lower frequency by means of the stable crystal oscillations. The intermediate-frequency appearing in the plate circuit of the converter is fed to the primary winding 50 of the discriminator. The primary circuit, including winding 50, is tuned by condenser 51 to the mid-frequency and the two secondaries including windings 54 and 56 are off-tuned by means of condensers 55 and 52 on either side of the carrier frequency. The discriminator linearly converts the frequency variations of the wave, whether they be due to modulation or drift, into amplitude variations. These amplitude variations are detected by diodes 57 and 58 and appear across the differentially-connected diode resistors 60 and 61.

The detected output is fed through time-constant circuit 62, 64 where the fast variations are removed and only the slow variations corresponding to carrier drift are passed on. These control potentials are fed to the grid 43 of the reactance tube 40 by way of leads 65 and 68 so that a drift of the carrier is corrected by the application of the properly-poled AFC potential. Modulating potentials are applied by means of transformer 46 the secondary winding of which is in series wth lead 32. Thus far the operation of the circuit follows the principles described in my United States application #136,578 filed April 13, 1937.

The circuit consisting of voltage amplifier tube 70, power amplifier tube 80, and peak voltage detectors 90 and 90′ constitutes the means for shifting the carrier frequency to one side when the modulation wave becomes unsymmetrical with respect to peak deviations thereof on opposite sides of the mean or carrier frequency. The voltage amplifier tube 70 may have its grid 71 fed directly from the modulation input transformer 46 by means of the extra winding 49 on transformer 46, or may be fed from the detected output of the AFC discriminator circuits, depending on the position of switch S.

Resistance-coupled amplifier 70 has its anode 73 coupled by resistance 72 and condenser 74 to the grid 78 of power tube 80. The tubes 70 and 80 derive bias by virtue of resistances 76 and 77 in their cathode return circuits. The anode 81 of tube 80 is coupled by condenser 82 and resistance 84 to the grid 78 and thus inverse feedback is applied by means of resistor 84 and blocking condenser 82 so as to produce a low-impedance drive with good regulation for driving the diode rectifiers 90 and 90′ which detect the peak voltage of the modulating wave. These rectifiers are fed by push-pull transformer 88 with opposite phase relation so that they detect opposite half cycles of the wave. Resistors 89 and 91 are adjusted in conjunction with condensers 66 and 67 so that the modulation frequencies are detected and the detected output consists of the peak voltage of the wave. Since the two diode resistors are connected differentially, the resultant detected output fed to leads 65 and 68 will consist of the difference between the peak voltages detected by the two diodes. Such a differential voltage will be directly proportional to the dissymmetry of the peak voltage of the modulating wave and, when applied to the reactance tube in the proper amount which is adjustable by means of potentiometer P, connected with the grid 71 of tube 70, will produce the required carrier shift to make the peaks of the frequency excursions symmetrical with respect to the middle of the assigned channel.

In order that the AFC mechanism will not automatically correct for the carrier shift produced in my system due to application to the reactance tube of the potentials from rectifiers 90 and 90′, the time constant of circuit 62, 64 is adjusted so that the relatively fast changes due to the carrier-shift circuits, which are detected in the discriminator circuits 50 to 64, are not passed.

Fig. 3 shows a receiving system to be employed to receive the carrier-shifted wave sent out by my transmitter. A superheterodyne receiver 101, including an aerial 100 amplifier heterodyning means and limiters, feeds a discriminator circuit of the same type used in Fig. 2. Since the discriminator here is similar to the one shown in Fig. 2, it will be described somewhat briefly. The discriminator comprises a tuned and damped circuit including a primary winding 102 coupled to the inductances of a two-tuned circuits 104 and 106. Two of the terminals of the tuned circuits 104 and 106 are connected to the anodes of diode rectifiers 107 and 109 and the other terminals are connected to the cathodes. The cathodes of tubes 107 and 109 are connected by resistances 114 and 116 shunted by condensers 115 and 117. One terminal of the series resistance is grounded and the modulation potentials are set up across these resistances. The output from the discriminator rectifiers is fed through condensers 126 and 128 and lead 123 to the grid 119 of audio amplifier tube 120. These connections feeding the grid 119 of amplifier 120 also supply a direct current which is inserted in the bias to the amplifier 120 to replace the dissymmetry removed from the modulating potentials at the transmitter. The detected output is amplified by tube 120 which is coupled to output jack 153 by means of transformer 151.

This direct current to be inserted is derived from the circuit composed of voltage amplifier 124, power amplifier 130 and diode rectifiers 140 and 150. This amplifier is in many respects similar to the amplifier of Fig. 2 comprising tubes 70, 80, 90 and 90′ and will be described briefly here. The variations representative of the signal modulations on the transmitted wave (the mean carrier of which has been shifted or controlled in accordance with peak swings) appear across the resistances 114 and 116, and are supplied to the grid 125 of tube 124 and also to one terminal of resistors 141 and 143. Those modulations are bypassed by condensers 126 and 128 and, as stated above, also reach the grid 119. The modulation potential supplied to grid 125 is amplified in tube 124 and supplied to the grid 131 of tube 130. Tube 130 has a feedback circuit comprising condenser 132 and resistance 133 the purpose of which is to provide a low impedance drive for rectifiers 140 and 150. The output of tube 130 is supplied by transformer 135 to the diodes 140 and 150. The non-symmetrical peaks are rectified in 140 and 150 to produce in resistors 141 and 143 opposing direct-current potentials the difference of which is added to the modulation potentials passed from the rectifiers 107 and 109 through condensers 126 and 128 to the grid 119. Such a restoration of the dissymmetry is necessary so that the received wave form will be an exact reproduction of the signal to be transmitted. The operation of this direct-current insertion device is in all respects the same as the operation of the corresponding circuit of Fig. 1 which imparted the carrier shift to the transmitter.

It will be apparent that the direct-current insertion at the transmitter and that at the receiver must be coordinated so that they are equal and opposite. Thus, at the transmitter potentiometer P (Fig. 2) is adjusted so as to cause the wave to properly fill the channel as shown by diagram C of Fig. 1. At the receiver, potentiometer 152 (Fig. 3) is adjusted until the direct-current insertion applied at the transmitter is removed and the resulting output wave is an exact reproduction of the applied modulating wave.

What is claimed is:

1. In a wave length modulation system in combination, means for generating wave energy to be modulated comprising, an electron discharge device including electrodes connected in oscillation generating circuits, a reactance tube coupled to said generating circuits to control the frequency of the wave energy generated, a source of signal voltages having unlike alterations with respect to a base voltage, connections between said last-named source and said reactance tube for controlling the gain of said reactance tube by said signal voltages to thereby modulate the length of the waves generated, a frequency stabilizing circuit including said reactance tube for opposing slow variations in the mean frequency of said generated waves, and a wave peak rectifier having an input coupled to said last-named source and an output coupled to said reactance tube for controlling the gain of said reactance tube in accordance with non-symmetrical alterations of the said signal voltage with respect to said base voltage to thereby confine said wave length variations of said generated waves within an assigned spectrum without reducing the degree of modulation.

2. In a wave length modulation system, an oscillation generator, a rectance tube coupled therewith for controlling the frequency thereof, a source of modulating potentials which may vary non-symmetrically about a base value, connections coupling said source with said reactance tube for controlling the gain thereof to thereby modulate the length of the waves generated, a wave peak rectifier for deriving potentials characteristic of peak swings of the frequency of said wave energy beyond a predetermined selected frequency due to said non-symmetry of the modulating potentials, a rectifier for deriving potentials characteristic of slow variations in the mean frequency of said generated wave, and connections between said reactance tube and said rectifiers for controlling the gain of said reactance tube in accordance with said derived potentials.

3. A system as recited in claim 2 wherein said derived potentials are combined in an impedance and wherein said impedance is connected to said reactance tube to control the gain thereof and wherein resistance and condenser elements provide time constant circuits for said derived potentials.

4. In a wave length modulation system in combination, means for generating wave energy to be modulated, means for modulating the length of the wave generated by said oscillation generator comprising, a reactance tube having an electrode serving as an anode, a control electrode and a cathode, means coupling said electrode serving as an anode and said cathode with said generating means to thereby control the frequency of the oscillations generated, phase displacing means

coupling said electrode serving as an anode and the control electrode of said reactance tube to said generating means to impress voltages in phase quadrature from said generating means on said electrode serving as an anode and said control electrode, and means for controlling the gain of said reactance tube in accordance with signals, a frequency discriminating rectifier system having input electrodes excited by the wave length modulated wave energy and having output electrodes coupled to an electrode in said reactance tube, means in said coupling for applying only potential variations of frequencies lower than the modulation frequency to said electrode in said reactance tube, a peak rectifier system having an input and having an output coupled to an electrode in said reactance tube to control the gain thereof, and means for impressing voltages characteristic of said signals on the input of said peak rectifier.

5. A system as recited in claim 4 wherein said last named means is excited by potentials from the output of said first rectifier system.

6. A system as recited in claim 4 wherein said means for controlling the gain of said reactance tube in accordance with signals includes a source of signal voltage and wherein said last named means is coupled to said source of signal voltage.

7. In a wave length modulated wave receiver, means for demodulating said wave length modulated wave to derive the modulation components therefrom, a modulation component amplifier, means for impressing the derived modulations thereon, means for rectifying the derived modulation components to obtain a potential characteristic of non-symmetrical peak deviations thereof, and means for controlling the gain of said amplifier in accordance with said derived potential.

8. The method of signaling with carrier wave energy the wave length of which is modulated in accordance with modulation potentials the peak deviations of which are non-symmetrical relative to their base amplitude which includes these steps, modulating the wave length of said wave energy in accordance with said modulation potentials, shifting the carrier frequency of the modulated wave energy in accordance with the non-symmetry of said peak deviations, demodulating said wave energy so modulated to derive current components characteristic of the modulation potentials and current components characteristic of the said shifts in the carrier frequency of the wave energy, amplifying said components characteristic of the modulation potentials, and controlling said amplification in accordance with said current components characteristic of the shifts in the carrier frequency of the said wave energy.

9. In a wave length modulation system, a source of signals which vary non-symmetrically relative to their mean value, a source of carrier wave energy, means coupling said sources for modulating the wave length of said wave energy in accordance with said signals, means coupled with said source of wave energy for shifting the carrier frequency thereof in accordance with the non-symmetry of the variations of the signals relative to their mean value, means for transmitting said wave energy so modulated and shifted, means for receiving and demodulating said wave energy to derive therefrom current components characteristic of the signals and of the shifts in carrier frequency of the modulated wave energy, an amplifier for said current components characteristic of the signals, and means for controlling the gain of said amplifier in accordance with the current components characteristic of said shifts in the carrier frequency of said wave energy.

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