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FREQUENCY MODULATION SYSTEM

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My invention relates to apparatus for modulating the frequency of a carrier wave, and more particularly to such apparatus of the type commonly termed phase modulation apparatus.

Certain types of frequency modulation apparatus introduce serious non-linearities in the relation between the intensity of the modulating wave and the resulting shift in frequency, or phase, of the carrier wave. That type of frequency modulation apparatus is subject to a peculiar type of distortion in which a carrier wave is transmitted through two channels and recombined, a different phase shift being introduced in each channel and the carrier wave in each channel being differently operated on by the modulating wave so that the recombined carrier wave is modulated in phase. Generally, in this type of phase modulating apparatus, the phase or frequency of the carrier wave is changed a larger amount per unit intensity of the modulating wave at low modulating wave intensities than at high modulating intensities. It is an object of my invention to provide a new and improved method and apparatus for modulating the frequency, or phase, of a carrier wave in accordance with the intensity of a modulating signal.

It is a further object of my invention to provide such new and improved method and apparatus in which the phase shift, or frequency change, of the carrier wave produced in accordance with the intensity of a modulating signal is more nearly linearly related to such intensity.

The features of my invention which I believe to be novel are set forth with particularity in the appended claims. My invention itself, both as to its organization and manner of operation, together with further objects and advantages thereof may best be understood by reference to the following description taken in connection with the accompanying drawing in which Fig. 1 illustrates apparatus embodying one form of my invention; Fig. 2 is a vector diagram illustrating certain electrical characteristics of a part of the apparatus of Fig. 1 and Fig. 3 is another vector diagram illustrating certain electrical characteristics of another part of the apparatus of Fig. 1.

In the form of my invention illustrated in Fig. 1 high frequency oscillations from a source 10 are transmitted through three electron discharge amplifier devices 11, 12 and 13, by means of which the phase of the carrier wave is modulated in accordance with audio signals from a microphone 14, and through appropriate frequency multipliers and power amplifiers, illustrated as a rectangle 15, to be radiated from an antenna

16. The source 10 may be any suitable generator of high frequency oscillations, such as a tuned circuit oscillator including an electron discharge device. The frequency multipliers indicated by the rectangle 15 are such as are usually utilized to increase the amount of phase, or frequency, shift of the carrier wave produced in response to the modulating signals of the microphone 14 and to increase at the same time the frequency of the carrier wave. The power amplifiers indicated by the rectangle 15 are such as are normally used to increase the intensity of the carrier wave before its impression on the antenna 16 so as to increase the amount of energy radiated therefrom.

High frequency oscillations from the source 10, impressed by suitable means on a tuned circuit including an inductance 17 and condenser 18, are also impressed across a phase shifting network connected in shunt to this tuned circuit, which network produces high frequency voltages in phase quadrature with each other. This network includes a resistance 19 and a condenser 20, the reactance of which at the frequency of the high frequency oscillations from the source 10 is equal to the resistance 19.

By reference to the vector diagram of Fig. 2 the voltage relations in this tuned circuit 17, 18 and across the resistance 19 and condenser 20 may be clearly seen. An electrically central point of the tuned circuit 17, 18 is grounded, as by the condenser 21, for high frequency oscillations, and all reference voltages are therefore referred to such ground. Vector E_1 represents the voltage of the upper terminal of the tuned circuit 17, 18, and vector E_2 the voltage of the lower terminal thereof. The voltage between these two terminals of the tuned circuit 17, 18 produces a flow of high frequency current through the resistance 19 and condenser 20, such current being represented by the vector I . Since the electrical path including the resistance 19 and condenser 20 is capacitive in nature, the current I is leading in phase with respect to the voltage across the tuned circuit 17, 18, and is so represented in the vector diagram of Fig. 2, the rotation of all vectors being considered to be counterclockwise. The current I leads the voltage E_1 by an angle of 45° , since the reactance of the condenser 20 at the frequency of the oscillations from the source 10 is equal to the resistance of resistor 19.

The high frequency voltage across the resistance 19 is in phase with the current I , and the high frequency voltage across the condenser 20 lags the current I by 90° , or by a quarter cycle. These voltages are respectively represented by

vectors E_r and E_c . The two vectors E_r and E_c are equal in length, since the reactance of the condenser 20 is equal to the resistance 19, and since the same current I flows through both elements.

The point 22 between the resistance 19 and condenser 20 is at a high frequency potential with respect to ground as represented by the vector E_3 , this high frequency potential differing in phase from the potentials of the terminals of the tuned circuits 17 and 18 by 90°, or a quarter cycle, due to the phase shifting action of the resistance 19 and condenser 20. By proper combination of the high frequency voltage represented by the vector E_3 with the high frequency voltages represented by the vectors E_1 and E_2 in accordance with modulating potentials from the microphone 14, a phase modulated carrier wave is produced in which the change in phase is substantially linear over a wide range with respect to the intensity of modulating signals.

To produce this effect, voltage between the upper terminal of resistance 19 and ground, represented by vector E_1 , is supplied to the electron discharge amplifier device 11; voltage between point 22 and ground, represented by vector E_3 , is supplied to discharge device 12; and voltage between the lower terminal of condenser 20 and ground, represented by vector E_2 , is supplied to discharge device 13 as follows: The first control electrode 30 of the device 11 is electrically coupled through a condenser 31 to the upper terminal of the resistance 19. The first control electrode 32 of the device 12 is electrically coupled through a condenser 33 to point 22 between the resistance 19 and condenser 20. The first control electrode 34 of the device 13 is electrically coupled through a condenser 35 to the lower terminal of condenser 20.

The devices 11, 12 and 13 are suitably arranged to amplify the respective three voltages applied to their first control electrodes, and to transmit such voltages to the frequency multipliers and power amplifiers 15. The respective anodes 36, 37 and 38 of the devices 11, 12 and 13 are connected together and to the upper terminal of a tuned circuit 39, resonant at the frequency of oscillations from the source 10. The tuned circuit 39 is coupled to an inductance 40 which is connected to the input of the frequency multipliers and power amplifiers 15. The lower terminal of the tuned circuit 39 is connected to the positive terminal of a source 41 of operating potential for the discharge devices 11, 12 and 13, the negative terminal of the source 41 being connected to ground.

The cathodes 42, 43 and 44 of the devices 11, 12 and 13 are respectively connected to ground through means for maintaining each cathode at a fixed potential, positive with respect to ground, such means respectively including resistances 45, 46 and 47 and bypassing condensers 48, 49 and 50. The control electrodes 30, 32 and 34 are respectively connected to ground through resistances 60, 61 and 62 by which the electrodes are maintained near ground potential, and consequently at a suitable negative potential with respect to the respective cathodes 42, 43 and 44.

The second, or screen, electrodes 63, 64 and 65 of the devices 11, 12 and 13 are connected through respective resistances 66, 67 and 68 to the positive terminal of the source 41, and are connected through respective condensers 69, 70 and 71 to the cathodes 42, 43, and 44, whereby the screen electrodes 63, 64 and 65 are maintained

at a constant positive potential with respect to the respective cathodes 42, 43 and 44.

Since these screen electrodes 63, 64 and 65 are maintained at a constant potential with respect to the cathodes of the devices 11, 12 and 13, they serve as electrostatic shields between the first control electrodes 30, 32 and 34 and the third, or suppressor, electrodes 76, 77 and 78 of the devices 11, 12 and 13. Consequently, interaction between the first control electrodes and the suppressor electrodes is minimized, and it is of advantage to apply the modulating potentials, in accordance with which phase shift of the carrier wave is produced, to these suppressor electrodes 76, 77 and 78.

The suppressor electrodes 76, 77 and 78 are respectively connected to ground through condensers 73, 74 and 75 which have low reactance at the frequency of oscillations from the source 10, but which have relatively high reactance at the highest frequency of modulating signals from the microphone 14. These condensers 73, 74 and 75 therefore maintain the suppressor electrodes 76, 77 and 78 at cathode and ground potential as far as high frequency oscillations from the source 10 are concerned, and are therefore made effective in suppressing bombardment of the screen electrodes 63, 64 and 65 by secondary emission from the anodes 36, 37 and 38.

The modulating signal potentials are applied to the suppressor electrodes 76, 77 and 78 as follows. Such modulating signals from the microphone 14 are amplified to suitable intensity in an audio amplifier 80, and impressed on the primary 81 of a transformer whose secondary 82 has its center tap connected to ground. One terminal of the secondary 82 is connected to the suppressor electrode 76 of the device 11 and the other terminal of the secondary 82 is connected to the suppressor electrode 78 of the device 13. The suppressor electrode 77 of the device 12 is connected through a resistance 83 to ground. It should be noted that modulating potentials from the secondary 82 are applied in push-pull, or balanced, relation to the suppressor electrodes of those devices 11 and 13 whose control electrodes are connected to opposite terminals of the phase shifting network 19, 20.

If it be assumed for the moment that no potential is impressed across the resistance 83, analysis of the operation of the carrier wave phase shifting arrangement may be easily understood. With no signal input from the microphone 14, the discharge devices 11 and 13 are so adjusted that they amplify equal amounts of the carrier wave from the source 10. Since these devices 11 and 13 amplify potentials which are exactly opposite in phase, as represented by the vectors E_1 and E_2 of Fig. 2, with no signal from the microphone 14, the outputs of the devices 11 and 13 exactly balance and produce no effect on the tuned circuit 39. The discharge device 12 is adjusted to amplify the carrier wave from the source 10 so that it appears in the tuned circuit 39 with suitable intensity, its phase being as represented by the vector E_3 . So long as this condition persists, that is, with no modulating signal from the microphone 14, the outputs of the devices 11 and 13 cancel, and the transmitted carrier wave is amplified through the device 12 and through the frequency multipliers and power amplifiers 15. This carrier wave is constant in intensity.

Now if a modulating potential is transmitted from the microphone 14, its effect on the transmission of the carrier wave from the source 10

through the devices 11, 12 and 13 may be explained most easily for a static condition. Consider, for example, the condition at one particular instant at which the suppressor electrode 76 is positive in potential with respect to ground, the suppressor electrode 78 is negative by an equal amount with respect to ground, and the potential on the suppressor electrode 77 remains unchanged. When the suppressor electrode 76 becomes positive in potential, the gain through the device 11 increases, and the gain through the device 13 similarly decreases when the suppressor electrode 78 becomes negative with respect to ground. Consequently the carrier wave potential represented by the vector E_1 is amplified through the device 11 to a greater extent than when no modulating signal was transmitted from the microphone 14, and the carrier wave from the source 10 is similarly amplified through the device 13 to a smaller degree. The result is that the outputs of the devices 11 and 13 no longer cancel each other completely, the output of the device 11 being greater than that of the device 13.

Under such conditions the potential impressed across the tuned circuit 39 is a combination of the carrier wave potential amplified by the device 12, represented by the vector E_3 in Fig. 2, and a second carrier wave potential which is in phase with the carrier wave potential amplified by the device 11, represented by the vector E_1 in Fig. 2. This combination produces a carrier wave potential across the tuned circuit 39 which is leading in phase with respect to the carrier wave potential amplified by the device 12 and represented by the vector E_3 in Fig. 2.

It is thus clear that opposite changes in potential on the suppressor electrodes 70 and 72 produce a phase shift in the carrier wave on the tuned circuit 39 in a particular direction. If the potentials of the suppressor electrodes 76 and 78 change in the other direction from that described above, that is, if the suppressor electrode 76 becomes negative in potential and the electrode 78 becomes positive in potential with respect to ground, an opposite phase shift of the carrier wave on the tuned circuit 39 occurs.

This results because the gain of the device 13 is under such conditions greater than the gain of the device 11 so that the carrier wave potential represented by the vector E_2 in Fig. 2 is then greater than the carrier wave potential represented by vector E_1 . Since the resultant of these two vectors is in phase with the vector E_2 , the resultant of this difference between carrier wave potentials amplified by devices 11 and 13 and the carrier wave potential amplified by device 12 is lagging in phase with respect to the potential amplified by device 12 and represented by the vector E_3 .

This vector relationship may be clearly seen in Fig. 3, in which the vectors E_1 , E_2 and E_3 are represented as they are shown in Fig. 2. A vector designated E_2-E_1 is shown at right angles to the vector E_3 , and represents the difference between the vectors E_2 and E_1 when the alternating potential amplified by the device 13 is greater than that amplified by the device 11. It may be seen that the vector 90 which represents the resultant of the vectors E_3 and E_2-E_1 is lagging with respect to the vector E_3 and is slightly greater in amplitude.

Since the discharge devices 11 and 13 in effect produce linearly a resultant difference between the alternating potentials of opposite phase represented by vectors E_1 and E_2 in response to modulating potentials from the microphone 14, such

modulating potentials may be considered as substantially equivalent in intensity to vectors drawn on a line passing through the vector E_2-E_1 in Fig. 3. That is, the intensity of the modulating signal from the microphone 14 at any particular instant may be plotted on the dotted line 91 drawn to include the vector E_2-E_1 in Fig. 3, such vector beginning at the end of the vector E_3 where it intersects the line 91 and extending in an appropriate direction, depending on whether the modulating signal voltage is positive or negative at the particular instant.

Now it is desired that the modulating potential at any instant shall produce a resultant carrier wave potential at the tuned circuit 39, which is shifted in phase from the carrier wave potential represented by the vector E_3 by an angle directly proportional to the modulating signal potential. That is, if the vector E_2-E_1 be taken to represent a modulating signal potential and vector 90 to represent the resultant carrier potential at tuned circuit 39, it is desired that the angle between the vectors 90 and E_3 be directly proportional to the vector E_2-E_1 .

This, however, is geometrically impossible in the arrangement shown. The vector E_2-E_1 represents a certain modulating potential, which produces a phase shift in the carrier represented by the angle θ . If the carrier wave potential has already been shifted in phase so that it may be represented by the vector 92, and the modulating signal potential be increased from that potential necessary to produce the phase shift resulting in the vector 92, the increase being represented by the vector 93, and being equal in amount to vector E_2-E_1 , the carrier wave potential is shifted in phase by a less amount than the phase shift between the vector E_3 and the vector 90.

The resultant of the vectors 92 and 93 is represented as a vector 94, the angle between the vectors 92 and 94 being represented as θ_1 . It is apparent that the angle θ_1 is less than the angle θ , because the vector 93 is at a greater angle with respect to the vector 92 than the vector E_2-E_1 forms with the vector E_3 . It may accordingly be concluded that as modulating signal intensity increases, each new increment of increase in modulating signal intensity produces a smaller angular phase shift in the carrier wave in the arrangement as thus far described.

Inspection of the lower part of the vector diagram of Fig. 3 shows that this is equally true where the carrier wave phase shift is in the opposite direction. A vector 95, equal to the vectors E_2-E_1 and 93, is shown extending between the ends of vectors 96 and 97. It is at once apparent that, although the vector 95 is equal to the vector E_2-E_1 , the angle between vectors 96 and 97 is less than the angle between vectors 90 and E_3 .

This effect may be substantially eliminated if, at the same time that the potentials of the suppressor electrodes 70 and 72 are changed oppositely by modulating signal potential from the microphone 14, the high frequency potential amplified by the device 12 be reduced a suitable amount as the difference in the high frequency potentials amplified through the devices 11 and 13 increases.

The reason for this may be seen by considering Fig. 3, in which the vector 100 represents the resultant of the vectors E_1 , increased a certain amount; E_2 , decreased a like amount; and E_3 , also decreased a certain amount. It may be seen that the angle between the vectors 92 and 100 may be made the same as the angle between the

vectors E_3 and 90, both phase shifts of the carrier wave having been made by equal modulating signal potentials, proportional in one case to the vector 93 and in the other case to the vector E_2-E_1 . The vector 101 may conveniently represent the required reduction in amplitude of the vector E_3 to produce the vector 100.

Symmetry of the vector diagram indicates that, for an opposite phase shift of the carrier wave, a similar reduction of intensity of the vector E_3 may be utilized to produce a similar phase shift of the carrier wave in response to a modulating signal potential. Vector 102 may represent the carrier wave potential shifted in phase from the carrier wave potential represented by vector 96 in response to a modulating signal potential represented by vector 95, the vector E_3 being reduced in intensity by an amount represented by the vector 103.

It is thus apparent that the carrier wave amplified by the device 12 should be reduced in intensity in response to an increase of modulating signal potential of either polarity. Suitable apparatus is therefore provided for impressing a negative potential on the suppressor electrode 71 of the device 12 whenever modulating signal potential of either polarity is transmitted from the microphone 14.

This apparatus includes a voltage dividing resistor 110 connected in shunt to the primary 81 of the transformer across which modulating signal potentials from the amplifier 80 are impressed. The primary winding of the transformer 111 is connected between the sliding tap 112 of the voltage divider 110 and one terminal 113 thereof. The two anodes 114 and 115 of a double diode electron discharge device 116 are respectively connected to the opposite terminals of the secondary 117 of transformer 111. The center tap of the secondary 117 is connected to a point between the resistance 83 and the suppressor electrode 77 of the device 12. The cathodes 118 and 119 of the double diode discharge device 116 are connected together and through a large condenser 120 to ground, and are maintained at a positive potential with respect to ground by a source 121 of potential, whose negative terminal is connected to ground. A voltage dividing resistance 122 is connected in shunt to the source 121, and the movable tap 123 of the resistance 122 is connected to the cathodes 118 and 119.

The apparatus just described including the double diode discharge device 116 constitutes a full wave rectifier having a load resistance 83 arranged to impress a negative potential on the suppressor electrode 77 during either half cycle of modulating signal potential from the microphone 14. The intensity of this negative potential with respect to the intensity of modulating signal potential impressed on the suppressor electrodes 76 and 78, may be adjusted by the movable tap 112 so that a suitable reduction in intensity of carrier wave potential amplified by the discharge device 12 is produced whenever there is a difference in the amount of carrier wave potential amplified by the devices 11 and 13.

The positive potential of the cathodes 118 and 119 with respect to ground is desirable to provide some adjustment of the point at which rectification begins. Generally adjustment of both the movable taps 112 and 123 of the voltage dividers 110 and 122 should be made at the same time to provide the most nearly linear relation between modulating signal potentials from the micro-

phone 14 and phase shift of the carrier wave on the tuned circuit 39.

The apparatus thus described, when properly adjusted, is effective to produce a carrier wave whose phase is modulated substantially linearly in response to the instantaneous intensity of a modulating signal over a substantial range of carrier wave phase angle. In fact, by the use of such apparatus carrier wave phase shifts may be obtained which are twice or three times as great as phase shifts obtained by previously used apparatus with comparable linearity.

While I have shown and described a particular embodiment of my invention, it will be obvious to those skilled in the art that changes and modifications may be made without departing from my invention in its broader aspects, and I, therefore, aim in the appended claims to cover all such modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. The method of producing a carrier wave having its phase modulated in linear relation with a desired signal which comprises generating a plurality of carrier wave components displaced in phase, combining said components to produce the desired carrier wave as a resultant, and increasing the intensity of one of said components in linear relation to the intensity of said signal from its minimum value thereby increasing said resultant and the phase angle between the other of said components and said resultant, and reducing said other component with increase of said signal to reduce said increase in intensity of said resultant to an increase of such amount that phase angle between said other of said components and said resultant increases linearly with increase in said signal over the useful range of variation of said signal.

2. The method of producing a carrier wave having its phase modulated in linear relationship to a desired signal which comprises generating three components of said wave, two of said components having a time phase relation different by equal and opposite amounts from that of the third component, modulating the intensity of said two components equally and oppositely in accordance with said signal, and varying the intensity of said third component in accord with signal and by such amounts that the angular phase relation of the resultant of said three components to said third component varies substantially linearly with the instantaneous intensity of the signal throughout the useful range of said intensity of said signal.

3. The method of producing a carrier wave having its phase modulated in linear relationship to a desired signal potential which comprises generating a component of such wave having a predetermined intensity, generating and combining with said first component a second component of said wave different in phase with respect to said first component by substantially a quarter cycle, said second component having an intensity proportional to said signal potential whereby a resultant is produced varying in phase relation to said first component in accord with said signal potential, and reducing the intensity of said first component in response to said signal potential by amounts such that said phase relation of said resultant to said first component varies by amounts substantially proportional to the instantaneous intensity of said signal potential.

4. The combination in a system for producing a carrier wave having its phase modulated in linear relationship to a desired signal, of means for generating three components of such a carrier wave, two of said components having a time phase relation different by equal and opposite amounts from that of the third component, means for modulating the intensity of said two components equally and oppositely in accordance with said signal, and means for so modulating the intensity of said third component that the angular phase variation of the resultant of said three components varies linearly with the instantaneous intensity of the signal throughout the useful range of said intensity of said signal.

5. In combination in a system for producing a carrier wave having its phase modulated in linear relationship to a desired signal, sources of such carrier wave and signal, a utilization device, means for impressing said carrier wave on said device in predetermined phase, means for impressing said carrier wave on said device with intensity substantially proportional to the absolute intensity of said signal, the phase of said carrier wave impressed on said device by said last means differing from that impressed on said device by said first means by an amount substantially greater than zero and substantially less than a half cycle, and means responsive to said signal of either polarity for reducing the intensity of said carrier wave impressed on said device by said first means.

6. The combination in a system for producing a carrier wave having its phase modulated in linear relationship to a desired signal, of sources of such carrier wave and signal, a utilization device, means for impressing said carrier wave on said device in predetermined phase, means for impressing said carrier wave on said device with intensity substantially proportional to the absolute intensity of said signal, the phase of the carrier wave impressed on said device by said last means differing from that impressed on said device by said first means by an amount substantially greater than zero and less than a half cycle, and means responsive to said signal of either polarity for reducing the intensity of said carrier wave impressed on said device by said first means by an amount such that the resultant of the carrier wave impressed by said first and second means on said device differs in phase from said predetermined phase by an amount proportional to the instantaneous intensity of said signal.

7. In combination, a source of alternating signal potential, a source of high frequency potential, a utilization device, means for impressing said high frequency potential on said device in predetermined phase, means for impressing said high frequency potential on said device in intensity substantially proportional to the absolute intensity of said alternating signal potential and in phase differing by substantially a quarter cycle from said predetermined phase, the phase of the high frequency potential impressed by said second means on said device being leading or lagging with respect to said predetermined phase in accordance with the polarity of said alternating signal potential, means comprising a full wave rectifier for producing a potential whose intensity is substantially proportional to the absolute intensity of said alternating signal potential, and means responsive to the potential produced by said rectifier to reduce the intensity of said high frequency potential

of predetermined phase by an amount such that the resultant of the high frequency potentials impressed on said device by said first and second means differs in phase from said predetermined phase by an amount substantially proportional to the absolute intensity of said alternating signal voltage.

8. In combination, sources of alternating signal potential and high frequency potential, a utilization device, means for impressing said high frequency potential on said device in predetermined phase, means for impressing said high frequency potential on said device in intensity substantially proportional to the absolute intensity of said signal potential and with phase differing by substantially a quarter cycle from said predetermined phase, means comprising a full wave rectifier for producing a potential whose intensity increases in proportion to the absolute intensity of said alternating signal potential, means responsive to the potential produced by said rectifier to reduce said high frequency potential of predetermined phase, and means for impressing bias potential across said full wave rectifier to adjust the relation between the potential produced thereby and said alternating signal potential, thereby to increase linearity between said signal potential and the resultant of high frequency potentials on said device.

9. In a system for producing a carrier wave having its phase modulated in linear relation to a desired signal, the combination of a carrier wave source producing two oppositely phased components balanced with respect to ground, a source of signals, a utilization device, a resistance and a capacity serially connected in shunt to said carrier wave source, the reactance of said capacity at the frequency of carrier waves from said source thereof being substantial whereby a carrier wave component between ground and a point between said resistance and condenser is produced which is substantially different in phase from said oppositely phased components generated by said carrier wave source, means for modulating the intensities of said oppositely phased components equally and oppositely in accordance with said signals, and means for varying the intensity of said component between ground and said point in accord with said signal and by such amounts that the angular phase variation of the resultant of said three components has a substantially linear relation with the instantaneous intensity of the signal throughout the useful range of said intensity of said signal.

10. The method of producing a carrier wave having its phase modulated in linear relation with a desired signal which comprises generating a plurality of carrier wave components displaced in phase, combining said components to produce the desired carrier wave as a resultant, modulating the intensity of one of said components in direct proportion to said signal electromotive force thereby to vary the phase angle between said resultant and another of said components by progressively decreasing amounts as said electromotive force increases, and decreasing said other of said components with increase in said signal electromotive force sufficiently to maintain said phase angle proportional to said signal electromotive force.

11. In a phase modulation system, the combination of means for generating a plurality of carrier wave components displaced in phase,

means to combine said components to produce a resultant, means to vary the intensity of one of said components in accord with a desired signal thereby to vary the phase angle between another of said components and said resultant, whereby said phase angle increases by progressively decreasing amounts with increase in the vector sum of said components, and means to reduce the intensity of said other of said components sufficiently to maintain said phase angle proportional to said signal.

12. In combination, a source of carrier wave oscillations, a load circuit, a pair of amplifiers connected in parallel between said source and said load circuit, means to displace the phase of oscillations supplied from said source to said load circuit by one of said amplifiers with respect to oscillations supplied by the other of said amplifiers, a source of signal electromotive force, means to vary the amplification of one of said amplifiers in direct proportion to said signal electromotive force thereby to vary the phase angle between the resultant of the oscillations supplied to said load circuit by said amplifiers and the oscillations supplied by the other of said amplifiers, and means to maintain the variations of said phase angle in linear relation to said signal electromotive force, said last means comprising means to reduce the amplification of the other of said amplifiers upon increase in said signal electromotive force.

13. In combination, a source of carrier wave oscillations, a load circuit, a pair of amplifiers connected in parallel between said source and said load circuit, means to displace the phase of oscillations supplied from said source to said load circuit by one of said amplifiers with respect to oscillations supplied by the other of said amplifiers, a source of signal electromotive force,

means to vary the amplification of one of said amplifiers in direct proportion to said signal electromotive force whereby the phase angle between the resultant of the oscillations supplied to said load circuit by said amplifiers and the oscillations supplied by said other amplifier varies first substantially linearly and then at progressively decreasing rates as said signal electromotive force increases, and means to reduce the amplification of the other of said amplifiers as said signal electromotive force increases in either direction thereby to extend the range over which said phase angle varies linearly with said signal electromotive force.

14. In combination, a source of carrier wave oscillations, a load circuit, a pair of amplifiers connected in parallel between said source and said load circuit, means to displace the phase of oscillations supplied from said source to said load circuit by one of said amplifiers to oscillations supplied by the other of said amplifiers, a source of signal electromotive force, means to vary the amplification of one of said amplifiers in direct proportion to said signal electromotive force thereby to vary the phase angle between the resultant of the oscillations supplied to said load circuit by said amplifiers and the oscillations supplied by the other of said amplifiers, and means to maintain the variations of said phase angle in linear relation to said signal electromotive force, said last means comprising means to produce a unidirectional electromotive force varying in direct relation to the magnitude of said signal electromotive force, and means to reduce the amplification of the other of said amplifiers in response to increase of said unidirectional electromotive force.

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