Sept. 7, 1948. E. K. STODOLA 2,448,558

MODULATION NETWORKS

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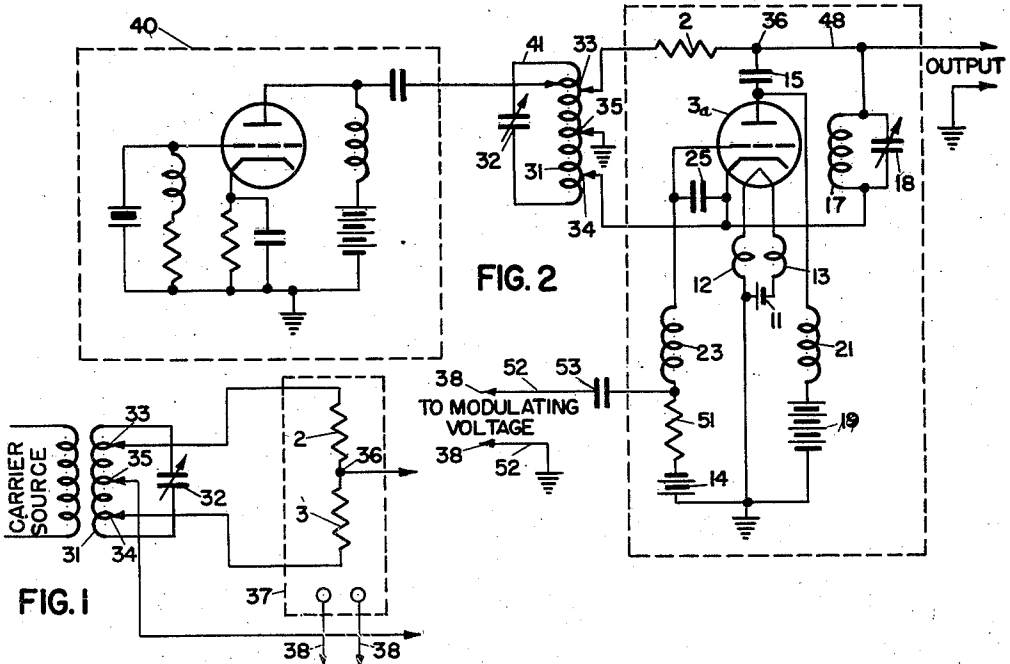


FIG. 2

FIG. 1

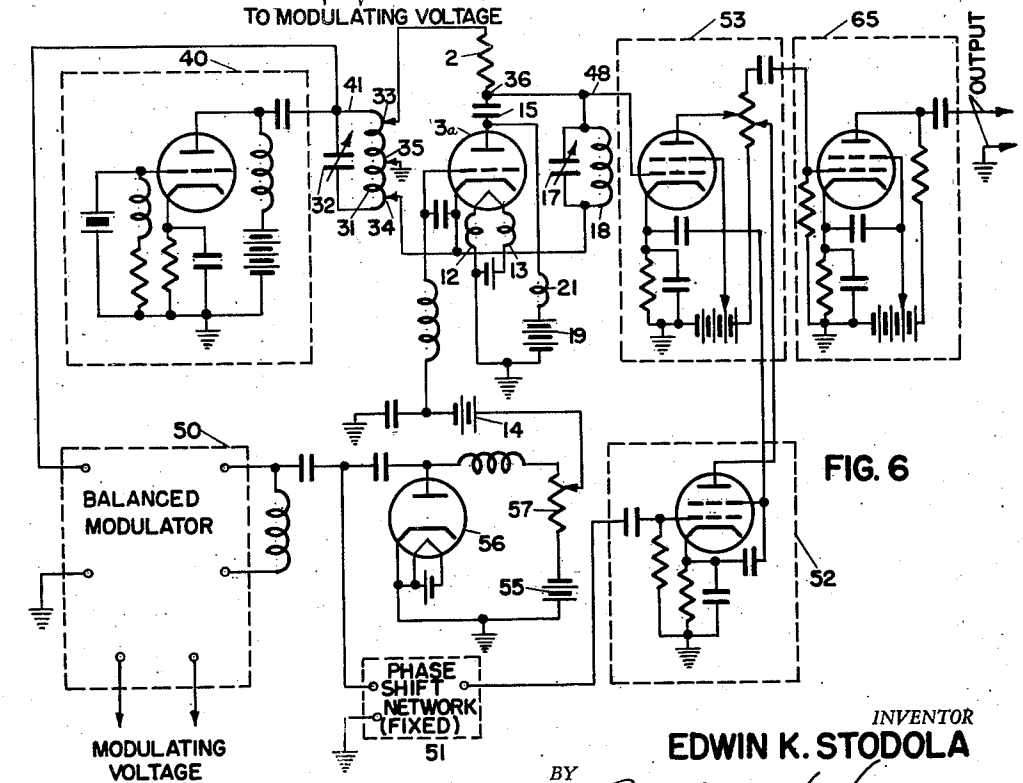


FIG. 6

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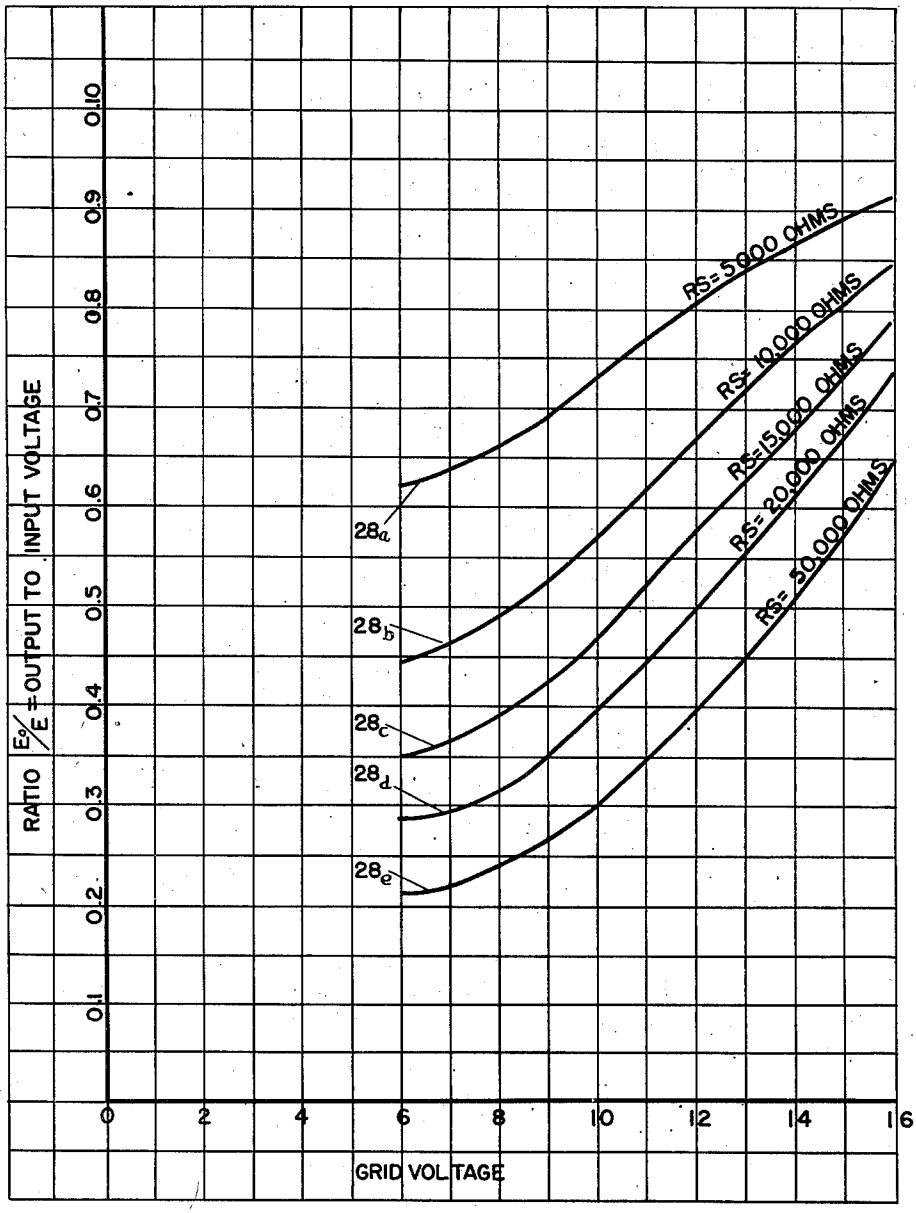
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MODULATION NETWORKS

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FIG. 3



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MODULATION NETWORKS

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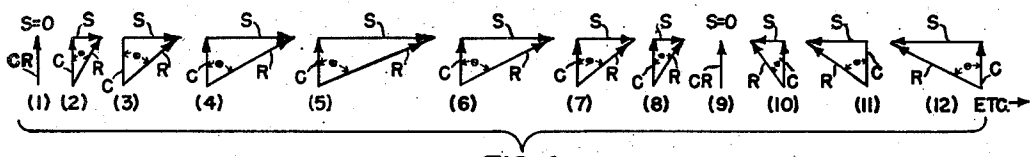


FIG.4

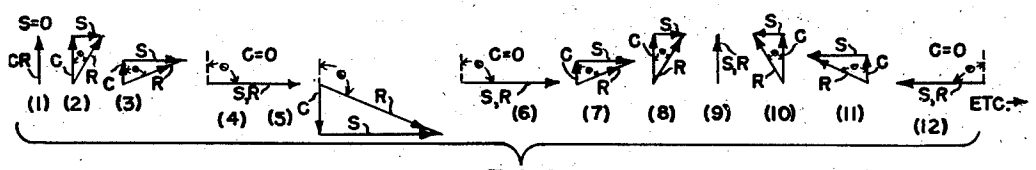
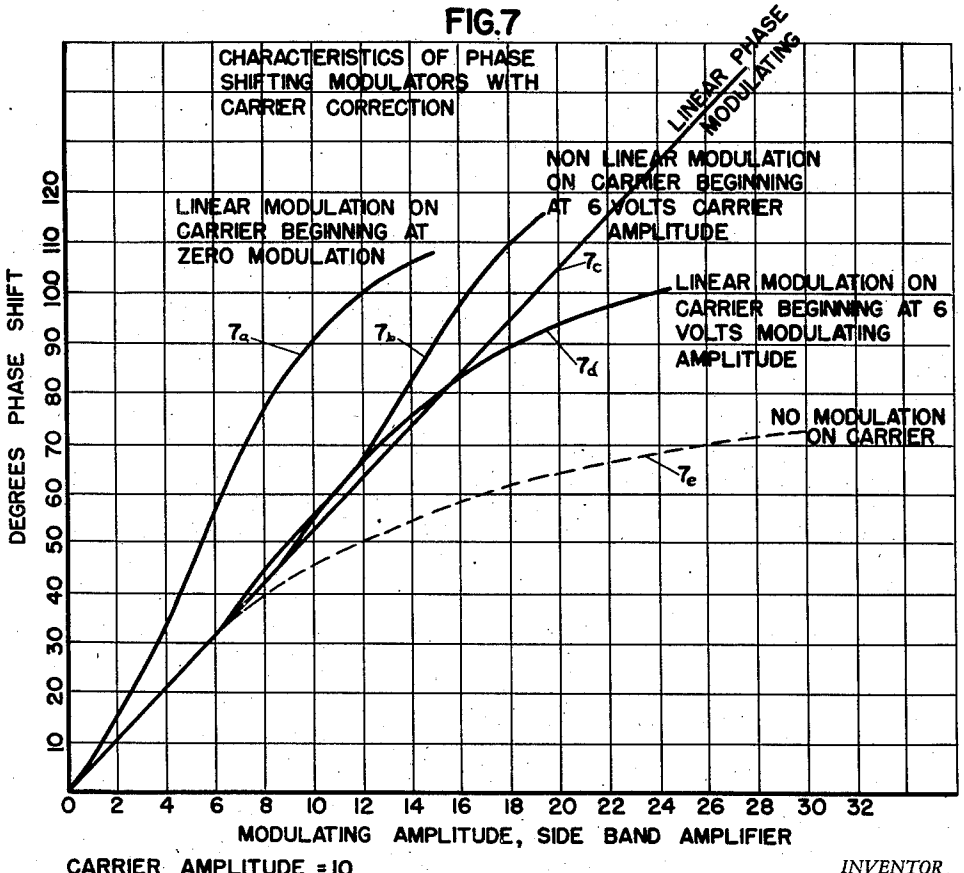


FIG.5

FIG.7



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MODULATION NETWORKS

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FIG.6 A

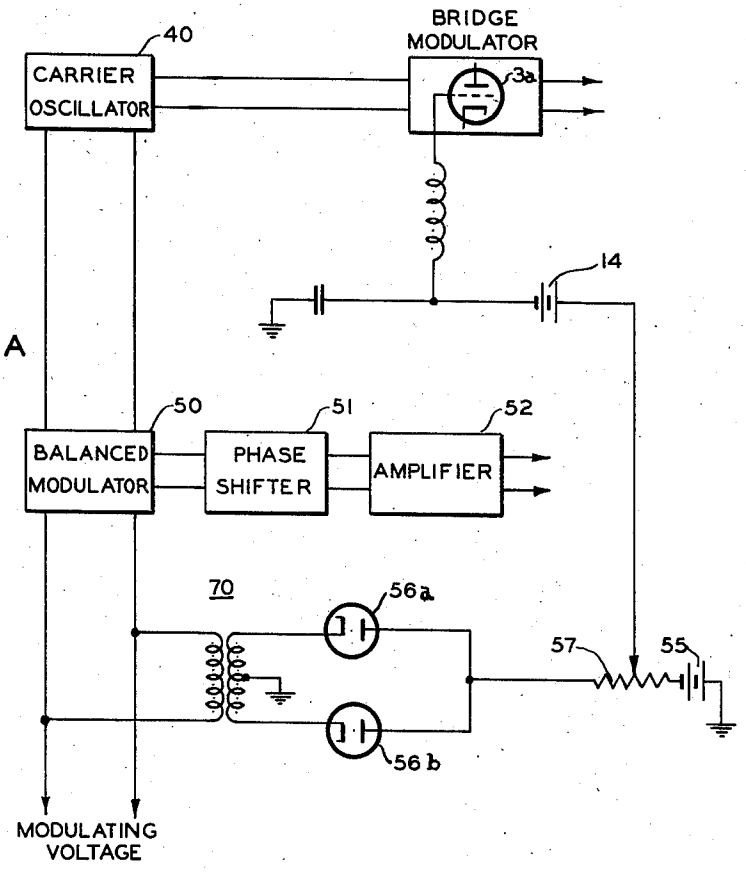
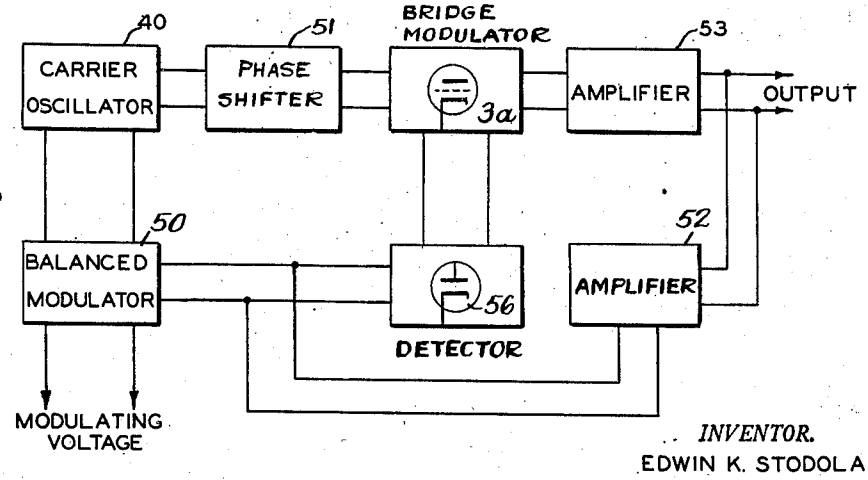


FIG.6 B



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Patented Sept. 7, 1948 2,448,558

UNITED STATES PATENT OFFICE

2,448,558

MODULATION NETWORKS

Edwin K. Stodola, Neptune, N. J.

Application November 17, 1942, Serial No. 465,922

47 Claims. (Cl. 179—171.5)

(Granted under the act of March 3, 1883, as amended April 30, 1928; 370 O. G. 757)

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The invention described herein may be manufactured and used by or for the Government for governmental purposes, without the payment to me of any royalty thereon.

My invention relates to modulation systems and methods, and more particularly to systems and methods for obtaining linear amplitude, phase, or frequency modulation over wide ranges.

In one well known type of phase and frequency modulation system, a carrier wave component is combined with a modulated, phase-displaced side-band component to derive a resultant phase displaced wave. Modulation is accomplished by varying the amplitude and direction of only the side-band component in accordance with the amplitude and direction of the modulating signal. However, in such a system, linear modulation is obtained over a range of about 30°.

It is an object of my invention to improve such system to provide linear modulation over a much wider range which may approach 90° or higher.

It is a further object of my invention to provide a novel method of modulating a carrier component in accordance with the amplitude of a side-band component.

It is a further object of my invention to provide a novel balanced modulator which is relatively simple in design and is linear over a relatively wide range extending from and on both sides of the balanced or zero output condition, and which, when used in an amplitude modulation system, will permit overmodulation, i. e., modulation in excess of 100%, without spurious side bands.

For a better understanding of the invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawings, wherein like parts are indicated by like reference numerals and wherein:

Figure 1 is a simplified circuit diagram showing a voltage-dividing circuit connected to a carrier source to establish modulation of the carrier voltage;

Figure 2 is detail diagram of the simple circuit of Figure 1.

Figure 3 is a graph of a family of curves showing the relationship between the grid voltage and ratio of the voltage drop across a standard commercial tube with respect to the total voltage drop across said tube and various values of resistance in series therewith.

Figure 4 shows several vector voltage diagrams of a fixed carrier voltage vector combined with a varying side-band vector to illustrate the corresponding variations in the phase angle between

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the carrier and the resultant voltage which represents the modulated voltage.

Figure 5 shows similar diagrams in which both the carrier and the side-band voltages are varied.

Figure 6 is a detailed diagram of a circuit for combining the carrier voltage and the side-band voltage.

Figure 6A is a schematic circuit diagram of a modification of Figure 6;

Figure 6B is a block diagram of another modification of Figure 6;

Figure 7 is a graph of a series of curves showing the extent of phase shift of the resultant voltage relative to the carrier, under different conditions of modulation.

In the arrangement shown in Figure 1, which is a simplified showing of my novel bridge or differential modulator, a voltage-dividing circuit is connected to a source of carrier voltage which serves as the input voltage for the voltage-dividing circuit. The output of the system is then derived as a function of a modulating voltage which controls and varies the relationship between the two elements of the voltage-dividing circuit.

As shown in simple form in Figure 1, the carrier voltage is derived from a tank circuit shown as including a reactor **31** and a condenser **32**, in closed circuit relationship. The voltage-dividing circuit, which is energized by the carrier from the tank circuit, includes the two resistors **2** and **3**, and is intended to provide a voltage that is a linear function of the modulating voltage. The voltage dividing circuit is connected to the coil **31** at two tap connections, **33** and **34**.

One terminal of the output circuit is derived from an intermediate tap **35** on the tank coil **31**, and the other terminal of the output circuit is taken at the juncture point **36** between the resistors **2** and **3** of the voltage-dividing circuit. The complete voltage-dividing circuit is indicated as being included within the broken line box **37**. An external modulating circuit **38** is also indicated to control the action of the voltage-dividing circuit within the box **37**.

If the intermediate tap **35** on the coil is chosen so the carrier voltage at that point **35** will be equal to the voltage at the juncture point **36** of the voltage-dividing circuit, when there is no displacement of the modulating voltage at the circuit **38**, then the output voltage, that is, the voltage between the point **35** on the tank coil, and the juncture point **36** on the voltage-dividing circuit, will be zero.

That becomes clear if the coil **31** be considered

as two arms of a bridge, and if the resistors 2 and 3 of the voltage-dividing circuit considered as the other two arms of the bridge. The bridge is energized at the top and bottom corners by the input voltage derived from between points 33 and 34 of the coil. Point 35 on the coil, and juncture point 36 between the two resistors 2 and 3, then constitute the other two corners of the bridge. The voltage between those two corners would normally be zero, when the bridge is balanced, which would be the condition when the modulating voltage is not effective to modify the characteristics of the voltage-dividing circuit.

When the modulating voltage becomes effective to vary the conditions of the voltage-dividing circuit, the consequent change in the resistance of the resistor 3 will cause a shift or displacement of the potential of the juncture point 36 between the resistor 2 and the resistor 3, and an unbalance voltage will then be available between the juncture point 36 and the intermediate point 35 on the coil 31, and that unbalance voltage will be the output voltage from the voltage-dividing circuit shown in Figure 1.

A more detailed version of the simple circuit of Figure 1 is shown in Figure 2, wherein the triode 3a is employed as the variable resistor 3 of the circuit of Figure 1. The modulating circuit 38 of Figure 1 is shown connected to the grid circuit for the triode in Figure 2. Assuming, for example, that the bridge is balanced, the output of the plate circuit voltage of the triode 3a will represent the side-band frequencies resulting from amplitude modulation, but with the carrier suppressed.

If it is desired to obtain carrier output along with the side-bands, the tap 35 should be placed at a point of carrier voltage differing from the point at which the bridge is balanced by an amount equal to the carrier voltage desired. Such a modulator produces an amplitude modulated output which may be modulated in excess of "100%" and in which no distortion arises at modulation percentages near or in excess of 100% as a result of discontinuity at the point on the modulation cycle at which the output voltage becomes zero.

A source of fixed frequency for generating a carrier voltage of constant frequency and amplitude is represented by the crystal-controlled oscillator equipment in the broken line box 40. The carrier voltage from the oscillator 40 is supplied to a tank circuit 41, including the coil 31 and the condenser 32. The tank coil 31 then serves as a source of carrier potential for the voltage-dividing circuit.

The voltage-dividing circuit includes the resistor 2 and the triode 3a connected through the blocking condenser 15 of negligible impedance to the oscillator frequency. The outer end of the resistor 2 is connected to the tap terminal 33 near the upper end of the tank coil 31, and the cathode of triode 3a is connected to the tap terminal 34 near the lower end of the tank coil 31. The intermediate tap point 35 of the tank coil 31 is grounded, so ground may serve as one terminal or conductor of the output circuit. The other conductor 48 of the output circuit is connected to the junction point 36 between the resistor 2 and the condenser 15, which, in so far as the impressed frequency is concerned, is the plate of triode 3a.

The triode 3a is shown as provided with a cathode heater energized from the battery 11 in series with R. F. chokes 12 and 13. The cathode itself is connected to the grid through the condenser 25. In order to control the biasing voltage and the operating potential of the grid of the tube 3a, the grid circuit is provided with a high value resistor 51 in the circuit including the fixed control voltage battery 14. The resistor 51 enables the modulating voltage to be introduced into the grid circuit to vary the instantaneous grid potential, and, thereby, to vary the instantaneous cathode-plate resistance of the triode 3a. The plate biasing battery 19 and grid biasing battery 14 are connected through R. F. chokes 21 and 23 to keep R. F. potentials at these points high with respect to ground.

The external modulating voltage 38 that varies the potential on the grid is applied through a circuit 52 of which one conductor is connected to the resistor 51 through a condenser 53 which serves merely as a blocking condenser, to prevent draining the batteries 14.

The reactor 17 and the condenser 18 are connected in parallel between the cathode and the output conductor at plate potential, to operate with the inter-electrode capacitance of the tube to set up a parallel resonant circuit which at operating radio frequency is non-reactive, and has a parallel resistance which is very high compared with the tube plate-cathode resistance.

The operation of the circuit in Fig. 2 may now be considered. Triode 3a is a type 6C5 tube. Let the resistor 2 be taken at 15,000 ohms, the plate battery 19 at 250 volts, and the grid battery 14 as 13 volts. On reference to Figure 3, it will be seen that under the above conditions, the output voltage Eo across the tube 3a between conductor 48 and ground would be 0.63 of the entire voltage E applied to the voltage-dividing circuit from the tank coil 31 between the tap terminals 33 and 34.

Consequently, if it is desired to obtain in the output circuit a voltage containing only the side-bands, the ground connection tap 35 should be set so that the voltage occurring between grounded tap 35 and the lower terminal tap 34 would be 0.63 of the total input voltage appearing between terminal tap 33 and terminal tap 34.

Under the foregoing conditions, the output voltage will be zero while the modulating voltage is zero; and, when a modulating voltage is applied to the grid circuit, the output voltage will contain only the side-bands, as explained above.

As shown in Figure 3, the linear portion of the curve 28c extends substantially only between the values of ten volts and sixteen volts on the grid. Consequently the modulating voltage should be limited to half the difference, or to a peak value of three volts, to avoid operating beyond the linear characteristic region of the tube-controlled voltage-divider circuit. Therefore, the grid battery 14 is set for 13.0 volts, at the middle value of the linear range. Thus, within that range of operation, the ratio of output voltage to input voltage is a linear function of the grid voltage. For a more detailed explanation of this type of voltage divider circuit, reference is made to applicant's copending application entitled Electrical networks, Serial No. 465,921, filed on even date herewith, Patent No. 2,397,992, issued April 9, 1946, in which application this circuit is described and claimed.

However, as already indicated, when it is desired to procure a portion of the carrier in the output voltage, together with the side bands, the output conductor, or ground tap in Fig. 2, at the intermediate point 35 on the tank circuit coil 31, instead of being located to be of the same potential as the junction point 36, may be shifted to a

point at either side of the point corresponding to the 0.63 point of the total voltage available from the tank circuit coil 31. The amount of the shift from the 0.63 point will depend upon the carrier amplitude desired in the output at zero modulation. Then, because of the linearity of the output of the above-described modulator, which linearity extends through, and on both sides of, the point at which the modulator output passes through zero, i. e., the point at which the carrier is 100% modulated, the modulator can be used in an amplitude modulation transmitting system in which the maximum modulation level can exceed what amounts to 100% without causing any discontinuities in the modulated wave, whereby no spurious side bands which cause interference in adjacent channels will be transmitted.

The modulator shown in Fig. 2 is particularly useful in connection with the system illustrated in Fig. 6, which provides means for obtaining linear phase or frequency modulation over a wide range of modulating potential.

In explaining my invention, it is appropriate to refer to the fact that pure frequency modulation is equivalent to phase modulation in which the maximum phase shift for a given modulating voltage is inversely proportional to the modulating frequency. At any single modulating frequency there is no distinction between phase modulation and frequency modulation. Consequently in the subsequent portion of the present description, reference will be made to phase modulation with the understanding that by appropriate control of the modulating voltage, the same devices and methods will produce frequency modulation. In the claims, "wave length modulation" will be used to designate both frequency and phase modulation.

In the following part of the specification, reference will be made to a "side-band vector." By this is meant a vector rotating at the angular velocity of the carrier vector but whose length is proportional to the instantaneous value of the modulating voltage and whose direction with respect to a rotating vector of fixed length is determined by the polarity of the modulating voltage. Such a vector represents the two sidebands which result from amplitude modulation.

In a type of phase modulator used heretofore the phase shift has been produced by adding to a fixed amplitude carrier a sideband displaced from it by ninety degrees. With such an arrangement a phase shift very nearly proportional to the modulating voltage is obtained up to about a thirty degree shift, but above this value the proportionality disappears.

This invention includes a method of phase modulation which consists in applying the modulating voltage to the carrier as well as using the modulating voltage in the production of the sidebands in a modulator similar to that described above. The modulating voltage is made to act upon the carrier in such a way that as the sideband vector increases in length, displacement of the resultant vector from the carrier vector is reasonably proportional to the modulating voltage with even large phase shifts. Phase shifts of over plus and minus ninety degrees are possible with this invention.

In Fig. 4, vector triangles 1 through 12, illustrate the effect on the resultant vector R, of combining a fixed magnitude carrier vector C and a varying magnitude sideband vector S. It will be seen that as the sideband vector increases in magnitude from zero (triangle 1) to a maximum (triangle 5) the angular displacement θ of the resultant, R, from the carrier C increases, but, as the magnitude of the sideband vector becomes larger the increase in angular displacement for a given increase in the sideband vector becomes progressively smaller introducing non-linearity, when the phase displacement is large, and definitely limiting the maximum phase displacement to less than 90°. Triangles 6 through 9 show the decrease in displacement angle θ as the sideband vector decreases to zero, and triangles 10 through 12 show the displacement of the resultant in the opposite direction as the sideband vector increases in the opposite direction. This process is continued and results in phase modulation.

In Fig. 5, vector triangles 1 through 12, correspond to Fig. 4, except that in this case the carrier is depressed or reversed as the magnitude of the sideband vector increases, to permit greater angular displacement of the resultant from the initial position of the carrier. In triangles 1 and 2 the carrier remains constant, while in 3 the sideband vector has increased as in triangle 3 of Fig. 4, but the carrier has been simultaneously decreased to give a further phase displacement than in Fig. 4. In triangle 4 the carrier is shown decreased to zero, giving a displacement angle θ of 90° and in triangle 6 the carrier is reversed to give an angle in excess of 90°. Triangles 6 through 9 show the return of the resultant to the initial position as the magnitude of the sideband vector decreases to zero while triangles 10 through 12 show the beginning of phase displacement in the opposite direction as the magnitude of the side-band vector increases in the opposite direction. The process illustrated continues and results in a modulated wave varying over a range of phase displacement of 90° or more in either direction.

In Fig. 6 is shown a practical circuit embodying the principles of operation described in the preceding figures. The circuit diagram in Fig. 6 includes the crystal controlled oscillator 40, represented as enclosed within the broken line box, which may also include buffer amplifiers to improve the stability and the isolation properties. The oscillator 40 feeds into a differential modulator in the form of a bridge such as shown in Figure 2. The bridge comprises the tank circuit including the coil 31 and the condenser 32. The tank circuit coil 31 energizes a voltage-dividing circuit to provide a variable carrier voltage, and energizes a balanced modulator 50 to provide a sideband voltage. The two voltages are then combined to constitute the output voltage. Balanced modulator 50 can be a differential modulator of any conventional type. Or, it may consist of a circuit such as shown in Figs. 1 and 2, said circuit being so adjusted that all or part of the carrier is normally balanced out.

The parts of the voltage-dividing circuit energized from the tank circuit are identified by the same numerals as used in Fig. 2. In Fig. 6, however, the modulating voltage, instead of being applied to the grid circuit directly, is applied to the balanced modulator 50, and the side-band voltage from the modulator is utilized to control the grid of the triode 3a in the bridge modulator circuit to effect a certain amount of variation of the carrier amplitude by the side-band voltage as a function of the modulating voltage.

Since it is desired to establish an output voltage phase-displaced from the carrier by an angle substantially proportional to the modulating voltage, the control of the carrier by suppression

or reversal must be correlated with the constants of the circuit and with the characteristics of the triode.

In Figure 7, several curves are included showing the relationship of the angle of phase shift to the amplitude of the modulating voltage, with different kinds of modulation control on the carrier, and without any modulation on the carrier.

In a circuit including the elements shown, with the characteristics and values already set forth, curve 7*d*, in Fig. 7, is closest to a direct linear relationship which is represented by the straight line 7*c*. Curve 7*d* represents a condition of substantially linear modulation on the carrier beginning at 6 volts modulating voltage. The circuit conditions for establishing the relation represented by curve 7*d* are provided in the circuit shown in Figure 6.

In order to establish the modulating control as required for curve 7*d* the grid circuit of triode 3*a*, in Fig. 6 is initially biased negatively at no modulation, and the modulating voltage is obtained by rectification in a diode of the output of the balanced modulator. The diode is biased so that no output is obtained from it until the peak output of the balanced modulator exceeds 6 volts.

The intermediate ground tap **35** on the tank coil **31** is set to provide a carrier voltage with a selected amplitude on the output circuit, while there is no modulation on the triode 3*a*. That output voltage constitutes the carrier voltage function with which the side-band voltage is to be combined.

The side-band voltage is derived from the balanced modulator **50**, that is fed from the oscillator **40**, and that is controlled by the modulating voltage of the system. The balanced modulator **50** is set up to provide a side-band voltage with the carrier completely suppressed and varying in amplitude with the amplitude of the modulating voltage applied to the modulator **50**.

In order to combine the side-band and the carrier voltage function in right angle relationship, the side-band voltage derived from the modulator **50** is first rotated by a fixed 90 degree phase shift network **51**, and is then fed into an isolating amplifier **52**. The isolating side-band amplifier **52** then feeds into an amplifier **53** which is also energized by the carrier voltage function from the output circuit **48** of the voltage divider. The output of amplifier **53** is then further amplified in amplifier **65**, the output of which can be further multiplied in frequency and/or amplified and radiated as a phase or frequency modulated wave.

As already stated, the carrier voltage function is controlled by the side-band voltage when the latter exceeds six volts. In a typical set of adjustments to establish such control, the grid circuit of triode 3*a* is biased by battery **14** as four and one-half volts, plus battery **55** as six volts, so the grid is initially and normally excited by negative ten and one-half volts. The resistor **2** having a resistance of 15,000 ohms, curve 28*c* of Figure 3 shows that the cathode-plate voltage across triode 3*a* will be 0.495 of the total carrier voltage as applied to the voltage dividing circuit from between terminal taps **33** and **34** on the tank coil **31**. Assuming the voltage between taps **33** and **34** to be fifty volts, the plate-cathode voltage would be 50×0.495 or 24.7 volts. If the ground tap is set however, so the voltage drop between the ground tap **35** and the terminal tap **34** will be 34.7 volts, the voltage difference between the ground tap point and the juncture point **36** will be 34.7 minus 24.7 or 10 volts, which will be the value of the carrier voltage supplied to the output circuit.

The carrier output voltage remains at that value in combining with the side-band voltage, until the side-band voltage attains a value of six volts. When the side-band voltage exceeds that value of six volts, the excess voltage becomes effective to increase the bias on the grid of triode 3*a*. The plate-cathode resistance of triode 3*a* then increases, with a corresponding increase in plate-cathode output voltage, and with a consequent shift in the potential of the juncture point **36** from which the output circuit conductor **48** proceeds, in such a way that for a range of 10 volts, the voltage between **48** and ground is decreased. Beyond 10 volts the voltage across **48** and ground increases for increasing negative voltage at the grid of 3*a*, but the phase of the voltage is reversed.

In order to control triode 3*a* according to the value of the sideband voltage, the grid circuit of the triode is further controlled by a small diode **56** that is negatively biased by a six-volt battery **55**. The side-band voltage from the modulator is applied to the diode plate. At six volts side-band voltage, diode **56** becomes conductive, and the charge impulses through the diode generate a voltage across a resistor **57** common to the grid and to the diode circuits. The voltage across the resistor **57** increases as the side-band voltage increases, and the triode 3*a* is controlled by that increased voltage to increase the negative grid potential and thereby to vary the plate-cathode voltage of the triode 3*a*. That variation of the triode voltage shifts the potential of the juncture point **36** and, consequently, changes the voltage of the carrier, available to the output circuit.

Thus, the carrier voltage function is reduced or reversed when the side-band voltage increases sufficiently, regardless of the direction of the side-band (i. e., the rate of amplitude variation is twice the frequency of the modulating wave). The side-band value varies with the modulating voltage, and, as the side-band vector exceeds the six volts delay bias carrier vector is thereafter proportionately diminished or reversed. Consequently, as the carrier voltage vector C is diminished, or even reversed, as illustrated in Fig. 5, the angle between the carrier voltage vector C and the resultant voltage vector R, which results from combining carrier C and the established side-band vector S, continues to vary substantially linearly in accordance with the modulating voltage amplitude, as shown in graph curve 7*d* in Fig. 7. It should be noted that the purpose of using a delay bias is to suitably distort the rectified voltage which modulates the carrier. Any other method of producing the required form of non-linearity may be used. One of such other methods is to provide a non-linear carrier modulator. This can be done in the system of Fig. 6 by altering the steady bias on tube 3*a* so that the operating range involves a suitable non-linear portion of the curve 28C in Fig. 3, which shows the input to output characteristic of the network including resistor **2** and tube 3*a*. A curve for such a system is also shown in Fig. 7, graph curve 7*b*. This can also be done by suitably altering the value of resistance **2**.

In the modulating system of Fig. 6, characterized by curve 7*d* in Figure 7, the resistor **57** in the circuit common to the grid of triode 3*a* and to the plate of diode **56**, is adjusted so the negative bias on the grid will increase to 14.2 volts when the side-band amplitude reaches 18.2 volts. At that

value of grid bias, the value of triode plate-cathode resistance reaches a ratio to the total resistance of triode 3a and resistor 2, that is equal to the ratio of the setting of ground tap 35 to the total carrier voltage between terminal taps 33 and 34. Consequently, the potential of the juncture point 36 reaches the same value as the potential of the ground tap 35, and no potential difference exists between those two points 35 and 36 to set-up the carrier voltage function as a combining vector voltage. The carrier is therefore zero and only the side-band voltage shows up as the resultant vector voltage, thus indicating a 90 degree phase shift from normal carrier position at zero modulation. When the side-band amplitude exceeds 18.2 volts the drop across the triode plate cathode resistance will further increase and cause the carrier voltage to start rising again but with its phase reversed from the condition of less than 18.2 volts side-band amplitude. Hence the output voltage will be shifted in excess of 90 degrees.

The phase angle at which reduction of the carrier begins and the extent to which the carrier is reduced may be easily controlled in the design of such a system. If desired, the delay bias battery 55 can be eliminated so that the carrier variation is a continuous function of the side-band amplitude. Many other methods of carrying out the method described are possible, the illustration given here being merely to show that the scheme is a practical one. For example, the modulating voltage which is applied to the grid of tube 3a could be obtained from a full wave rectifier the output of which is distorted by a delay bias analogous to that used above or in any other suitable manner, driven by the alternating modulating voltage which is applied to the balanced modulator, rather than by rectification of the balanced modulator output as shown in Figure 6. For a description of this modification, reference is made to Figure 6A, in which the components corresponding to those of Figure 6 are similarly numbered. The modulating voltage is applied directly to a conventional full-wave rectifier circuit including a transformer 70 having a center-tapped secondary, the output of which is full-wave rectified by diodes 56A and 56B feeding into a common load resistor 57. A delay-bias battery 55 maintains the diode anodes at a predetermined negative potential with respect to their cathodes so that no rectified output is developed until the modulating voltage exceeds said predetermined potential. The rectified output across load resistor 57 is now applied as a negative bias, in series with the fixed potential source 14, to the grid of the tube 3a of the bridge modulator. In all other respects this circuit is similar to Figure 6 in structure and function.

The phase shifter 51 can be inserted in the carrier channel instead of the side-band channel or a portion of the phase shift can be secured in both channels. This is illustrated in Fig. 6B, wherein the 90° phase shifter 51 is inserted in the carrier channel between oscillator 40 and the bridge modulator, although it can obviously be inserted at any other point in said channel with the same results. In practice, relatively simple circuits could be used to achieve the desired result.

Figure 7 also shows the performance curves of several phase modulators of the type described, showing the results which may be obtained by using various combinations of control of the carrier by the modulating voltage, and including the use of a non-linear portion of the characteristic of the tube-controlled voltage divider. The improvement over a modulator using a fixed carrier, for which the characteristics is also shown in curve 7e, is evident; and combinations of carrier and side-band control other than those for which characteristics are shown can produce even better results.

The circuits described are to be considered as only illustrative of the principles of the invention. Many equivalent components can be used and modifications may be made without departing from the spirit of the invention as defined in the appended claims.

I claim:

1. The method of modulating a carrier frequency potential which comprises modulating said carrier in such manner as to provide separated carrier and side-band components, utilizing only the side-band component to generate a voltage, and utilizing said voltage to modify the amplitude of said carrier component.

2. The method of modulating a carrier frequency potential which comprises modulating said carrier in such manner as to provide separated carrier and side-band components, demodulating only the side-band component to generate a voltage, and utilizing said voltage to decrease the amplitude of only said carrier component.

3. The method according to claim 1, wherein said modified carrier is combined with said side-band component to yield a resultant wave to be utilized.

4. The method according to claim 1, wherein said components are phase shifted with respect to each other and then combined to yield a resultant phase modulated wave.

5. The method of establishing wave-length modulation of a high frequency carrier voltage which comprises applying a modulation voltage to the carrier to derive a side-band voltage varying with the modulation voltage; combining the carrier voltage and the side-band voltage in phase quadrature to establish a resultant modulated output voltage; and proportionately reversing the phase of the carrier voltage, when the side-band voltage exceeds a predetermined value, at which the resultant voltage forms a predetermined angle with the carrier voltage.

6. A wave-length modulation system comprising a source of carrier voltage; a voltage-dividing circuit energized therefrom and including a resistor and an electron tube having such relative characteristics that control of the tube by the grid establishes a plate-cathode voltage drop bearing a substantially linear relationship to the modulating grid-voltage; means for deriving a modulated carrier voltage function from between two points, one being the juncture between the resistor and the tube, and the other being an intermediate point on the carrier voltage source; a source of modulating voltage; a balanced modulator for deriving a side-band voltage from said carrier source, as controlled by the modulating voltage; means for shifting the side-band voltage through a predetermined angle; means responsive to the modulating voltage in excess of a predetermined value for controlling the modulation of the tube to control the carrier voltage function; and means for combining the carrier voltage function and the shifted side-band voltage to provide a resultant phase modulated voltage.

7. A wave-length modulation system comprising a source of carrier voltage; a source of modulating voltage; means energized from the carrier source for establishing a carrier voltage function;

means energized from the carrier source for establishing a side-band voltage function; means energized by said side-band voltage function for controlling the carrier voltage function as the side-band function exceeds a predetermined value; means for shifting the side-band function to a fixed angular relation with respect to the carrier voltage function; and means for combining the carrier voltage function and the shifted side-band voltage function to establish a resultant wave-length modulated output voltage.

8. A wave-length modulation system comprising a source of high-frequency carrier voltage; a tank circuit including a reactor coil; a voltage-dividing circuit including a resistor and an electron tube in series connected to two spaced selected points of the coil; an output circuit connected to an intermediate point on the coil, and to the juncture between the resistor and the tube; a balanced modulator energized from the carrier source and controlled by the modulating control voltage to provide a side-band voltage function; phase shifting means for angularly displacing the side-band voltage function; means for controlling the amplitude and the direction of the voltage function of the output circuit in accordance with the amount of the modulating voltage in excess of a predetermined value; and means for combining the output voltage and the side-band voltage.

9. A wave-length modulating system comprising a source of high-frequency carrier voltage; a modulating circuit for deriving, from said carrier, a voltage vector component having an initial predetermined amplitude at zero modulation; a balanced modulator circuit for deriving a side-band voltage component; means responsive to said side-band component for modulating the amplitude of the derived carrier vector component; a phase shifting network for angularly shifting the side-band voltage component relative to the derived carrier component; and means for combining the two components to establish a resultant output voltage phase displaced from the original carrier voltage.

10. The method of establishing wave-length modulation, which consists in generating a basic carrier voltage of relatively fixed frequency and amplitude; deriving from said carrier voltage a side-band voltage function in accordance with the modulating voltage; deriving from said carrier voltage a combining carrier voltage function having its normal carrier amplitude controlled by said side-band voltage function in proportion to the amount by which the side-band voltage function exceeds a predetermined value; phase-shifting the side-band voltage function to a right angle position relative to the carrier voltage function; and combining the two functions to establish a resultant voltage to be utilized.

11. A wave-length modulation system comprising a source of carrier voltage; means energized therefrom to establish a carrier voltage function having a predetermined amplitude at zero modulation; a source of modulating voltage; means energized from the carrier source and from the modulating source to develop a side-band voltage function; means responsive to the amplitude of the side-band voltage and operative, when that side-band voltage exceeds a predetermined value, to control the amplitude of the carrier voltage; means for angularly shifting the side-band voltage relative to the carrier voltage; and means for combining the carrier voltage and the side-band voltage to establish the phase-modulated output voltage.

12. The method of wave-length modulating a carrier voltage which comprises modulating said voltage in such manner as to provide separated carrier and side-band components, detecting said side-band component to provide a voltage, utilizing said latter voltage to control the amplitude of said separated carrier component, phase shifting one of said components with respect to the other and then combining said components to produce a resultant wave length modulated wave.

13. The method according to claim 12, wherein the amplitude of said carrier component is varied as an inverse function of instantaneous amplitude of said modulation voltage.

14. The method of wave-length modulating a carrier wave which comprises using modulation voltage on said carrier in such manner as to generate separated carrier and side-band vectors, causing one of said vectors to lead the other and then combining it with the other vector to produce a resultant wave-length modulated wave, and reversing one of said vectors when said modulation voltage exceeds a predetermined magnitude.

15. The method of wave-length modulating a carrier voltage which comprises using modulation voltage on said carrier in such manner as to provide carrier and side-band vectors, phase shifting one of said vectors 90° and then combining it with the other vector to provide a resultant wave-length modulated wave, and reversing the carrier vector when said side-band vector exceeds a predetermined value.

16. The method of generating a wave-length modulated wave which comprises providing two waves of the same frequency, using modulation voltage to amplitude modulate one of said waves, rectifying said amplitude modulated wave to provide a voltage, using said voltage to amplitude modulate the other wave, phase displacing said amplitude modulated waves with respect to each other, and combining said phase displaced waves to provide a resultant wave-length modulated wave.

17. The method set forth in claim 16, wherein said phase displacement amounts to substantially 90°.

18. A wave-length modulated transmitter system comprising a source of carrier frequency energy, a channel comprising a normally unbalanced bridge modulator circuit having its input circuit coupled to said source, a second modulator circuit coupled to said source and adapted to be excited by a modulating potential, means responsive to said modulating potential to vary the amount and direction of unbalance of said bridge modulator, means to phase displace the outputs of said modulators with respect to each other, and means to combine said phase displaced outputs to yield a resultant output which is wave-length modulated in accordance with said modulating potential.

19. A wave-length modulated transmitter system comprising a source of carrier frequency energy, a channel comprising a normally unbalanced amplitude modulating bridge circuit having its input circuit coupled to said source, a second amplitude modulator circuit coupled to said source and adapted to be excited by a modulating potential, a rectifying network energized by the output of said second modulator, means responsive to the output of said rectifying network to vary the balance of said bridge modulator, means

to phase displace the outputs of said modulators with respect to each other, and means to combine said phase displaced outputs to yield a resultant output which is wave-length modulated in accordance with said modulating potential.

20. A wave-length modulated transmitter system comprising a source of carrier frequency energy, a channel comprising a normally unbalanced amplitude modulating bridge circuit having its input circuit coupled to said source, said bridge modulator having in one of its arms the anode-cathode path of an electron tube, a second amplitude modulator coupled to said source and adapted to be excited by a modulating potential, a rectifying network energized by the output of said second modulator, means responsive to the output of said rectifying network to vary the impedance of said electron tube with resultant variation of the balance of said bridge circuit, means to phase displace the outputs of said modulators substantially ninety degrees with respect to each other, and means to combine said phase displaced outputs to yield a resultant output which is wave-length modulated in accordance with said modulating potential.

21. A system as set forth in claim 20, wherein said second modulator is of the carrier suppressing type.

22. A system as set forth in claim 20, wherein said rectifying network includes a diode having a delay bias impressed thereon, whereby only potentials above a predetermined amplitude will be rectified.

23. A system as set forth in claim 20, including a circuit connected across said anode-cathode path of said tube, said circuit together with the capacity of said tube being parallel resonant to said carrier frequency energy.

24. The method of wave-length modulating a carrier wave which comprises impressing said carrier upon two channels, using a first modulation voltage to amplitude modulate said carrier in one of said channels, deriving from said amplitude modulated wave a second modulation voltage, using said second modulation voltage to amplitude modulate the carrier wave in the first channel, phase shifting the modulated wave in one channel by a substantially fixed amount relative to the modulated wave in the other channel, and combining said phase displaced waves to derive a resultant wave which is phase modulated with respect to said carrier wave in accordance with said modulating voltage.

25. The method of wave-length modulating a constant frequency carrier wave which comprises impressing said carrier upon two channels, using a first modulation voltage to amplitude modulate said carrier in one of said channels, deriving from said amplitude modulated wave a second modulation voltage, using said second modulation voltage to vary the amplitude and reverse the phase of the wave in the first channel, phase shifting the modulated wave in one channel substantially ninety degrees relative to the output of the second channel, and combining said phase displaced waves to derive a resultant wave which is phase modulated with respect to said carrier wave in accordance with said modulating voltage.

26. The method of wave-length modulating a constant frequency carrier wave which comprises impressing said carrier upon two channels, using a first modulation voltage to amplitude modulate said carrier in one of said channels, rectifying said amplitude modulated wave to derive a second modulation voltage, using said second modulation voltage to amplitude and phase modulate the wave in the first channel, phase shifting the modulated wave in one channel substantially ninety degrees relative to the modulated wave in the second channel, and combining said phase displaced waves to derive a resultant wave which is phase modulated with respect to said carrier wave in accordance with said modulating voltage.

27. The method of wave-length modulation which comprises generating a carrier vector and a side-band vector, impressing said vectors upon separate channels, using a first modulation voltage to vary the amplitude of said side-band vector, rectifying said side-band vector to derive a second modulation voltage, using the latter to modulate the amplitude of said carrier vector, phase shifting said vectors relative to each other, and combining said phase displaced vectors to derive a resultant wave which is wave-length modulated in accordance with said first modulation voltage.

28. In a wave-length modulated carrier wave system wherein carrier and side-band vectors are phase displaced with respect to each other and then combined to produce a resultant vector which is phase displaced with respect to the carrier vector, the method of modulation which comprises using modulation voltage below a predetermined amplitude to vary only the amplitude of the side-band vector, using modulation voltage in excess of said amplitude to vary both vectors in opposite senses, and using still higher modulation voltages to reverse the direction of said carrier vector.

29. A wave-length modulation system for a source of carrier frequency energy comprising a pair of modulators adapted to be coupled in parallel to said source, one modulator being a normally unbalanced differential modulator, the other modulator being adapted to be coupled to a source of modulation voltage, means responsive to said modulation voltage to vary the amount and direction of unbalance of said differential modulator, means to phase displace the outputs of said modulators with respect to each other and means to combine said phase-displaced outputs to yield a resultant wave-length modulated wave.

30. A system as set forth in claim 29, wherein said other modulator is a balanced modulator which normally suppresses the carrier.

31. A wave-length modulation system for a source of carrier frequency energy comprising first and second differential modulators adapted to be coupled in parallel to said source, the first modulator being normally unbalanced and the second being normally balanced, said second modulator being adapted to be coupled to a source of modulation voltage, means to demodulate the output of said second modulator, means responsive to said demodulated output to vary the amount and direction of unbalance of said first modulator, means to phase displace the outputs of said modulators with respect to each other, and means to combine said phase displaced outputs to yield a resultant wave-length modulated wave.

32. In a wave-length modulated carrier wave system wherein a pair of phase-displaced wave components are combined to produce a resultant which is phase displaced with respect to said components, the method of modulation which comprises varying the amplitude of only one component to phase displace said resultant from said other component up to approximately 30°, and then oppositely varying both components to further phase displace said resultant.

33. In a wave-length modulated carrier wave system wherein a pair of phase-displaced wave components are combined to produce a resultant which is phase displaced with respect to said components, the method of modulation which comprises first increasing the amplitude of one component while maintaining the other component constant until said resultant is phase displaced from the other component approximately 30°, and thereafter further increasing the amplitude of said one component and simultaneously decreasing the amplitude of said other component.

34. In a wave-length modulated carrier wave system wherein carrier and side-band vectors are phase displaced approximately 90° with respect to each other and then combined to produce a resultant vector which is phase displaced with respect to said carrier vector, the method of modulation which comprises first increasing the amplitude of said side-band vector while maintaining said carrier vector constant until said resultant vector is phase displaced from said carrier vector approximately 30°, and thereafter decreasing the amplitude of said carrier vector.

35. In a wave-length modulated carrier wave system wherein carrier and side-band vectors are phase displaced approximately 90° with respect to each other and then combined to produce a resultant vector which is phase displaced with respect to said carrier vector, the method of modulation which comprises first increasing the amplitude of only said side-band vector until said resultant vector is phase displaced from said carrier vector approximately 30°, thereafter further increasing the amplitude of said side-band vector and simultaneously decreasing the amplitude of said carrier vector until said resultant vector is phase displaced approximately 90°, and thereafter increasing the amplitude of said carrier vector, but with a reversal in the direction thereof.

36. In a system for modulating the phase of a carrier wave in linear relationship in accordance with a desired signal, the combination of means for generating two components of such a carrier wave, the time phase between said two components being substantially greater than zero and susbtantially less than one-half cycle, means for modulating the intensity of one of said components in accordance with such desired signal, means for combining said components after such modulation of one to produce a carrier wave whose phase is shifted in response to such desired signal, and means responsive to increases in the amplitude of said one of said combined component for reducing the intensity of the other of said components.

37. In a system for modulating the phase of a carrier wave in linear relationship in accordance with the desired signal, the combination of means for generating two components of such a carrier wave, the time phase between said two components being substantially greater than zero and substantially less than a half cycle, means for modulating the intensity of one of said components in accordance with such desired signal, means for combining said components after such modulation of one to produce a carrier wave whose phase is shifted in response to such desired signal, means for detecting variations in intensity of said one of said combined components for generating a potential varying in accordance with a function of said signal, and means for reducing the intensity of the other of said components in accordance with said potential.

38. 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 in response to increase of said one component to reduce said increase in intensity of said resultant to an increase of such amount that said 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.

39. 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 response to variation in said intensity of said two components 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.

40. 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 increase of said second component 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.

41. 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 responsive to variation in intensity of said two components 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.

42. 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, first means for impressing said carrier wave on said device in predetermined phase, second 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 second 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 the output of said second means for reducing the intensity of said carrier wave impressed on said device by said first means.

43. 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, first means for impressing said carrier wave on said device in predetermined phase, second 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 second 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 the output of said second means 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.

44. 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 rectifier coupled to the output of the second means 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.

45. 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 rectifier coupled to the output of the second means 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 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.

46. 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 in response to increase in said intensity sufficiently to maintain said phase angle proportional to said signal electromotive force.

47. 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 responsive to said intensity variation to vary the intensity of said other of said components sufficiently to maintain said phase angle proportional to said signal.

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Certificate of Correction

Patent No. 2,448,558. September 7, 1948.

EDWIN K. STODOLA

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows:

Column 12, line 30, claim 15, before the words "carrier and" insert *separated*;

and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 28th day of December, A. D. 1948.

[SEAL]

THOMAS F. MURPHY,
Assistant Commissioner of Patents.