

Nov. 10, 1931.

R. B. STEWART

1,831,516

MODULATING SYSTEM AND METHOD

Filed Jan. 10, 1928

3 Sheets-Sheet 1

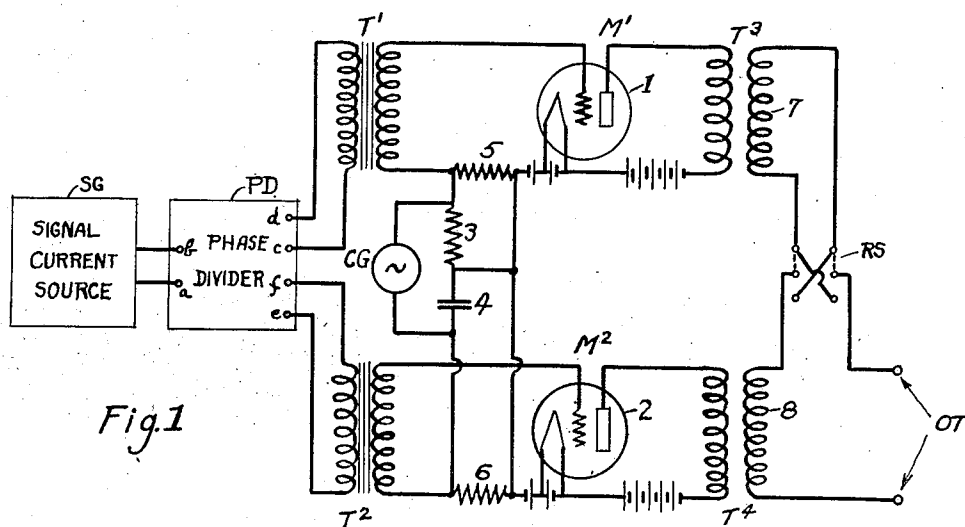


Fig. 1

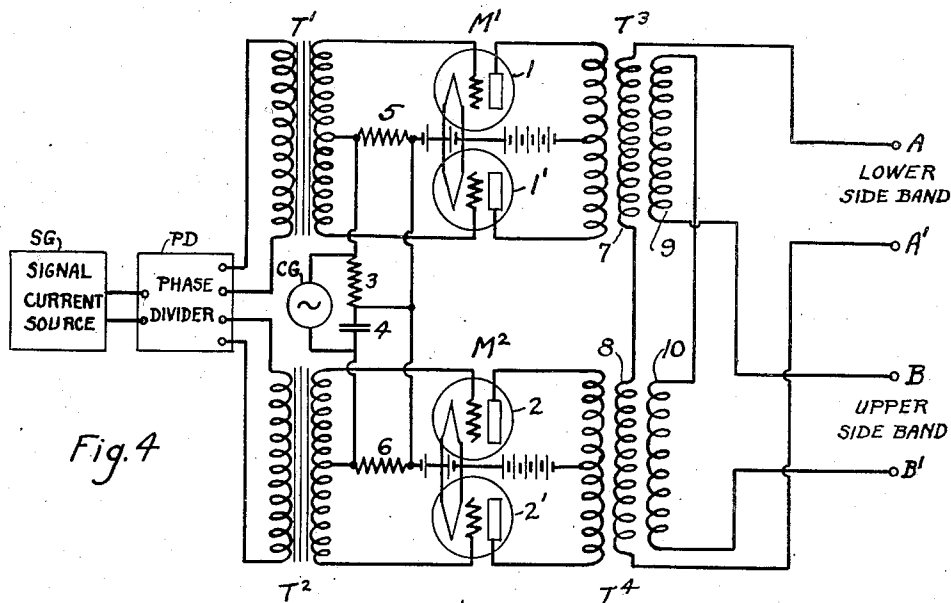


Fig. 4

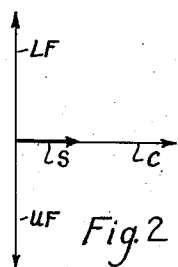


Fig. 2

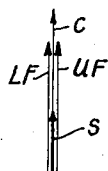


Fig. 3

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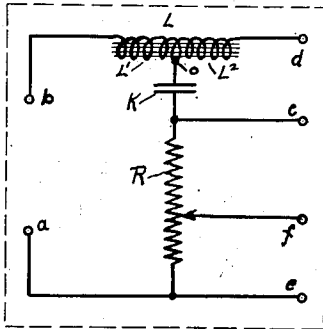


Fig. 5

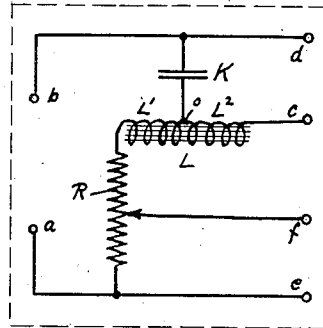


Fig. 10

Fig. 7

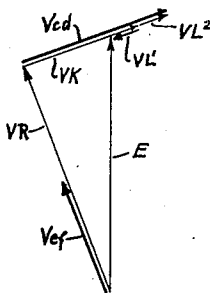


Fig. 6

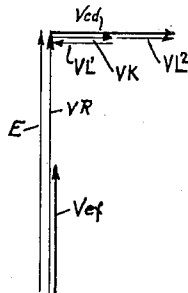


Fig. 8

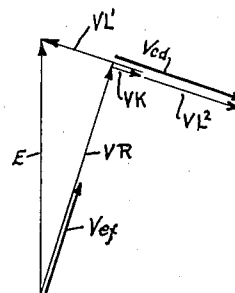
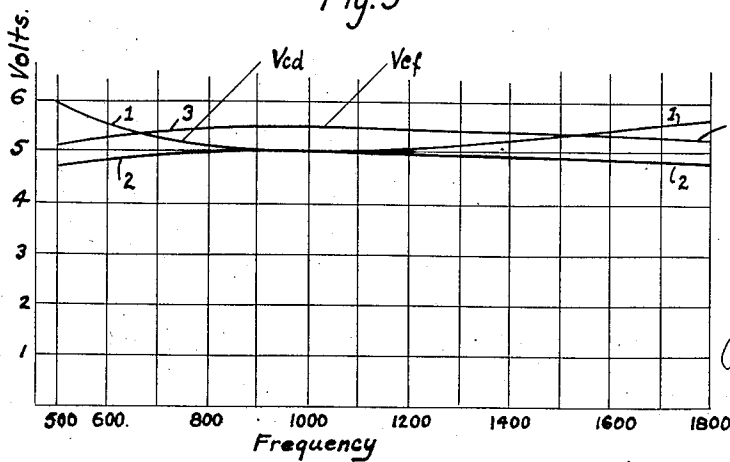


Fig. 9



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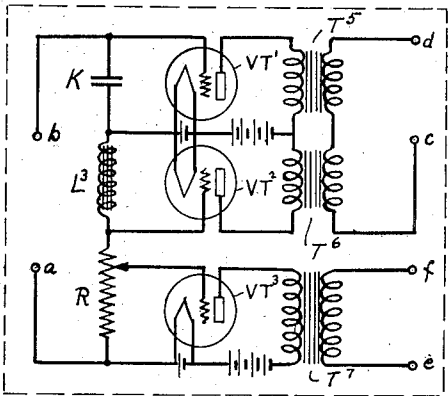


Fig. 11

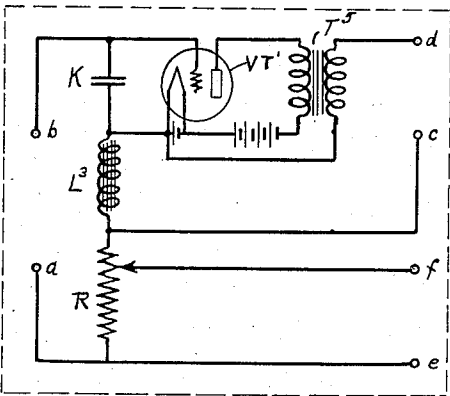


Fig. 12

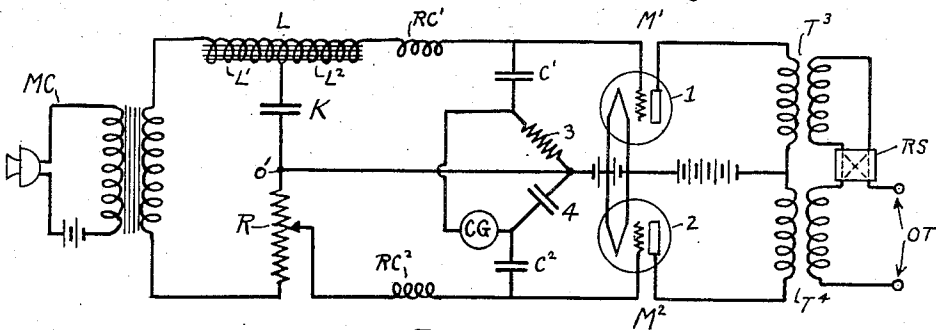


Fig. 13

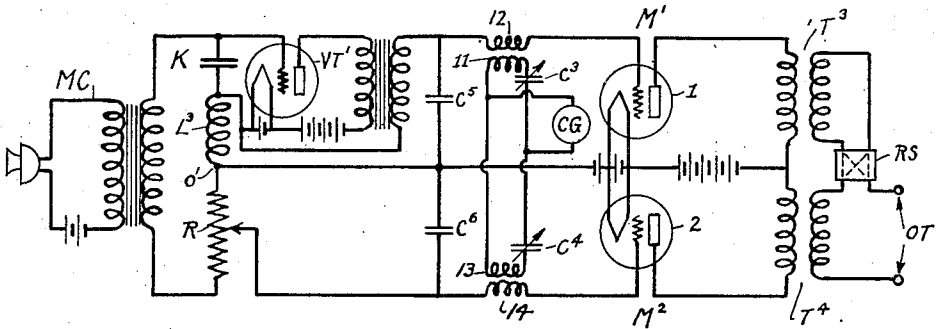


Fig. 14

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## UNITED STATES PATENT OFFICE

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## MODULATING SYSTEM AND METHOD

Application filed January 10, 1928. Serial No. 245,750.

My invention relates to modulating systems and methods and in particular to systems and methods in which the various components of the modulated wave may be segregated into separate circuits.

In radio transmitting systems, it is sometimes desirable to transmit certain components only of the modulated current; for example, it is common to transmit only one side-frequency or side-band and suppress or eliminate the other side-frequencies and the carrier. Heretofore, the undesired components were eliminated or suppressed by use of filters. Where the modulating current comprises a band of frequencies, the filters must be designed to pass the desired band and eliminate or suppress all frequencies above and below the band. For ideal operation the filter should have the same transmitting properties for the entire range of frequencies, that is, it should transmit all frequencies with the same relative degree of attenuation, and it should have sharp cut-off points.

It is difficult to design a filter to approach ideal conditions, and it is therefore an object of my invention to devise a modulating system in which the various components of the modulated current or wave are separated from each other without the use of filters.

It is an object of my invention to devise a modulating system in which the two side-frequencies or side-bands are separated into separate circuits by means other than filters.

A further object of my invention is to devise a modulating system in which either side-band may be selectively supplied to one and the same output circuit by a simple switching arrangement, and without the use of filters.

Another object of my invention is to devise a phase dividing circuit, that is, an arrangement for deriving currents of definite phase relations from a single-phase source.

I accomplish the objects of my invention by employing a duplex modulating system in which the two modulators are connected to a common output circuit and are supplied with signal and carrier currents from common sources but of such phase relations that the currents corresponding to one side-band from the two modulators have the same phase and

appear in the output circuit, while the currents of the other side-band or in phase opposition and do not appear in the output circuit.

My invention is illustrated in the accompanying drawings in which,

Fig. 1 shows one form of my invention for selectively eliminating either side-band;

Figs. 2 and 3 are vector diagrams illustrating the operation of Fig. 1;

Fig. 4 shows a second form of my invention in which the carrier wave is eliminated and the two side-bands are segregated into separate circuits;

Fig. 5 shows one form of phase divider for use in connection with Figs. 1 and 4;

Figs. 6, 7 and 8 are vector diagrams illustrating the operation of the phase divider shown in Fig. 5;

Fig. 9 shows the amplitude of the signalling currents produced by the phase divider over a range of frequencies;

Figs. 10, 11 and 12 show modified forms of phase dividers; and,

Figs. 13 and 14, show simplified forms of my invention.

Referring to Fig. 1, SG represents a suitable source of signal current, which may be a source of current having a single frequency or a source having a number of frequency components, such as a microphone circuit for the transmission of speech or music. The signalling currents are supplied to a phase-divider PD, the purpose of which is to divide the signalling current into currents of the same frequency but differing in phase. In other words, the divider serves to convert the signalling currents into currents of one phase impressed across the terminals  $c-d$ , and currents of a different phase impressed across terminals  $e-f$ . The arrangement is such that the two currents are displaced in phase by 90 degrees. Various arrangements may be employed for this purpose as will be seen hereinafter. Terminals  $c-d$  of phase divider PD are connected to the primary winding of a transformer  $T^1$  in the input circuit of a modulator  $M^1$ . Also, terminals  $e-f$  of the phase divider are connected to the primary winding of transformer  $T^2$  in the input

circuit of modulator  $M^2$ . Modulators  $M^1$  and  $M^2$  are of a well known type employing three-electrode vacuum tubes 1 and 2, respectively. Carrier current for both modulators are supplied from a common generator CG, but the carrier currents supplied to the two modulators are not of the same phase. The two carrier currents should be displaced in phase by 90 degrees, and for the purpose of securing such phase relation between the two carrier currents, a resistance 3 and a condenser 4 are connected in series across the carrier generator CG, carrier current for modulator  $M^1$  then being supplied across resistance 5 in the input circuit of the modulator by the voltage drop across resistance 3, and, for modulator  $M^2$ , across resistance 6 in the input circuit of the modulator by voltage drop across condenser 4. It is apparent that other arrangements may be employed to supply the carrier currents in proper phase relation. Modulators  $M^1$  and  $M^2$  are provided with output transformers  $T^1$  and  $T^2$ , the secondary windings 7 and 8 of which are connected in series across output terminals OT. A reversing switch RS is provided so the direction of connection of secondary winding 7 may be reversed, for a purpose which will appear hereinafter.

The operation of Fig. 1, is as follows:

The phase divider PD supplies signalling currents in phase quadrature to the modulators  $M^1$  and  $M^2$ . The carrier currents supplied to modulators  $M^1$  and  $M^2$  are also in phase quadrature as explained above. For the purpose of explanation, assume the signal to be a single frequency current represented by the equation  $B \sin. (pt + \theta)$ , the carrier current being represented by the equation  $A \sin. (qt + \alpha)$ . The currents in the output circuits of each modulator may be represented by

$$A \sin (qt + \alpha) + K \cos [(q-p)t + \alpha - \theta] - K' \cos [(q+p)t + \alpha + \theta] \quad (1)$$

The first term of this equation represents the unmodulated carrier component, the second term the lower side-frequency current, and the third term the upper side-frequency current.

For modulator  $M^1$  assume  $\alpha$  and  $\theta$  to be zero, then for modulator  $M^2$ ,  $\theta$  and  $\alpha$  must be either plus 90° or minus 90°, assume, for example plus 90°. With these values of  $\theta$  and  $\alpha$ , the equation for modulator  $M^1$  becomes

$$A \sin qt + K \cos (q-p)t - K' \cos (q+p)t \quad (2)$$

and for  $M^2$ ,

$$A \sin (qt + 90^\circ) + K \cos (q-p)t - K' \cos [(q+p)t + 180^\circ] \quad (3)$$

The currents represented by the equation for modulator  $M^1$  are indicated vectorially in Fig. 2, and the currents for modulator  $M^2$

are indicated vectorially in Fig. 3, that is, Figs. 2 and 3 represent the initial phase relations of the currents in the output circuits of modulators  $M^1$  and  $M^2$ , respectively.

In Figs. 2 and 3, C indicates the carrier current vector, S the signal current vector, LF the vector for the lower side-frequency current, and UF the vector for the upper side-frequency current. In Fig. 3, all the vectors have the same phase, but vectors LF and UF have been drawn on opposite sides of C in order to avoid confusion. While vectors C, S, LF and UF represent currents of different frequencies, and, therefore, their phase relations are constantly changing, nevertheless, vectors representing currents of the same frequency will maintain the relative phase relations indicated in Figs. 2 and 3.

From an inspection of Figs. 2 and 3, it will be seen that the lower side-frequency currents LF in the two modulators have the same phase relation and will add in the output circuit, while the upper side-frequency currents UF are opposite in phase in the two modulators and will cancel out in the common output circuit provided they are of the same amplitude. The unmodulated components of the carrier wave C are in phase quadrature and will add to produce a resultant current lagging behind the lower side-frequency current.

By reversing the connection of secondary winding 7 by means of reversing switch RS, the phase relations of the various currents will be such that the upper side-frequency currents will add together and appear at the terminals OT, while the lower side-frequency currents will oppose each other and will not appear across the output terminals. It is obvious that instead of reversing the direction of connection of winding 7, the same result may be obtained by reversing any winding or its direction of connection in any of the transformers. It is also obvious that instead of reversing a transformer winding in order to eliminate one side-frequency and obtain the other, either the signal current or the carrier current of one of the modulators may be reversed in phase; however, the two signalling currents, as well as the two carrier currents, must always be maintained in phase quadrature with each other. The signal current or the carrier current may be reversed in phase either by mechanical or by electrical means, such as by reversing switches in the supply leads, or by substituting, for example, an inductance for condenser 4. Instead of making the complete phase change by actual reversal of one current, effective reversal may be obtained by displacing both currents by complementary amounts, such as by exchanging the positions of resistance 3 and condenser 4.

In Fig. 4, I have shown a form of my invention in which the carrier as well as one side-band may be eliminated from the output

circuit. In this figure, elements serving the same function as corresponding elements in Fig. 1 are indicated by corresponding reference characters. In Fig. 4 the modulators  $M^1$  and  $M^2$  are of the well-known push-pull type employing vacuum tubes 1—1' and 2—2'. The carrier currents for the two modulators are supplied across resistances 5 and 6 connected, respectively, in the common branch of the input circuits of the two modulators. As is well understood, this arrangement does not permit the transmission of the unmodulated carrier current component to the output circuit.

The operation of Fig. 4 will be apparent from the above description of operation of Fig. 1. In Fig. 4, however, transformers  $T^3$  and  $T^4$  are supplied with additional secondary windings 9 and 10 respectively. Windings 7 and 8 are connected in series in the same direction across output terminals A—A', and windings 9 and 10 are connected in series in opposite directions across output terminals B—B'. From the operation of Fig. 1, it will be understood that for the particular phase relations given above, the lower side-frequency will be delivered at terminals A—A', and, due to the reverse connection of winding 9 with respect to 10, the upper side-frequency will be delivered at terminals B—B'. Thus, the two side-frequency currents are separated into separate circuits without the use of filters.

While the operation of my invention has been described for signal current of a single frequency, it is obvious that the only condition necessary for operation with signal current comprising a band of frequencies is that the currents supplied to the two modulators shall be in phase quadrature for each frequency component, and if the two modulators are identical, the two signalling currents should be substantially the same in amplitude.

One form of phase-divider which may be employed in Figs. 1 and 4 when the signalling source comprises a band of frequencies is shown in Fig. 5. In this arrangement an inductance coil L is connected between terminals b and d. A resistance R and a condenser K are connected in series between terminal a and the midpoint o of inductance coil L. Terminal a is connected by a direct connection to terminal e; terminal f is connected to a variable tap on resistance R; and terminal c is connected to a point between resistance R and condenser K. For the purpose of explaining the operation of the phase-divider the two halves of inductance coil L will be designated by  $L^1$  and  $L^2$  respectively. The two halves of the inductance coil L are as closely coupled as possible, and for this purpose it is desirable to employ an iron magnetic circuit with very small leakage.

The operation of arrangement shown in Fig. 5 is as follows:

Single-phase signalling currents are impressed across terminals a and b from a suitable source. Assume that the signal currents are currents of voice frequencies ranging from 500 to 1800 cycles per second. The values of coil L and condenser K are so chosen that the circuit across terminals a and b, including the left half  $L^1$  of coil L, condenser K and resistance R, is tuned to a frequency approximately at the middle of the frequency band to be transmitted, for example, 1000 cycles. At the resonant frequency the voltage drop across  $L^1$  will be equal and opposite to the voltage drop across condenser K, and the drop across resistance R will be equal to the voltage applied at terminals a—b. The voltage relations in the arrangement for currents of a frequency of 1000 cycles per second is indicated vectorially in Fig. 6. Vector E indicates the applied voltage, vector VR the drop across resistance R, vector VK the drop across condenser K, and vector  $VL^1$  the drop across the left half  $L^1$  of coil L. Due to the mutual induction between the two halves of coil L, the right half  $L^2$  of the coil will have induced therein a voltage substantially equal to the voltage drop across the left half of the coil. This voltage is indicated by vector  $VL^2$  in Fig. 6. The voltage appearing across terminals c—d will be the vector sum of the drops across condenser K and across the right half  $L^2$  of coil L. From Fig. 6, it will be seen that this voltage is indicated by vector Vcd, which is the sum of vectors VK and  $VL^2$ . Also, the voltage appearing between terminals e—f is indicated by the vector Vef. It will be seen that these two vectors are at right angles to each other and, therefore, the voltages across terminals c—d and e—f at 1000 cycles are in phase quadrature. The value of the voltage Vef may be controlled by adjusting the variable tap on resistance R.

The relations of the various voltages for currents having a frequency of 500 cycles per second are vectorially indicated in Fig. 7. From an inspection of this figure, it will be seen that while the voltage drop across condenser K has increased, the voltage drop across  $L^2$  has decreased, with the result that the voltage between terminals c—d remain substantially the same in value as for 1000 cycle current.

The phase relations of the voltages for 1800 cycle currents are indicated in Fig. 8. In this figure, it will be seen that while the drop across the condenser K is smaller than in Fig. 6, the drop across  $L^2$  is larger than in Fig. 6, and the resultant voltage between terminals c—d is substantially the same in magnitude as in Fig. 6.

It will be noted from Figs. 7 and 8 that the vectors Vcd and Vef are in phase quadrature

for frequencies both above and below the resonant frequency.

The values of voltages  $V_{cd}$  and  $V_{ef}$  for the entire range of frequencies are indicated by the curves in Fig. 9. These curves represent the operation of the arrangement in Figs. 5 for the following conditions:

The applied voltage across terminals  $a-b$  is assumed to be 10 volts for all frequencies, resistance  $R$  is 100 ohms, the reactance of condenser  $K$  is 25 ohms at 1000 cycles, and the reactance of  $L^1$  is also 25 ohms at 1000 cycles. Curves 1 and 2 of Fig. 9 represent respectively the voltages  $V_{cd}$  and  $V_{ef}$  for the various frequencies with the adjustable tap on resistance  $R$  adjusted to make the two voltages equal at 1000 cycles, that is, curves 1 and 2 represent the conditions when the adjustable tap includes half of resistance  $R$  between terminals  $e-f$ . In order to reduce the maximum relative change between the two voltages  $V_{cd}$  and  $V_{ef}$  over the entire frequency range, the adjustable tap may be moved to include a greater portion of resistance  $R$  between the terminals  $e-f$ . For example, when the tap is moved to include 55 ohms of resistance  $R$  between terminals  $e-f$ , the voltage relations are indicated by curves 1 and 3 in Fig. 9.

From an inspection of Figure 9 it is apparent that the phase divider circuit which I have devised produces two-phase currents in which the amplitudes of the different frequency components in each phase are substantially the same for the same applied voltage. In other words, amplitudes of the component frequency currents are substantially independent of frequency over the frequency band employed. The relatively high value of resistance  $R$  as compared with the resultant reactance of the two reactance elements renders the phase currents substantially independent of frequency. It is to be noted that the frequency band over which there is substantially no variation in amplitude with frequency has a frequency width at least of the order of the mean frequency of the band.

The elements comprising the phase divider shown in Fig. 5 may be re-arranged in a manner shown in Fig. 10. In both arrangements, the half  $L^2$  of coil  $L$  which is not included in the tuned circuit is connected in series with condenser  $K$  in a circuit between terminals  $c$  and  $d$ , and the voltage induced in  $L^2$  is in phase with the voltage drop across condenser  $K$ .

In order to prevent the impedance of external circuits connected across terminals  $c-d$  and  $e-f$  from disturbing the proper phase relations within the phase-divider, it is obvious that vacuum tube repeaters may be inserted in each circuit between the respective terminals and the circuits to be supplied.

Another form of phase-divider is shown in Fig. 11. A resonant circuit, including con-

denser  $K$ , inductance coil  $L^3$ , and resistance  $R$ , is connected across terminals  $a$  and  $b$ . The inductance  $L^3$  has the same relative value as one-half of coil  $L$  in Figs. 5 and 10, and at resonant frequency the drop across coil  $L^3$  is equal and opposite to the drop across  $K$ . The input circuit of a vacuum tube repeater  $VT^1$  is connected across condenser  $K$ , and the input circuit of a second vacuum tube repeater  $VT^2$  is connected across inductance  $L^3$ . These repeaters are provided with common energizing batteries as shown. The output circuits of the two repeaters  $VT^1$  and  $VT^2$  are provided with transformers  $T^5$  and  $T^6$  respectively, the secondary windings of these two transformers being connected in series between terminals  $c$  and  $d$ . In a like manner, the input circuit of a third repeater  $VT^3$  is connected across a variable portion of resistance  $R$ , and the output circuit of this repeater is connected across terminals  $e$  and  $f$  by means of a transformer  $T^7$ . The windings of transformers  $T^5$  and  $T^6$  are connected in such manner that the voltages delivered by the secondary windings in the output circuit are added together in the same phase.

The operation of the arrangement shown in Fig. 11 will be readily understood from the description of operation of Fig. 5 above. The resonant circuit is tuned to a frequency approximately at the center of the frequency band. Instead of using two separate transformers  $T^5$  and  $T^6$  in the output circuits of the repeaters  $VT^1$  and  $VT^2$ , a single transformer having a primary provided with a midpoint tap, may be employed. In other words, the two transformers  $T^5$  and  $T^6$  may be provided with a common magnetic circuit.

A simplified form of the phase-divider shown in Fig. 11 is illustrated in Fig. 12. In this arrangement the vacuum tube repeaters  $VT^2$  and  $VT^3$  with the corresponding transformers are dispensed with. The secondary winding of transformer  $T^5$  is connected between terminal  $d$  and the upper end of inductance  $L^3$ , and the lower end of inductance  $L^3$  is connected directly to terminal  $c$ . In this arrangement, vacuum tube repeater  $VT^1$  and transformer  $T^5$  serve to repeat (and to reverse the phase of) the voltage drop across condenser  $K$  and to add this drop to the drop across inductance  $L^3$  in the circuit between terminals  $c$  and  $d$ .

In connecting the arrangement shown in Fig. 11 to the modulators of Fig. 1 the connections may be made as shown in Fig. 1, or if desired transformers  $T^1$  and  $T^2$  may be omitted and the terminals  $c-d$  and  $e-f$  will then be connected directly to the input circuits of modulators  $M^1$  and  $M^2$ , respectively. Fig. 11 may be connected in the same manner to the arrangement shown in Fig. 4 by providing midpoint taps in the secondary circuits connected between terminals  $c-d$  and  $e-f$ . The vacuum tube repeaters in Fig. 11

serve to prevent the phase relations in the phase divider from being disturbed by the output circuits.

It will be seen that each arrangement of phase divider includes a tuned circuit having an inductive reactance and a capacity reactance, with means for developing a voltage proportional to the drop across one of the reactances and adding it to the voltage drop across the other reactance and in phase therewith.

In Fig. 13 I have shown a simplified form of my invention in which the two modulators are provided with common energizing batteries, and the modified phase dividing arrangement is connected directly to the input circuits of the modulators without the interposition of transformers. In this arrangement, MC represents a microphone circuit for supplying signalling current. The phase-divider comprises inductance coil L, condenser K and resistance R connected in a manner similar to that shown in Fig. 5. The free end of the right half of coil L is connected through a radio frequency choke coil RC<sup>1</sup> to the grid of modulator M<sup>1</sup>. The point o' between condenser K and resistance R is connected to the filaments of the modulators through a biasing battery for the usual purpose. The variable tap on resistance R is connected through a radio frequency choke coil RC<sup>2</sup> to the grid of modulator M<sup>2</sup>. The carrier generator CG has resistance 3 and condenser 4 in series across its terminals, and carrier current for modulator M<sup>1</sup> is supplied through condenser C<sup>1</sup> from the voltage drop across resistance 3. Carrier current for modulator M<sup>2</sup> is supplied through condenser C<sup>2</sup> by the voltage drop across condenser 4. Condensers C<sup>1</sup> and C<sup>2</sup> are of sufficient capacity to permit the passage of high frequency current, but small enough to offer very high impedance to the flow of signalling current. Transformers T<sup>3</sup> and T<sup>4</sup> and reversing switch RS are connected to output terminals OT in the same manner as shown in Fig. 1. The signalling current for modulator M<sup>2</sup> is supplied in this arrangement by the voltage drop in resistance R from the point o' to the variable contact on resistance. The operation of Fig. 13 will be apparent from the description of operation of Fig. 1.

Fig. 14 is a second simplified arrangement of my invention employing a modified form of the phase-divider shown in Fig. 12, and a modified arrangement for supplying the two modulators with carrier currents. The phase-divider shown in Fig. 14 is the same as that shown in Fig. 12, except that the signalling current for modulator M<sup>2</sup> is supplied from the voltage drop across resistance R from the point o' to the variable contact. This re-arrangement is made necessary in order to adapt the phase-divider to supply signalling currents to the modulators when

they are provided with common energizing batteries as shown. Carrier current is supplied to modulator M<sup>1</sup> from generator CG by inductively coupled coils 11 and 12, and a similar arrangement of coils 13 and 14 supply carrier current to modulator M<sup>2</sup>. Variable condensers C<sup>3</sup> and C<sup>4</sup> are provided in series with coils 11 and 13 respectively for the purpose of adjusting the phase of the respective carrier currents. Condensers C<sup>5</sup> and C<sup>6</sup> serve to by-pass the carrier currents around the signalling current source. These condensers are small and do not disturb the phase relations of the signalling currents. The remainder of Fig. 14 is the same as the arrangement shown in Fig. 13. The operation of Fig. 14 will be apparent from the description of operation of Fig. 1.

It is apparent from the foregoing description that my invention may be embodied in several different arrangements, and that the details may be varied in many ways without departing from the invention in its broadest aspect.

What I claim is:

1. In the art of wave modulation, the method of segregating the upper and lower side-bands into separate circuits which consists in, producing two carrier currents having quadrature phase relation, modulating one of said carrier currents by signalling currents, modulating the other carrier current by signalling currents in phase quadrature to the first mentioned signalling currents, and supplying modulated currents from both carrier currents to two output circuits having the two modulated currents supplied to one circuit reversed in relative phase with respect to the modulated currents supplied to the other circuit.

2. In a modulating system, a pair of modulators, means for supplying carrier currents to said modulators from a common source in quadrature phase relation, means for supplying signalling currents to said modulators from a common source but in quadrature phase relation, a pair of output circuits, and means for coupling each modulator to both output circuits with the two couplings in one circuit reversed in relative phase with respect to the couplings in the other circuit.

3. In a modulating system, a pair of modulators, means for supplying carrier currents to said modulators from a common source but in quadrature phase relation, means for supplying signalling currents to said modulators from a common source but in quadrature phase relation, a pair of output circuits, a pair of transformers for connecting the modulators to the output circuits each including two secondary windings, each output circuit including one secondary winding of each transformer with the two windings in one circuit relatively reversed with

respect to the two windings in the other circuit.

4. In a modulating system, a pair of carrier-suppression modulators, means for supplying carrier currents to said modulators in quadrature phase relation respectively, means for supplying signalling currents to said modulators in quadrature phase relation respectively, a pair of output circuits, transformers for supplying modulated currents from each modulator to both output circuits, said transformers being so connected that the two resultant modulated currents supplied to one circuit are reversed in relative phase relation with respect to the modulated currents supplied to the other circuit.

5. In a modulating system, a pair of carrier-suppression modulators, means for supplying carrier currents to said modulators in quadrature phase relation respectively, means for supplying signalling currents to said modulators in quadrature phase relation respectively, a pair of output circuits, a pair of transformers for connecting the modulators to the output circuits each including two secondary windings, and each output circuit including in series circuit one secondary winding of each transformer, the two windings in one circuit being relatively reversed with respect to the two windings in the other circuit.

6. In a modulating system, a pair of push-pull modulators, means for supplying carrier currents in quadrature phase relation to the common portions of the input circuits of said modulators respectively, means for supplying signalling currents in quadrature phase relation to the divided branches of the input circuits of said modulators respectively, an output transformer for each modulator, each including two secondary windings, an output circuit including in series circuit relation one secondary winding of each transformer, and a second output circuit including in series circuit relation the remaining secondary windings of said transformers, the two windings in one of said circuits being relatively reversed with respect to the windings in the other circuit.

7. In the art of wave modulation, the method of eliminating the carrier and segregating the side-bands into separate circuits which consists in, producing two carrier waves of the same frequency and equivalent phase relations, separately modulating the two carrier waves by signaling waves from a common source, combining the modulated waves from the two carrier waves with the unmodulated carrier components opposed to each other to produce resultant side-band waves without the carrier, producing two additional phase-equivalent carrier waves of the same frequency as the first mentioned carrier waves but having a resultant phase in quadrature to the resultant phase of the first

two carrier waves, separately modulating the last mentioned carrier waves by signaling waves from said common source but in phase quadrature to the modulating waves for the first mentioned carrier waves, combining the modulated waves from said last mentioned carrier waves with the unmodulated carrier components opposed to each other to produce a second resultant of side-band waves without the carrier, and supplying modulated waves from both resultants to two output circuits, having the waves supplied to one circuit reversed in relative phase with respect to the waves supplied to the other circuit.

8. In combination, two sources of modulated waves each containing upper and lower side-bands, two corresponding side-bands in said sources having the same frequency components of substantially equal amplitudes and the same phase relations, the remaining two side-bands having the same frequency components of substantially equal amplitudes and opposite phase relations, two work circuits, and means for coupling each source to each work circuit, the two coupling means for one circuit being relatively reversed with respect to the coupling means for the other circuit.

9. In combination, two sources of modulated waves each containing upper and lower side-bands derived from the same carrier and modulating waves, two corresponding side-bands in said sources being of the same phase and the remaining pair of side-bands being of opposite phase, two work circuits, means for coupling both sources to one of said work circuits in the same direction, and means for coupling both sources to said other work circuit with one of said sources coupled in reverse sense with respect to the other source.

10. In combination, two sources of complex waves containing component currents of the same frequency and same phase relation and containing other component currents of the same frequency but differing from said first frequency and of opposite relative phase relation, two work circuits, means for coupling both sources to one of said work circuits in the same direction, and means for coupling both sources to said other work circuit with one of said sources coupled in reverse sense with respect to the other source.

11. A phase dividing circuit comprising an input circuit including an inductive reactance, a capacity reactance, and a resistance in series, an output circuit including a portion of said resistance, means for developing a voltage proportional and opposite to the voltage across one of said reactances, and a second output circuit including said means and said other reactance.

12. Means for obtaining a reactive voltage of substantially constant amplitude for alternating currents having a range of frequencies comprising, a tuned circuit including an inductive reactance and a capacity reactance,

and means for developing a voltage proportional to the voltage drop across one reactance and adding said voltage to the drop across the other reactance and in phase therewith.

stantially equal amplitudes for the same applied voltage.

20. In combination, a circuit containing a source of current having a band of component frequencies, means for producing a voltage proportional to the current flowing in said circuit, and means for producing a voltage in quadrature phase relation to said first voltage and in which the component amplitudes are substantially the same for the same applied voltage for all frequencies in the band.

21. In combination, a circuit containing a source of current having a band of component frequencies, a resistance element connected in series with said circuit, and means connected in series to said resistance element for producing a voltage drop in quadrature to the voltage drop across said resistance and of substantially the same amplitude for the same applied voltage for all frequency components in said band.

22. In combination, a source of alternating current having a range of frequencies, means for deriving from said source a voltage substantially independent of frequency variations, means for deriving from said source a second voltage in quadrature to said first voltage and having an amplitude variable with frequency, means for deriving from said source a third voltage in phase with the second voltage and varying with frequency in substantially complementary relation to the variation of said second voltage, and means for combining said second and third voltages in an output circuit.

23. Means for obtaining a reactive voltage of substantially constant amplitude from alternating currents having a range of frequencies comprising, a circuit including an inductive reactance and a capacity reactance tuned to a frequency near the middle of said range of frequencies, and means for developing a voltage proportional to the voltage drop across one reactance and adding said voltage to the drop across the other reactance and in phase therewith.

24. Means for obtaining two-phase currents from a source of alternating current having a range of frequencies comprising an input circuit including an inductive reactance and a capacity reactance of equal values at a frequency near the middle of said range, a resistance in series with said input circuit having a value to render the current substantially independent of frequency over said range of frequencies, a phase output circuit tapped across at least a portion of said resistance, a second phase output circuit including one of said reactances, and means for developing a voltage proportional to the voltage drop across the other reactance and adding said voltage to the drop across the first reactance and in phase therewith in the second phase circuit.

25. A phase dividing circuit comprising an

13. In a phase dividing circuit a pair of input terminals and a pair of output terminals, an inductance coil between an input terminal and an output terminal, a condenser connected between an intermediate point on said coil and the second output terminal, a resistance connected in series with said condenser and the input terminals, a second pair of output terminals tapped across a portion of said resistance, the values of said inductance, capacity and resistance and the tapping points on said coil and resistance being adjustable in relation to each other to produce substantially constant and equal voltages across said pairs of terminals over a range of frequencies.

14. In combination, a source of speech frequency current containing frequency components essential to intelligible speech, and means comprising a static impedance network for deriving from said source substantially equal two-phase currents with the component currents in each phase of substantially equal amplitudes for the same applied voltage.

15. In combination, a source of current comprising a band of frequencies, means comprising a static impedance network for deriving from said source two-phase currents with the component currents in each phase of substantially equal amplitude for the same applied voltage for all frequencies in the band.

16. In combination, a source of current comprising a band of frequencies, and means comprising a static impedance network for deriving from said source, two-phase currents whose component amplitudes are substantially independent of frequency.

17. In combination, a source of speech frequency current containing frequency components essential to intelligible speech, and means comprising a static impedance network for deriving from said source two-phase currents with the component amplitudes in each phase substantially independent of frequency.

18. In combination, a source of current of variable frequency, and means comprising a static impedance network for deriving from said source two-phase currents having amplitudes substantially equal and substantially independent of frequency.

19. In combination, a source of current comprising a band of frequencies having a frequency width of the order of the mean frequency of said band, and means comprising a static impedance network for deriving from said source two-phase currents with the component currents in each phase of sub-

input circuit including an inductive reactance, a capacity reactance, and a resistance in series, a phase output circuit, a uni-directional relay having an input circuit including at least a portion of said resistance and an output circuit connected to said phase circuit, a second phase circuit, a uni-directional relay having an input circuit connected across one of said reactances, and a third uni-directional relay having an input circuit connected across the other reactance element, said second and third relays having their output circuits connected in series across said second phase circuit for supplying to said circuit in phase voltages proportional to the voltage drops across said reactance elements.

In testimony whereof I have hereunto signed my name.

RALPH B. STEWART.

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