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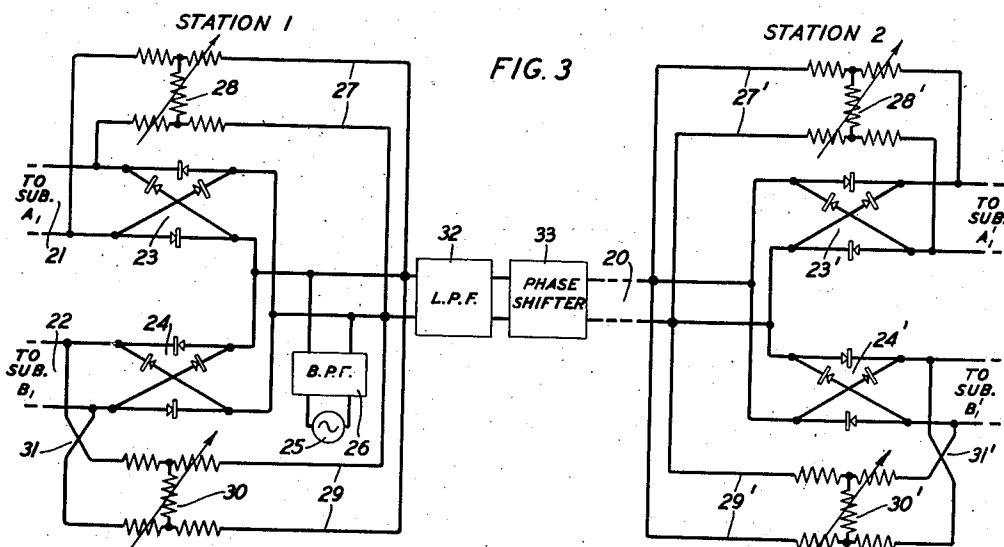
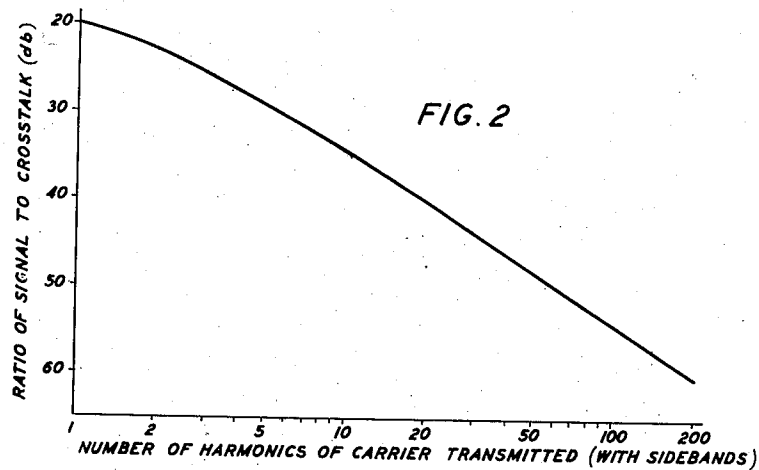
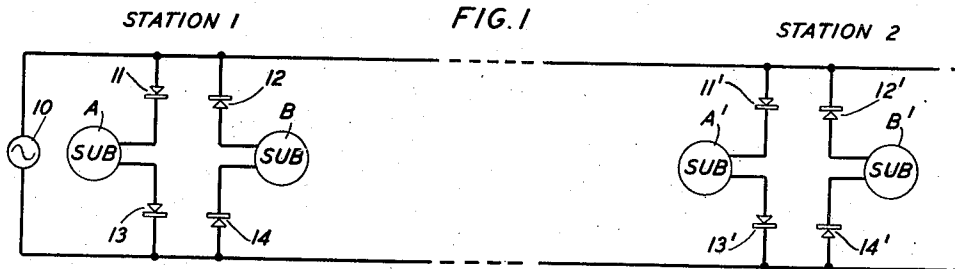
R. S. CARUTHERS

2,185,687

CARRIER SYSTEM WITH PHASE DISCRIMINATION

Filed Feb. 11, 1938

2 Sheets-Sheet 1



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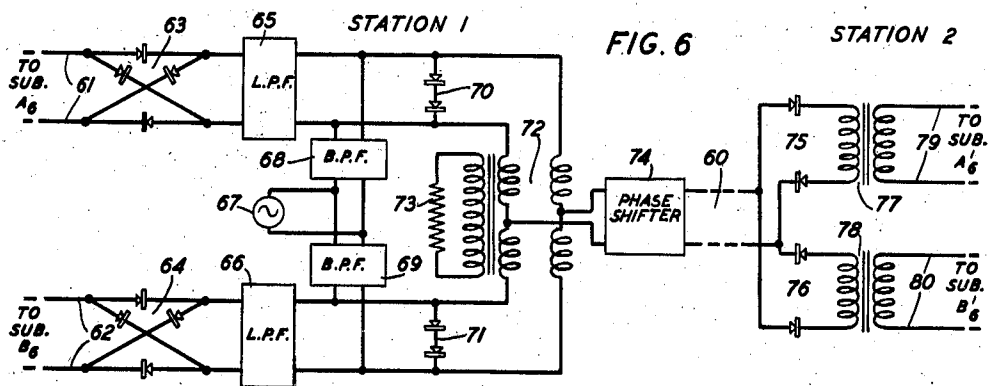
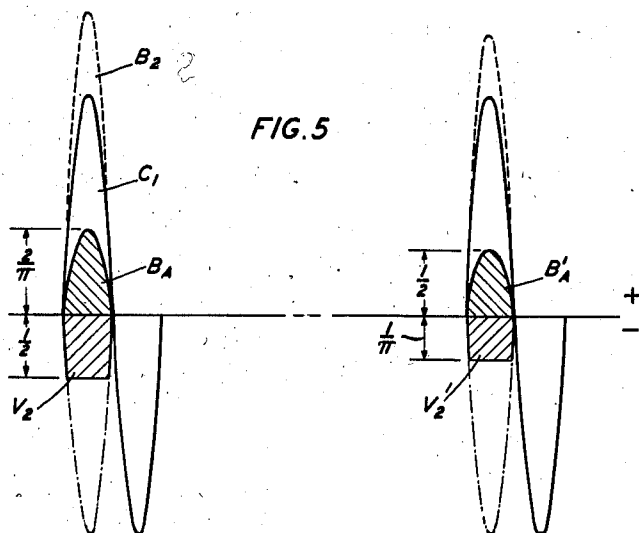
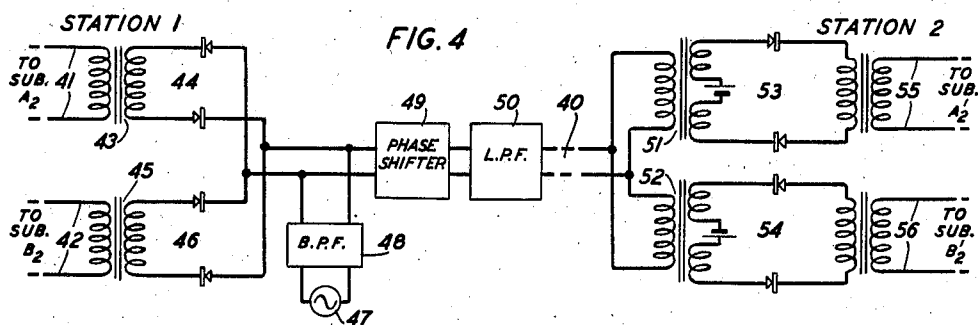
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CARRIER SYSTEM WITH PHASE DISCRIMINATION

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2 Sheets-Sheet 2



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UNITED STATES PATENT OFFICE

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CARRIER SYSTEM WITH PHASE
DISCRIMINATION

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9 Claims. (Cl. 179-15)

The present invention relates to carrier wave transmission and has for its object a simplification of the terminal apparatus required for selective transmission and reception of a plurality of messages over the same circuit.

In the types of multiplex carrier systems in commercial use at present, separation of the messages in the different channels is effected by use of frequency-selective circuits such as band filters or resonant circuits. One filter per channel is required at each terminal. The present invention relates to message wave separation on a different basis and specifically on the basis of the phase relations distinguishing the message waves in respective channels. The message waves in different channels need not in such a case occupy mutually exclusive ranges but can have the same frequencies. Differences in phase relations used to distinguish the different channels may be secured by producing a phase shift in the carrier as between one channel and another or by producing a phase shift in the message waves in order to distinguish channels, examples of both of which will be given in the description to follow.

It has been proposed heretofore to transmit one message on carrier half waves of one polarity and another message on the opposite half waves of the same carrier wave. In such case the separation of the messages at the receiver, even assuming a perfect line, has not been complete unless a very broad frequency band is used. Limiting the frequency band increases the cross-talk from one channel into the other. In such a system, therefore, the terminal apparatus, although simpler than the usual type employing frequency selective filters, was simplified at the expense of requiring a very wide frequency range in order to make possible the separation of the messages at the receiver.

In accordance with a feature of this invention, the apparatus at opposite ends of the line for respectively impressing messages on the line and deriving the messages therefrom, have cooperating characteristics such as to enable effective separation of messages at the receiver without the necessity of sending frequencies higher than those comprised in the upper side-band of the message-modulated carrier.

The further features and the various objects of the invention will be made clear in the following detailed description of illustrative embodiments as shown by way of example in the accompanying drawings.

In the drawings Fig. 1 represents a prior art

system and Figs. 3, 4 and 6 are schematic circuit diagrams showing typical ways in which the invention may be practiced, and Figs. 2 and 5 show curves to be referred to in the explanatory portions of the specifications.

In a system of the character described valves are used at the transmitting station to separate positive from negative half waves of the carrier and, similarly, valves are used at the receiver to admit to respective receiving branches the half waves of respectively opposite polarity. Each of the valves at the transmitter has associated with it a message input circuit so that the amplitude of the half waves which pass through each of the valves is varied in accordance with the respective message to be sent. At the receiver the valves admit the respective message-modulated waves of different polarity to the respective receiving branches, and the receivers in the respective branches respond to the message component.

Such a system is diagrammatically shown in Fig. 1 where at station 1 the source of carrier waves 10 is provided, together with two branches for the A and B subscriber sets or other message circuits. Set A is included in circuit with one-way devices or valves 11 and 13 in a branch across the line. Set B is similarly connected in a line branch including one-way devices or valves 12 and 14, poled oppositely to devices 11 and 13. Similar branches are indicated by primed numerals at station 2. Communication can take place in either direction over the line between A and A' and between B and B'.

It seems obvious from considering the system of Fig. 1 that complete separation of the messages at a receiving point is possible if none of the A message is on the line during the half cycles allotted to the B message and vice versa. What this means is that the currents used by the A message must be zero during the B message half periods and vice versa. The Fourier analysis shows that in order for this to happen it is necessary to transmit practically an infinite frequency band since it is necessary to have present a sufficient number of sine waves of harmonic frequencies to add up to the required wave shape comprising only half waves of the carrier modulated by message currents. The number of harmonics of the carrier wave together with side-bands of the harmonics, required to give certain degrees of separation of messages in the receiver expressed in decibels has been calculated and is shown by the plot in Fig. 2. It is found that in order to provide 60 decibel reduction in

cross-talk it would be necessary to transmit a band of frequencies about 200 times the carrier frequency. This contrasts strongly with systems using frequency discrimination as a basis of separation, in which the total band width need be no greater than the product of the speech band by the number of channels.

Referring again to Fig. 1, unless the practically infinite frequency range indicated by Fig. 2 is to be required, it must be permissible to have currents representing the A message flow during the half periods allotted to the B message and vice versa. In other words, it was the requirement that the current half waves of one message must fall to zero throughout the half periods of the other message that led to the condition of practically infinite frequency band. Narrowing the band width necessitates permitting current representing both messages to be on the line together.

Applicant has discovered that this can be done and that the messages can still be separated at a receiving point if the voice channel as well as the carrier side-band channels are used in certain ways presently to be described.

Still referring to Fig. 1, let it be supposed that the amplitude of the carrier wave is very large compared to the message waves so that the carrier is effective in opening and closing the valves at the respective stations while the message waves vary the carrier amplitude only, say, a few per cent. Let it also be supposed that the line has a cut-off frequency or has a low-pass filter in it so that the frequency band transmitted is limited to the top frequency of the upper side-band resulting from the message modulation of the carrier wave. Under these conditions the A message currents cannot be assumed to be zero throughout the B message half periods. When the carrier opens the B receiving branch, therefore, some of the message currents intended for the A subscriber are admitted and this results in producing cross-talk. Applicant has found that this cross-talk can be just canceled by an equal component of voice wave transmitted not through the carrier channel but in the voice channel in proper relation to the side-band waves. Thus, the speech currents sent through the voice channel augment the speech waves sent through the carrier channels in the receiving circuit branches for which the messages are intended and neutralize the messages sent through the carrier channels in the opposite receiving branch. This is due to the phase relations of the speech components received by carrier in the respective branches and the speech components directly received. In this way the voice channel of the line is used to assist in the separation of the carrier messages. Different ways of accomplishing this action will now be described.

Referring to Fig. 3, line 20 is shown connecting two two-way two-channel stations, station 1 and station 2. Station 1 has voice frequency terminal circuits 21 and 22 leading respectively to subscribers' stations A₁ and B₁ or other two-way message sets. A double balanced copper-oxide modulator 23 is connected in circuit 21 and a similar apparatus 24 is connected in circuit 22. These modulators may be of the type shown in my prior Patent 2,086,601, July 13, 1937. They suppress the input wave components and transmit only the modulated wave components. The carrier generator 25 is connected to the line through a band-pass filter 26 which excludes the

side-band and voice components from the generator circuit. Since the modulator-demodulator 23 does not pass the voice, a by-pass 27 is provided for impressing some of the original voice from set A₁ to the line, the amplitude being controlled by variable pad 28. A similar by-pass around modulator-demodulator 24 is provided at 29, with a cross-over for reversing the phase indicated at 31. Low-pass filter 32 is included in the line for limiting the frequency band transmitted and phase shifter 33 is used because the carrier source is only at one station and the phase shift of the line must be such as to produce proper phase relation between received side-band waves at station 1 and the beating carrier oscillations from source 25. The phase shifter 33 builds out the line to the proper phase shift value to insure efficient message reception at station 1. This function of the phase shifter is more fully disclosed in U. S. patent to R. W. Chesnut 1,983,537, 20 issued December 11, 1934.

The apparatus at station 2 is similar to that at station 1 except that no carrier source is provided and no additional line filter or phase shifter is needed. Corresponding elements to those of station 1 are indicated by the similar numbers primed.

The operation of the system of Fig. 3 will now be described. It will be assumed at first that both side-bands of the modulated wave are sent and that line filter 32 passes frequencies from zero up to the highest frequency of the upper side-band. Speech waves from both sub-stations A₁ and B₁ modulate the same carrier wave from source 25 in modulators 23 and 24, respectively. The voice waves do not pass directly through these modulators but do pass through respective circuits 27 and 29 to the line. The line currents comprise: voice waves from sub-sets A₁ and B₁ with the voice from sub-set B₁ in reversed phase, unmodulated carrier waves from source 25 in relatively large amount, and upper and lower side-band waves representing modulation of the carrier by the voice from both sub-sets A₁ and B₁. All of these waves are impressed on the circuits at station 2.

Considering first the waves that reach sub-set A₁, these comprise the detected side-band components from 23' and the directly received voice components that traverse the by-pass circuit 27'. It is assumed that as to the waves from A₁ the demodulated side-band components and directly transmitted voice components are in aiding phase relation whereas those from sub-set B₁ are, due to the cross-over at 31, in phase opposition. By proper control of pads 28, 30 and 28' the strength of these various components may be controlled to reduce the cross-talk the required amount. The reception of waves by sub-set B₁ is in the same manner, the direct voice from A₁ undergoing a phase reversal at 31' while that from B₁ undergoes two reversals, at 31 and 31'.

Direct transmission between subscriber A₁ and subscriber B₁ is prevented by the fact that any transmission through the two modulators 23 and 24 is neutralized by the transmission through the voice circuits 27 and 29. By virtue of the cross-over at 31 the currents transmitted through the two paths cancel each other.

If only the lower side-bands of the modulated waves are utilized, filter 32 has a cut-off just above the carrier frequency. In this case the pads 28, 30 and 28', 30', must be readjusted to transmit only about half as much direct voice as

formerly since the strength of the detected side-band waves is only half what it was in the case of double side-band transmission.

Fig. 4 illustrates another type of system, according to the invention, capable of supplying the right amount of direct voice component at a receiving point to neutralize the cross-talk from the opposite talker. In this figure the line 40 terminates at station 1 in two line or channel branches 41 and 42 leading to respective subscribers' stations or other message circuits A₂ and B₂. Channel branch 41 includes repeating coil 43 and a pair of linear rectifiers 44 such as diodes or copper-oxide rectifiers having the characteristic of infinite impedance for impressed negative voltages and finite linear impedance for impressed positive voltages. Channel branch 42 has a similar repeating coil 45 and linear rectifiers 46 oppositely poled in relation to rectifiers 44. The source of carrier waves is at 47 and is connected to line 40 through narrow band-pass filter 48. Phase shifter 49 and low-pass filter 50 serve, in general, the same purposes as described in connection with Fig. 3. Filter 50 passes both side-bands of the carrier modulated wave but suppresses harmonics of the carrier.

At station 2 the line 40 leads to circuit branches including repeating coils 51 and 52 capable of transmitting voice and carrier frequencies. These repeating coils are associated with modulators 53 and 54 comprising suitably biased diodes or copper-oxide rectifiers or similar devices having the characteristic of infinite impedance for negative polarity of impressed wave and finite impedance for positive polarity of impressed wave, such that the current varies as some power of the voltage, for example as the square of the voltage. Modulators 53 and 54 are oppositely poled and biased by the batteries shown. On the drop side of these modulators are voice circuit branches 55 and 56 leading to subscribers' stations or other message terminals A₂' and B₂'.

The operation of the system of Fig. 4 and the manner in which the unwanted voice component is canceled out in the receiver will be more clearly understood by the aid of some mathematical formulae.

It is known that when voice is impressed on a linear rectifier together with a large amplitude carrier wave which in effect opens and closes the valve, the transmitted wave is the product of the voice wave by a function which has the value +1 during the positive half cycle of the carrier and the value zero during the negative half cycles of the carrier, this function being:

$$\frac{1}{2} + \frac{2}{\pi} \left(\cos c - \frac{1}{3} \cos 3c + \frac{1}{5} \cos 5c + \dots \right) \quad (1)$$

where $C \cos c$ is the carrier. Assuming the voice wave in circuit branch 41 to be $A \cos a$ and that in branch 42 to be $B \cos b$, the two carrier-modulated waves transmitted from station 1 are

$$A \cos a \left[\frac{1}{2} + \frac{2}{\pi} \left(\cos c - \frac{1}{3} \cos 3c + \dots \right) \right] \quad (2)$$

and

$$B \cos b \left[\frac{1}{2} - \frac{2}{\pi} \left(\cos c - \frac{1}{3} \cos 3c + \dots \right) \right] \quad (3)$$

When these two waves are received at station 2 they are again multiplied by the Function 1, with proper sign, in the modulators 53 and 54 and they are also multiplied by $C \cos c$ in view of the fact that these modulators are square law devices. The effects of multiplying Expressions

2 and 3 by $C \cos c$ are respectively 4 and 5 as follows:

$$AC \cos a \left[\frac{1}{\pi} + \frac{1}{2} \cos c + \dots \right] \quad (4)$$

$$BC \cos b \left[-\frac{1}{\pi} + \frac{1}{2} \cos c + \dots \right] \quad (5)$$

The effect of admitting these waves to the receivers only in respective half periods of the carrier is found by multiplying them by Function 1 with the proper sign, as above stated, giving, for branch 55, Expressions 4 and 5 multiplied by

$$\left[\frac{1}{2} + \frac{2}{\pi} \cos c \right] \quad (6)$$

or, for the audible components,

$$AC \left[\frac{1}{2\pi} + \frac{1}{2\pi} \right] \cos a + BC \left[-\frac{1}{2\pi} + \frac{1}{2\pi} \right] \cos b \quad (6)$$

For branch 56 these same two expressions are multiplied by

$$\left[\frac{1}{2} - \frac{2}{\pi} \cos c \right]$$

and give the audible components

$$BC \left[-\frac{1}{2\pi} - \frac{1}{2\pi} \right] \cos b + AC \left[\frac{1}{2\pi} - \frac{1}{2\pi} \right] \cos a \quad (7)$$

The direct voice component transmitted over the line from sub-set B₂ has its maximum amplitude related to that of the sum of the two side-band components in the proportion of

$$\frac{1}{2} \text{ to } \frac{2}{\pi}$$

If these were impressed on the receiving branch leading to the A₂' receiver and if this branch had linear rectifiers instead of square law devices, they would only partially cancel each other for they would emerge in the proportion of

$$\frac{1}{4} \text{ and } \frac{2}{\pi^2}$$

leaving a considerable amount of cross-talk. But when these two components of the B₂ channel voice are impressed on the square law devices 53, their values are changed, according to Expression 5, to be in the proportion of

$$-\frac{1}{\pi} \text{ to } \frac{1}{2}$$

which when multiplied by the Function 1 emerge in the proportion of

$$-\frac{1}{2\pi} \text{ and } +\frac{1}{2\pi}$$

as seen from 6.

This effect is illustrated graphically in Fig. 5 where the portion of the sine wave C₁ indicates one cycle only of the carrier wave the positive half of which is extended in dotted lines to indicate the instant of maximum modulation by speech from B₂. It is assumed that the positive half of the carrier wave is the half that is admitted to circuit A₂' by rectifiers 53. The A₂ signal modulation is not shown. Subtraction of the carrier lobe from the total dotted extension gives, for greater convenience of comparison, the half wave B_A of maximum amplitude.

in arbitrary constants. This may be taken as the energy content of that fragment of the speech from B₂ which is comprised in both side-bands of the modulated wave from linear rectifier 46 but confined to one-half period of the carrier for

illustrative purposes. This component is represented in Expression 3 by the term

$$\frac{2}{\pi} B \cos b \cdot \cos c$$

Expression 3 shows that there is a direct voice component (represented by the term $\frac{1}{2} B \cos b$), which is illustrated as V_2 in Fig. 5, this being the fragment of the direct speech that is admitted to receiving circuit A_2' during the positive half cycle of the carrier C_1 . V_2 is shown with opposite sign to B_A . If circuit 53 were a linear rectifier similar to rectifier 46, the impulses B_A and V_2 would simply be multiplied by the Function 1 and would not cancel each other in the process. However, circuit 53 multiplies these components by $\cos c$ as well as by Function 1. Multiplying by $\cos c$ converts the impulses B_A and V_2 , respectively, to B_A' and V_2' (Fig. 5) with maximum amplitudes of

$$\frac{1}{2} \text{ and } -\frac{1}{\pi}$$

respectively, which when multiplied by Function 1 cancel each other, the areas covered by these impulse diagrams B_A' and V_2' being equal.

In converse manner the direct speech from branch A_2 (corresponding to impulse V_2) would be drawn above the zero line in Fig. 5 because it is in a direction to augment the speech component of the side-bands (see Expression 6).

Speech directly transmitted from sub-set A_2 to receiving branch associated with sub-set B_2' cancels out the speech arriving from set A_2 in the form of the carrier side-bands, when received by square law demodulator 54.

Transmission from station 2 to station 1 takes place in analogous manner to that occurring in the opposite direction. The waves impressed on line 40 from modulators 53 and 54 include side-band components and direct speech components in the ratio of

$$\frac{1}{2} \text{ and } \frac{1}{\pi}$$

respectively for maximum amplitudes, and have the form indicated by Expressions 4 and 5. The components that would give rise to cross-talk have the form shown at V_2' and B_A' in Fig. 5 at their arrival at station 1. The received components are multiplied in respective rectifiers 44 and 46 by

$$\left[\frac{1}{2} + \frac{2}{\pi} \cos c \right]$$

and

$$\left[\frac{1}{2} - \frac{2}{\pi} \cos c \right]$$

causing the wanted components to add and the cross-talk components to cancel as indicated in Expressions 6 and 7.

It is seen, therefore, that a high degree of cross-talk suppression is obtained without having to transmit an infinite frequency band, if a linear rectifier is used at one station (either station) and a square law or some other type of pure product modulator is used at the opposite station, on the assumption of large carrier amplitude.

In Fig. 6, line 60 terminates at station 1 in line branches leading from respective message sets 61 and 62 and at station 2 in branches leading to message sets 79 and 80. A source of carrier waves 67 is provided only at station 1. This source is connected to the line branches through narrow band-pass filters 68 and 69. Double bal-

anced modulators 63 and 64 are connected respectively through low-pass filters 65 and 66 to opposite ends of hybrid coil 72 which has line terminals for line 60 and a line balance impedance at 73. One-way devices 70 and 71 are directly connected across the line branches. The phase shifter 74 is for the same purpose as in Figs. 3 and 4. At station 2 one-way devices 75 and 76 are provided in respective line branches and respectively oppositely poled. They are connected to the message sets 79 and 80 by means of repeating coils 77 and 78. The one-way devices 70, 71, 75 and 76 may be diodes or dry-plate rectifiers as in the previous figures. Similar elements may be used in the modulators 63 and 64.

Since modulators 63 and 64 are double balanced, message waves are not directly transmitted through them but only the side-band components appear at their outputs. These are passed through filters 65 and 66 which suppress higher frequencies. Considering the side-bands coming from filter 65, these are rectified in linear rectifier 70 which preferably has infinite impedance for waves of one polarity and linear finite impedance for waves of the opposite polarity. This rectifier therefore short-circuits the line for the half waves of one polarity but allows the opposite half waves to be transmitted. Rectifier 71 acts similarly on the side-bands from filter 66 except that it allows transmission of the half waves of opposite sign to those transmitted from the other channel.

The action of these rectifiers is to supply to the line 60 side-band and voice frequency components from each transmitter, the voice components resulting from the rectifications at 70 and 71.

On the assumption of large carrier amplitude so that the modulation is always less than one hundred per cent, the transmission from this point on and reception at station 2 is similar to that of Fig. 4.

In Fig. 6 all modulators can be linear rectifiers in view of the fact that three of these devices are traversed in tandem, as will appear.

Thus, in Fig. 6 the side-band components, direct voice currents and large amplitude carrier arrive at station 2. The wanted side-bands and speech cooperate as in Fig. 4 to reinforce each other in one channel and cancel each other in the other. Sub-set 79 receives the message from 61 substantially free of cross-talk and sub-set 80 similarly hears talker at 62 without cross-talk interference.

Transmission from station 2 to station 1 takes place in the following manner. The message sent from sub-set A_2' to the line is

$$A' \cos a' \left[\frac{1}{2} + \frac{2}{\pi} \left(\cos c - \frac{1}{3} \cos 3c + \dots \right) \right]$$

It is assumed that the voice component and side-band components about the fundamental of the carrier arrive at rectifiers 70 and 71 unaltered in relative phase and amplitude. The higher harmonic side-bands are unimportant as they will eventually be suppressed by the low-pass filter 65 or 66. The message wave arriving at 71 is multiplied by

$$\frac{1}{2} - \frac{2}{\pi} \left(\cos c - \frac{1}{3} \cos 3c + \dots \right)$$

producing the signal wave

$$A' \cos a' \left[\frac{1}{\pi} \cos c - \frac{1}{\pi} \cos c \right] + \text{voice}$$

and higher harmonic side-bands. Inasmuch as

the side-band components cancel, no voice is produced by the double balanced demodulator 64 into sub-set B_s. Multiplication of the assumed arriving signal wave at rectifier 70 by

$$\frac{1}{2} + \frac{2}{\pi} \left(\cos c - \frac{1}{3} \cos 3c + \dots \right)$$

causes the side-band components to add and produce the desired voice signal in sub-set A_s.

The circuits that have been shown for illustration are to be considered as typical rather than as limiting, the scope of the invention being defined by the claims.

What is claimed is:

1. The method of multiplex carrier wave transmission comprising sending a plurality of message modulated carrier waves and simultaneously sending the message current waves to a distance, there impressing the sent waves on each of a plurality of receiving circuits, and producing in the various waves such phase relations that each message modulated wave and the message current wave representing the same message augment each other in one only of said receiving circuits while neutralizing each other's effects in other than said one receiving circuit.

2. In the selective reception of messages, the method comprising utilizing a voice frequency component to augment the detected component of a voice modulated carrier wave in one receiver circuit and causing said voice frequency component to neutralize the detected component of said voice modulated carrier wave in a receiving circuit intended for a different message.

3. The method of selective transmission of messages comprising sending each message simultaneously through a common carrier channel and through a common message channel, utilizing the phase relations between the message currents representing the same message received from the two channels to reinforce each other in producing message currents in one receiver and utilizing the phase relations between the message currents representing another message received from the two channels to neutralize each other in said receiver.

4. In a multiplex transmission system, means to modulate the same carrier wave separately by a plurality of message currents and to transmit the modulated currents to a distance, means to transmit simultaneously the corresponding message currents, a plurality of receiving circuits, and means in each receiving circuit to receive a message component of the modulated wave and the corresponding message current in aiding relation and the corresponding components representing another message in neutralizing relation.

5. In a multiplex transmission system, a source of message wave components, means to modulate a carrier wave by the message wave components, to produce side-band components, means to send both the side-band components and the message wave components over the system, one receiver cumulatively responsive to the two components

so sent representing one message and differentially responsive to other components so sent representing another message, and a second receiver cumulatively responsive to the two components so sent representing said other message and differentially responsive to the two components representing said one message, the components differentially received neutralizing each other in each case.

6. In a signaling system, means at a sending station to separately modulate a carrier wave by two speech messages simultaneously, means to transmit side-band components representing both such modulations, and means to send along with the side-band components the speech message wave components representing the two speech messages, means for separately receiving the two speech messages comprising two receiving circuits, each producing additive effects from the components of one message transmitted as side-band components and as speech components and each causing the speech components and side-band components representing the other message to cancel each other.

7. In a multiplex signaling system, a source of carrier waves, a pair of paths containing one-way devices at one station for controlling the opposite half waves of the carrier in accordance with two different messages to be sent, a pair of paths at the other station containing one-way devices for separating the currents representing the respective messages, and receivers associated with the respective last-mentioned paths, the devices at one station being linear rectifiers and those at the other station having substantially pure product modulator characteristics throughout their transmitting regions whereby cross-talk in said system is reduced.

8. In a multiplex signaling system, a source of carrier waves, means at one station to modulate half waves of the carrier by one message, means thereat to modulate the opposite half waves of the carrier by another message, and at a different station, means to detect the said messages received from the first station, the said means at one of said two stations being square law rectifiers and the said means at the other of said stations being linear rectifiers whereby cross-talk in said system is reduced.

9. The method of selective transmission and reception of messages comprising sending each message simultaneously through a common carrier channel and through a common message channel, utilizing the phase relations between the message currents representing the same message received from the two channels to reinforce each other in producing message currents in one receiver and producing such phase relations between the message currents representing said message received from the two channels in another receiver that said currents representing said message neutralize each other in said other receiver.

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