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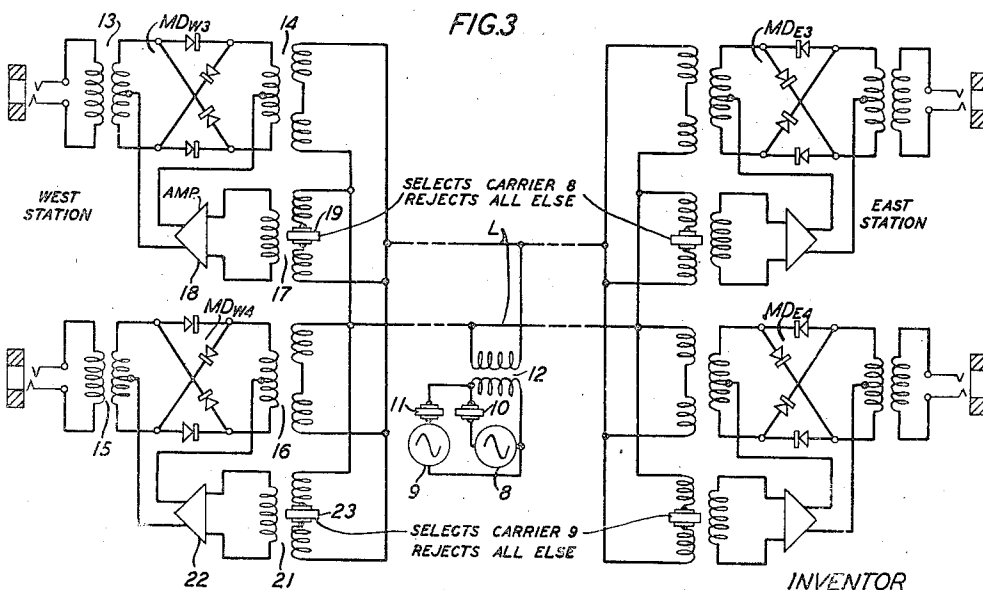
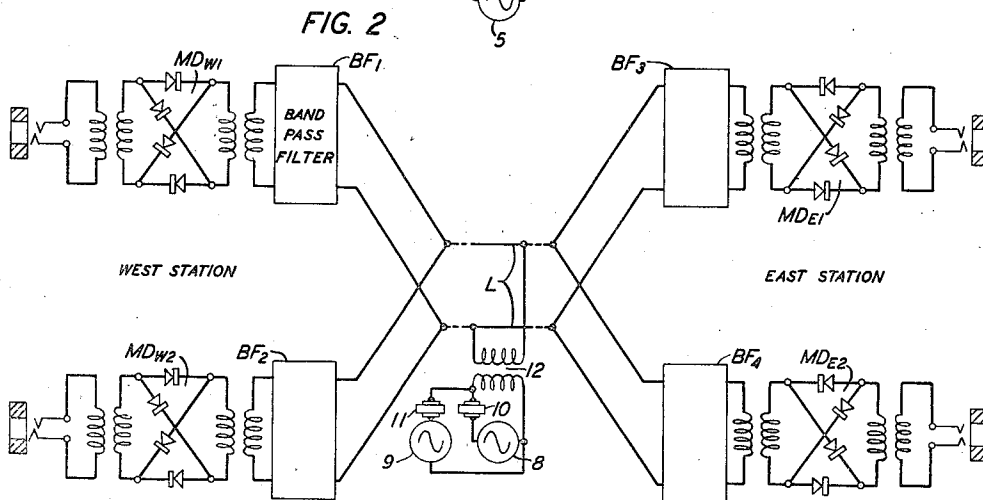
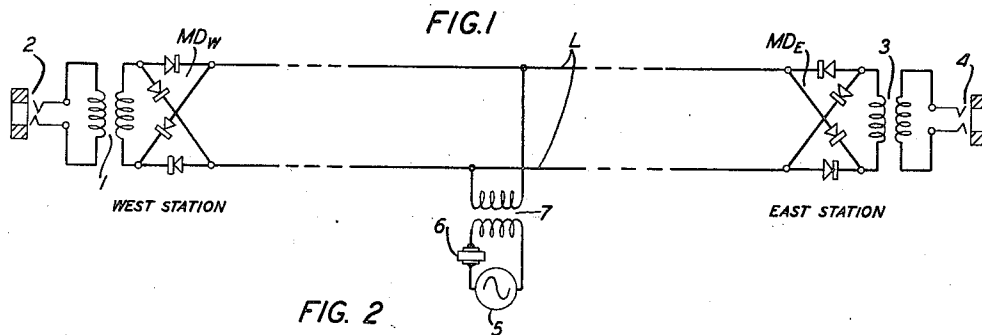
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2,337,878

CARRIER WAVE SIGNALING SYSTEM

Filed May 13, 1942

4 Sheets-Sheet 1



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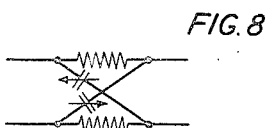
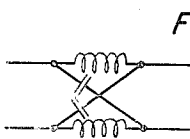
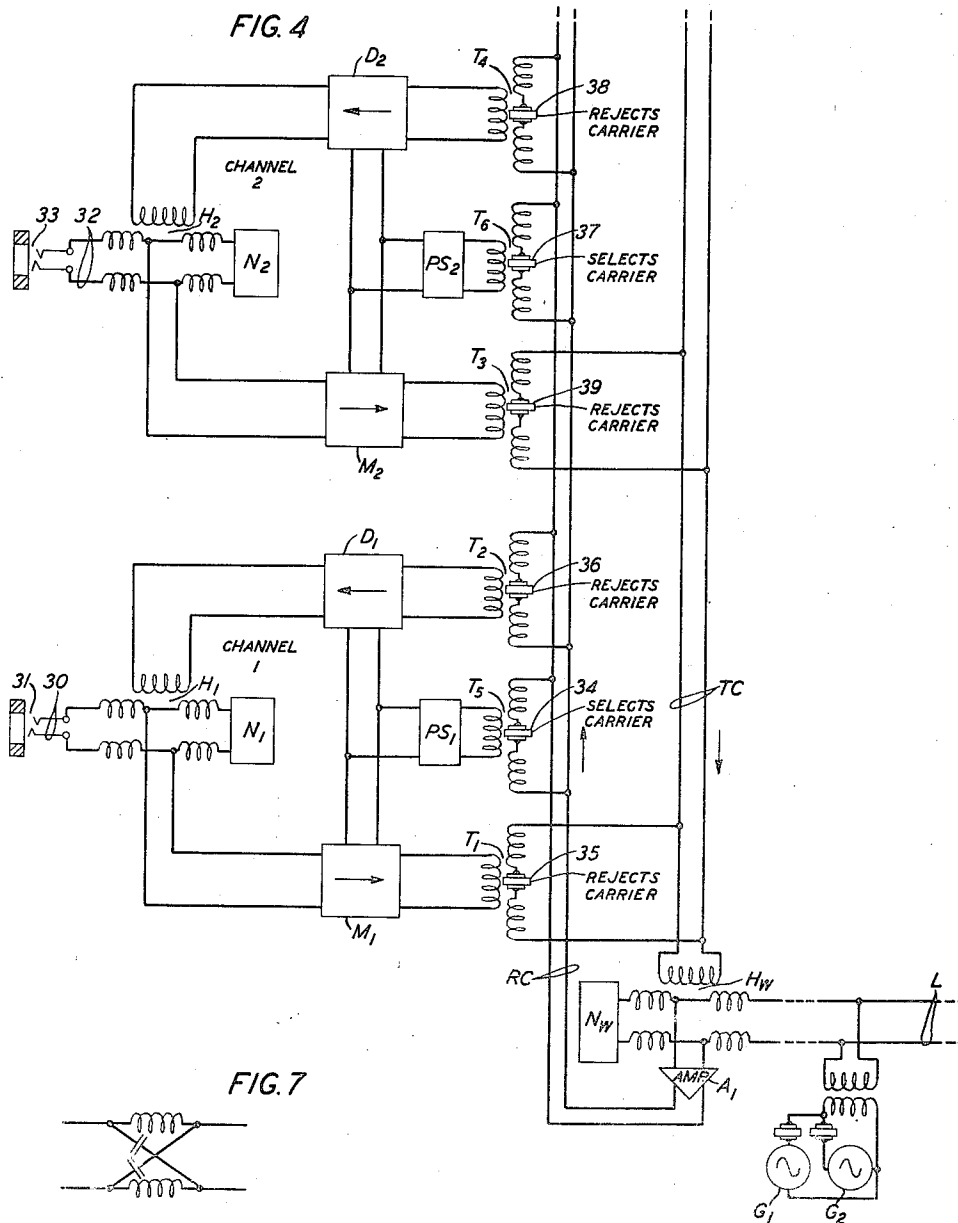
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CARRIER WAVE SIGNALING SYSTEM

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4 Sheets-Sheet 2



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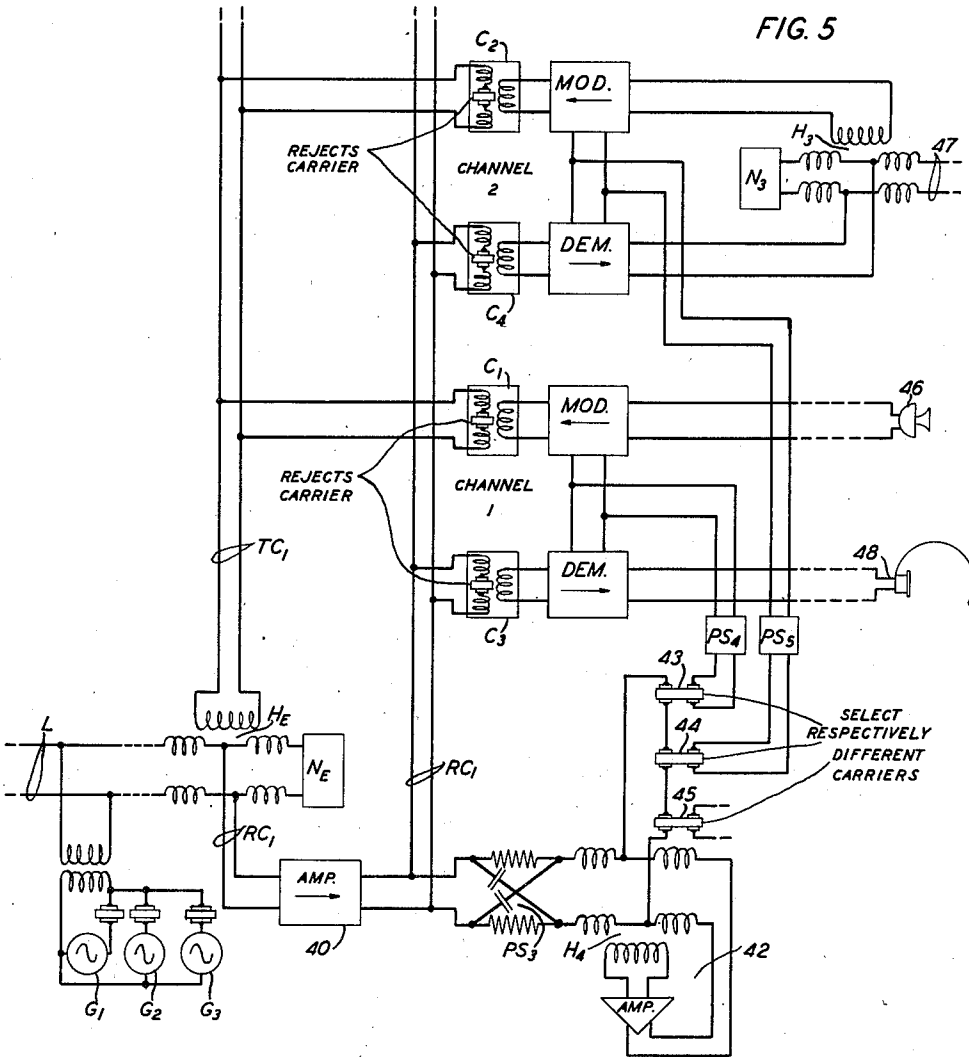
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CARRIER WAVE SIGNALING SYSTEM

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4 Sheets-Sheet 3



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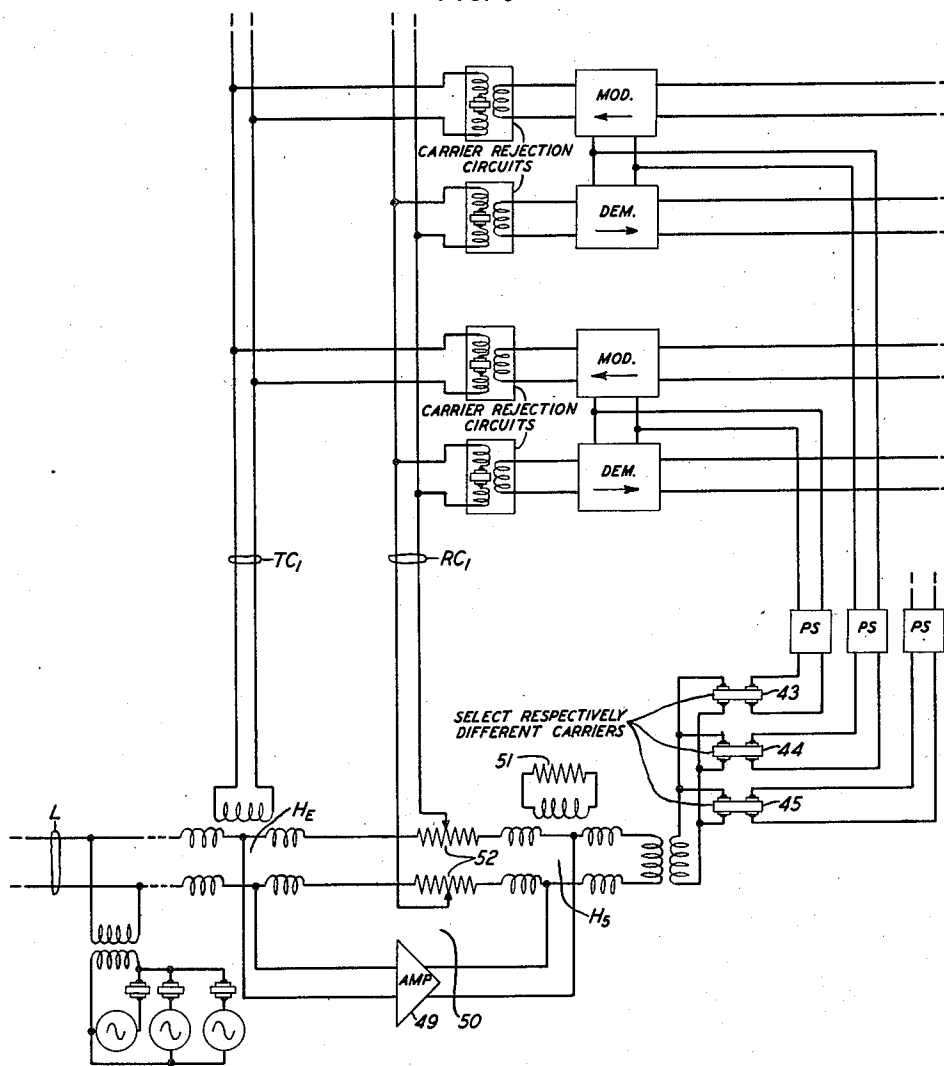
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CARRIER WAVE SIGNALING SYSTEM

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FIG. 6



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UNITED STATES PATENT OFFICE

2,337,878

CARRIER WAVE SIGNALING SYSTEM

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Application May 13, 1942, Serial No. 442,870

16 Claims. (Cl. 179-15)

The invention relates to carrier wave signaling systems particularly those transmitting over wire guides.

Because of the relatively high cost of frequency range in carrier telephone transmission over long distances, it has been the practice to crowd the carrier channels closely together in the frequency spectrum requiring the use of complex and expensive terminal equipment including expensive filters for separating carrier channels. The realization of simpler and cheaper terminal equipment has long been sought for the purpose of "proving in" carrier operation over shorter distances of the order of ten miles or even less, but has not generally been obtained.

However, attenuation is no longer a serious limiting factor in transmitting at high frequencies because of the great advance in the technique of amplification, and this is the more so the shorter the distance of transmission. By means of high frequency amplifiers and of improved line wires, better balanced and better shielded, it is becoming possible to realize generally in the telephone plant transmission frequency bands some hundreds of kilocycles wide, and for short distances, in the local telephone plant, frequency bands of the order of a megacycle may become generally available.

An object of the invention is to make use of these factors to reduce the cost of carrier signal transmission, particularly for short distances.

A related object is to simplify and cheapen the cost of the terminal equipment in carrier signaling systems without appreciably reducing the quality of transmission.

These objects are attained in accordance with the invention by the use of wider channel spacing and higher carrier frequencies than heretofore used, and by employing instead of the usual channel band filters for segregating the individual carrier channels at the terminals, simple and inexpensive sharply tuned circuits, such as piezoelectric quartz crystals, directed at selecting the carriers only as distinct from the channel band filters which select side-bands. In accordance with the invention the side-bands are left free to pass between the channel terminals and the high frequency carrier line without the intermediary of band filters, and by making use of certain balanced types of modulators and demodulators and employing carriers of sufficient amplitude with respect to the side-bands to make predominant the products resulting from the intermodulation of any one carrier with its side-bands, as compared with second order effects, such as

the intermodulation between side-bands of different channels, interchannel crosstalk is effectively overcome.

Heretofore, discrimination by such means has been considered to be impossible on the ground that extremely sharp tuning would not accommodate the relatively wide side-bands of carrier telephony. It is a part of the conception of the present invention that the accommodation of the two side-bands or of a single side-band within the selective circuit is unnecessary if the selection is suitably directed at the single frequency carrier itself.

In general, there may be said to be two types of high-frequency selecting and detecting circuits in common use. One used in ordinary radio broadcast reception in which both the carrier and the side-bands are present, to select one channel to the exclusion of others, is required to have a sufficiently wide transmission frequency range to pass both the carrier and one or both of the side-bands, and yet to be sufficiently sharp as to the cut-off to prevent interchannel interference. The other type of high-frequency selecting circuit is the one which is commonly used in long distance wire carrier current telephony usually to suppress the carrier and one side-band, and wherein the transmitted channel-bands are packed relatively closely together in the frequency spectrum. It is the practice to select the individual channels of such transmission by means of band filters the cut-offs of which coincide closely with the limits of the transmitted side-band and which because of their complexity and the nicety of requirements are quite expensive and account for a large proportion of the cost of a carrier telephone terminal.

But in all high-frequency transmission systems the thing which determines the position of a given channel in the frequency spectrum is the carrier itself, whether actually transmitted or not; and in accordance with the present invention the channel-selecting action is built around the carriers themselves, in fact is limited to the frequency selection of the carriers alone, leaving the side-bands free access as between the individual channel terminals and the high-frequency line without the intervention of band filters. One thing that makes this result possible is the appearance in the art of selecting elements so sharp in their frequency discrimination as to enable carriers to be selected and separated from their side-bands without making inroads upon the side-bands. Reference is made particularly to the electromechanical oscillators of the piezo-

electric crystal or electrostriction type, in which extremely high Q 's, ratios of reactance to resistance, are realized. Another thing which makes this result possible is the appearance in the art of balanced types of variable resistance modulators and demodulators wherein, by properly introducing the carrier, separated from the side-bands and of large amplitude, it is possible to have the modulator and demodulator unit, although composed of non-linear elements, present to the signaling path a linear voltage-current relation such that intermodulation between two or more components entering it from either the low-frequency or high-frequency line does not take place. Thus spurious modulation or demodulation is avoided and each modulating and demodulating action is carried out selectively and definitively with respect to its own carrier, and in effect with no other, as observed in the low-frequency signaling terminal, and this result is obtained without the employment of complicated and expensive band filters individual to each high-frequency channel.

The various features of the invention will be better understood from the following detailed description when read in conjunction with the accompanying drawings, in which:

Fig. 1 shows schematically one modification of the invention applied to a single channel carrier telephone system;

Fig. 2 shows schematically two single channel systems of the type shown in Fig. 1 superposed to form a two-channel system by prior art methods;

Fig. 3 shows schematically a two-way, two-channel carrier telephone system in accordance with the invention;

Figs. 4 to 6 show schematically the invention applied to one terminal of a two-way multichannel carrier system employing separate modulators and demodulators with respectively different arrangements for applying the carriers with selective amplification and phase shifting; and

Figs. 7 and 8 show schematically different types of carrier phase shifters which may be used in the systems of Figs. 4 to 6.

In the single channel carrier telephone system of Fig. 1, a two-way line L connects a west station and an east station each including an identical bilateral modulator-demodulator MD_w and MD_e , respectively. The modulator-demodulators MD_w and MD_e may be of the bilateral copper-oxide rectifier type described in the paper by R. S. Caruthers in the Bell System Technical Journal for April 1939 (volume 18, pages 315-357). An analysis of this type of modulator unit in respect to its linear voltage-current behavior in the signaling path is given in the paper by E. Peterson and L. W. Hussey entitled "Equivalent Modulator Circuits," published in the Bell System Technical Journal for January 1939 (volume 18, pages 32-48). The particular modulator-demodulator units illustrated are of the single balanced type such as shown in Fig. 2e of the Caruthers paper, which is arranged to balance out in the signal branch circuit all carrier frequency components entering it from the high-frequency line.

At the west station, two terminals of the modulator-demodulator MD_w are connected directly to the line L and the other two terminals connect through a transformer 1 and the plug and jack arrangement 2 to the signal transmitting and receiving circuit (not shown) of the west subscriber. Similarly, at the east station two ter-

minals of the modulator-demodulator MD_e are connected directly to the line L and the other two terminals connect through the transformer 3 and the jack and plug arrangement 4 to the signal transmitting and receiving circuits (not shown) of the east subscriber.

Carrier waves of suitable frequency generated by the source 5 at any point along the line L are supplied thereto through the transformer 7 and a resonator 6 sharply tuned to that frequency, such as a quartz crystal oscillator or a magnetostriction oscillator, and are transmitted over the line to the modulator-demodulator units MD_w and MD_e at the two stations. The side-band components produced by modulation of the received carrier waves in the modulator MD_w and MD_e at one station with the signal waves from the west or east subscriber supplied through the associated transformer and plug and jack arrangement, will pass out over the line L to the demodulator MD_e or MD_w at the other station in which they will be demodulated with the received carrier wave to detect the signals which will be supplied through the associated transformer and jack and plug arrangement to the receiving circuit of the other subscriber.

The transmitted side-bands are made to pass the point in the line L to which the carrier wave source 5 is connected without being affected by the latter by making the tuning of the resonator 6 extremely sharp. This may be accomplished with prior art apparatus, for example, by the use of a quartz crystal resonator at 100,000 cycles, which may be built to have an impedance at the resonating frequency of, say 100 ohms, and at the same time to present an impedance of 40,000 or 50,000 ohms only 100 cycles off resonance. In other words, the shunting effect of the carrier supply branch upon the lower audio frequencies of the side-bands may be made negligible.

The arrangement of Fig. 1 provides two-way signal transmission by means of a single carrier with a minimum of terminal apparatus and without the use of the relatively expensive channel filters for selecting as between the speech frequencies on the one hand and the carrier waves on the other. If the system is long compared with the wave-length of the carrier, care must be taken to insure the correct phasing of the side-bands as received at the demodulator at the receiving end of the line. For that case, the necessary phase adjustment may be made by means of suitable phase shifters in the carrier supply leads at the terminal stations, such as shown, for example, in connection with Figs. 4 to 6.

Fig. 2 is intended to indicate what would happen with a two-channel system made by simply superposing on one line two such arrangements as shown in Fig. 1. The two carrier waves of different frequencies from the sources 8 and 9 transmitted to the line L through the resonators 10 and 11 sharply tuned to the respective frequencies, and the transformer 12, would be supplied over the line to modulators MD_{w1} and MD_{w2} and to MD_{e1} and MD_{e2} in the two channel terminating branches of the two stations. Each of the two units operating as modulators at one station would then send out over the line a set of side-bands on each carrier, plus other products of modulation, and this would prevent the use of each channel for an individual message. In accordance with the method of the prior art, this intermodulating or scrambling-together of the two channels would be prevented by including in each of the terminal branches between the

modulator-demodulator and the line L, a separate channel band filter BF₁, BF₂ or BF₃, BF₄, having such characteristics that it passes the side-band, or side-bands and carrier, of one channel and excludes those of the other. Thus we appreciate that in the prior art the selecting circuit is made to encompass the whole side-band of the channel with or without the carrier as the case may be, and sometimes both side-bands as in ordinary radio broadcast reception.

Fig. 3 shows how in accordance with the present invention, the modulating-demodulating units of a system such as shown in Fig. 2 may be made to operate on their individual carriers, to the exclusion of interference from other channels, without the use of such band-comprehending channel filters.

The modulator-demodulator circuits of the Fig. 3 are of bilateral, double-balanced type shown by Caruthers in Fig. 2c of his aforementioned paper, in which the unmodulated carrier is suppressed in both the signal input and signal output circuits, and in which low-frequency signals are suppressed in the high-frequency line and high-frequency components excluded from the low-frequency signal terminals. The type of modulator-demodulator disclosed in the patent application of E. I. Green, Serial No. 426,140, filed January 9, 1942 is also suitable for this purpose.

As shown in applicant's Fig. 3, the modulator-demodulator unit MDw₃ in the upper signal branch at the west station comprises a network having series and lattice shunt arms each including a copper-oxide rectifier poled as indicated, which is connected in the signal branch between the transformers 13 and 14, and the modulator-demodulator unit MDw₄ in the lower signal branch comprises a similar copper-oxide rectifier network connected in that branch between the transformers 15 and 16. These modulator-demodulator units present to the through signaling path a substantially linear impedance; i. e. due to their balanced character they present a high degree of resistance against cross-modulation between components impressed on them from either the high-frequency or low-frequency line.

The carrier supply circuit for the modulator-demodulator MDw₃ includes an input transformer 17 having its primary winding connected across the line L in parallel with the high-frequency winding of the transformer 14 in the upper signal branch, and the one-way amplifier 18 having its input connected to the secondary winding of transformer 17 and its output connected across mid-taps on the inner windings of transformers 13 and 14. In series with the primary winding of the transformer 17 is an element sharply tuned to one of the two carrier frequencies received over the line L, say that from the carrier generator 8. This element may be a resonant crystal 19 connected between the two halves of the primary winding. The crystal should be ground for positive resonance at that frequency, i. e., to present a minimum impedance sharply at this frequency, whereby the carrier frequency from source 8 is passed through the transformer 17 and all other frequencies are rejected.

Similarly, the carrier supply circuit of the modulator-demodulator MDw₄ in the lower signal branch at the west station includes a transformer 21 having its primary winding connected across the line L in parallel with the high frequency winding of the transformer 16 in the lower signal branch, and a one-way amplifier 22 hav-

ing its input connected to the secondary winding of transformer 21 and its output connected across mid-taps on the inner windings of the transformers 15 and 16 in the lower signal branch.

In this carrier supply arrangement the primary winding of transformer 21 is made to sharply admit the other carrier frequency received over the line, that is, the carrier frequency from generator 9, by a suitable positively-resonant crystal 23 connected between the two halves of the primary winding, and to reject all frequencies other than this carrier.

At the east station, the similar modulator-demodulator units MD₃ and MD₄ are employed in the upper and lower signal branches, and are respectively supplied with carrier waves received over the line L from the carrier generators 8 and 9 by auxiliary circuits similar to those described for the modulator-demodulator units at the west station, utilizing sharply tuned resonant crystals for selecting out from the waves supplied to these units the desired carrier and feeding it to the balanced points of the modulator-demodulator units in amplified form.

The selecting of the carriers from the side-bands on the line side of the modulator-demodulator units at the two terminal stations in the system of Fig. 3, as described, allows both side-bands for each message to be transmitted over the line between the two stations without the use of channel band filters. In this system inter-channel interference is prevented by several co-acting factors. First, the two carriers are spaced far enough apart in the frequency spectrum so as not to cause a serious beat note in a telephone receiver connected to a channel terminal. If the channel spacing were made 10,000 cycles, for example, this frequency would not appreciably interfere with the hearing of the average individual, and what small interference there was could be obviated by the inclusion in the audio-frequency circuit of each channel of a shunt condenser or simple low-pass filter (not shown). Some such audio-frequency filtration is desirable also to limit the width of the side-bands on the carriers and prevent the overlapping of them. If the frequency interval between the two carriers were made 20 kilocycles, the beat note would be inaudible and all that one would need to protect against would be the transmission of it over the audio frequency terminals to any other connecting apparatus where remodulation might take place, and against unnecessarily wide side-bands, which again may be done by very simple audio frequency, low-pass filters connected in the voice frequency terminals.

Contributing to this avoidance of interchannel interference is the characteristic of the balanced type of modulator employed. In accordance with it, the components that enter on its high-frequency side are not intermodulated, or at least are intermodulated to a negligible extent. This means that the carrier and side-bands of another channel, which are impressed on the modulator of the first channel, are not detected by it, or are detected so weakly that they are not heard. This linearity is accomplished in the type of modulator circuit shown by virtue of the balance, as is explained in the aforementioned papers by Caruthers and Peterson et al. Thus, it is seen that by the combination of the circuits sharply tuned to the desired carrier alone, the balanced type of modulator-demodulator circuit and the use of a carrier large compared to the

signal band, there is realized an effective means of discriminating between channels. This discrimination may be supplemented if desired by the use of channel filters having a few sections or of a cheaper type so that the cost of the terminal apparatus is kept low.

It is important that the carriers be made large in amplitude as compared to the side-bands, and in order to conserve carrier energy and to prevent the carriers from overloading the modulator-demodulators from the high-frequency line, it is desirable to transmit only weak carriers and to amplify each in the carrier supply leads at the terminals as indicated. This insures that the products resulting from intermodulation between the carrier and the desired signal be large in comparison with other components. This large carrier feature constitutes the third of three factors cooperating to prevent interchannel interference in the absence of channel band filters.

Fig. 4 shows schematically one of two identical terminals of a multichannel carrier telephone system employing the sharp tuning method of the invention for discriminating between carriers and side-bands, in combination with high frequency line balance for preventing the outgoing channels which are of higher energy levels than the incoming channels by the amount of line attenuation, from overloading the demodulators of the incoming channels.

As in the system of Fig. 3, in Fig. 4 the carrier waves of different frequencies, one for each two-way channel are supplied over the line L from two carrier generators $G_1, G_2 \dots$, which are connected to the line through transformer T_1 , and the crystal resonators $\dots$ respectively sharply tuned to a different one of the carrier frequencies, each carrier being supplied to both terminals. The common transmitting leg TC for the outgoing channel branches and the common receiving leg RC for the incoming signal branches are coupled in conjugate relation with each other and in energy transmitting relation with the two-way high frequency line L by the hybrid coil Hw and associated balancing network Nw. The output of the transmitting branch including modulator M_1 , for channel 1, is connected to the outgoing circuit TC by transformer T_1 and the input of the receiving branch including demodulator D_1 , for that channel is connected by transformer T_2 to the circuit RC. The input of the transmitting branch and the output of the receiving branch of channel 1 are coupled by the hybrid coil H_1 and the associated balancing network N_1 to a two-wire circuit 30 which is adapted for connection by the plug and jack device 31 to the transmitting and receiving circuit (not shown) of one telephone subscriber. Similarly, a transmitting branch including modulator M_2 , for the carrier channel 2, is connected to the outgoing circuit TC by transformer T_3 , and the input of the receiving branch including demodulator D_2 , for that channel is coupled by transformer T_4 to the incoming circuit RC. The input of the transmitting branch and the output of the receiving branch of channel 2 are coupled by hybrid coil H_2 and associated balancing network N_2 to the two-wire circuit 32 adapted for connection by jack and plug device 33 to the signal transmitting and receiving circuits (not shown) of the second telephone subscriber.

The modulators M_1 and M_2 and the demodulators D_1 and D_2 in the terminal of Fig. 4 may be of any of the well-known types but are prefer-

ably of the double balanced, copper-oxide rectifier type illustrated in Fig. 3.

The same carrier frequency, for example, that supplied from the generator G_1 , is supplied to the carrier supply terminals of the modulator M_1 and demodulator D_1 of carrier channel 1, through the transformer T_1 having its primary winding connected across the receiving circuit RC, and the phase shifter PS_1 . The transformer T_1 is sharply tuned to select the carrier frequency supplied by generator G_1 by means of the resonant crystal 34 connected between the two halves of its primary winding. The carriers are prevented from entering and being absorbed in the output of the modulator M_1 by way of transformer T_1 , and in the input of the demodulator D_1 through transformer T_2 , by means of the carrier rejection resonant crystals 35 and 36 respectively connected between the halves of the high frequency windings of those transformers, and tuned to be antiresonant to the carrier frequency to which the resonant crystal 34 in the carrier supply circuit is tuned.

Similarly, the carrier of the other frequency generated by generator G_2 associated with the line L is picked off from the receiving circuit RC by the transformer T_3 tuned to that frequency by the resonant crystal 37 connected between the two halves of its primary winding, and is then fed through the phase shifter PS_2 to the carrier terminals of the modulator M_2 and demodulator D_2 of channel 2. The carriers are kept out of the output of the modulator M_2 and the input of the demodulator D_2 by means of the carrier rejection resonant crystals 39 and 38, respectively, tuned to be antiresonant to the frequency selected by the resonant crystal 37 in the carrier supply circuit for that modulator and demodulator.

The phase shifters PS_1 and PS_2 in the carrier supply leads to the modulator and demodulator of channel 1 and channel 2, respectively, which may be of the type disclosed in Fig. 7 or Fig. 8, are adjusted to provide proper phasing of the applied carriers so the side-bands received by the demodulators at the other end of the line L are not in a 90-degree relation with respect to the carriers as they arrive at that point. In addition to the receiving amplifier A_1 in the common receiving leg RC for the several channels, an individual amplifier (not shown) may be included in the individual carrier supply leads for each channel for the purpose of increasing the carrier amplitude compared with that of the side-bands, thereby diminishing the chance of interference in the system by intermodulation between two unwanted components lying in the high-frequency spectrum outside the desired bands.

Since it is desirable in this type of system that the carrier which is supplied to each modulator-demodulator be strong as compared with the side-bands, for the purpose of obtaining a relatively strong product for the beating together of the carrier and the desired signal, as compared with the beating together of two components within the signal frequency range or two unwanted components outside the signal frequency range, and since it is desirable that in the high-frequency line itself the level of the carrier be kept relatively low for the purpose of facilitating amplification en route, selective terminal amplification of the carriers alone is desirable. In general, it is quite feasible to amplify each carrier alone as it is taken out of the high-frequency line preparatory to the introduction of it into the modu-

lator, as already indicated. But it would require fewer amplifiers were it possible to amplify all the carriers as a group, after they are separated from their side-bands. For example, the carrier supply leads in the terminal of Fig. 4 could be connected to a common amplifier, but in this case there would be required in the output circuit means for separating the carriers once more preparatory to supplying them to their individual modulators. This separation could be readily and cheaply carried out because of the very considerable frequency spacing of the carriers with the side-bands previously eliminated, so that the common amplifier for a group of carriers is a reasonable arrangement.

The terminal for a multichannel carrier telephone system illustrated in Fig. 5 shows a modification of the invention differing from that shown in Fig. 4 essentially only in the provision of an amplifying circuit which enables the same crystal resonator used for obtaining the initial selecting of the carrier also to select the amplified carriers.

In Fig. 5, the incoming carrier line L to which the carrier frequencies from the generators G_1 , G_2 , G_3 are supplied through resonant crystals in a manner which has been described in connection with the previous figures, is coupled by the hybrid coil H_E and associated balancing network N_E to the common transmitting leg TC_1 and the common receiving leg RC_1 for the several channels. The transmitting leg TC_1 connects in parallel to the outputs of the modulators in the several channels 1, 2 . . . through coupling networks C_1 , C_2 . . . which may be transformers sharply tuned by resonant crystals, as shown, to be antiresonant respectively to the carrier frequencies for the respective channels so as to prevent transmission of the carrier frequencies into the outputs of the modulators in the channels.

The receiving leg RC_1 includes an amplifier 40 which amplifies both the carriers and the side-bands received from the line L. The output of the amplifier 40 connects in parallel to the inputs of the demodulators in the channels 1, 2 . . . by coupling networks C_3 , C_4 . . ., similar to the networks C_1 , C_2 sharply tuned to be antiresonant to the carrier frequencies for the respective channels to keep those frequencies out of the signal inputs to the demodulator. Actually such carrier rejection elements will not be needed in either the modulators or demodulators if those devices are chosen to be of the double balanced type and are made of sufficient carrying capacity to prevent overloading; for such modulator-demodulator units present a linear characteristic to all components on the high-frequency line side. They are shown as safeguards against overloading of the modulators in cases where relative strong line carriers are employed.

The output circuit of amplifier 40 also connects through the phase shifter PS_3 and the unbalanced hybrid coil H_4 of the booster amplifier circuit 42, similar to that disclosed in the United States patent to H. S. Black No. 2,209,955 issued August 6, 1940, to the resonant crystals 43, 44, 45 respectively sharply tuned to the carrier frequencies assigned to the respective channels 1, 2, 3 . . . Crystals 43, 44, 45 are made with double coatings in order to provide separate output and input terminals. The input terminals of the crystals 43, 44, 45 are connected in series across the points of hybrid coil H_4 to which the

receiving leg would be connected in the ordinary hybrid coil.

The carrier frequency selected by crystal 43 is supplied from its output terminals through the individual phase shifter PS_1 to the carrier terminals of the modulator and demodulator of channel 1 and the carrier frequency selected by crystal 44 is supplied from its output terminals through the individual phase shifter PS_2 to the carrier terminals of the modulator and demodulator in channel 2. The booster amplifier 42 serves to amplify the voltage impressed on the crystals 43, 44, 45 to make the carrier supplied thereby to the channel modulators and demodulators of sufficient amplitude to make the carrier side-band modulation products strong compared with side-band to side-band modulation to reduce inter-channel crosstalk. The necessary phase adjustment of the carriers can be made in the one phase shifter PS_3 in the common portion of the carrier supply circuit in case the carriers are in harmonic relation, but, if they are not, the phase adjustment is made by the phase shifters PS_1 , PS_2 . . . in the individual carrier supply leads between the selecting crystals and the modulators and demodulators of the several channels.

The modulators and demodulators in the channels 1, 2 . . . of the terminal of Fig. 5 are also preferably of the double balanced copper-oxide rectifier type shown in the system of Fig. 3.

In the operation of the terminal of Fig. 5, the voice signals generated in the transmitter 46 are modulated in the modulator of channel 1 with the carrier waves supplied by the selective crystal 43 and both produced side-bands are passed through the carrier rejection coupling network C_1 to the common transmitting leg TC_1 ; and the voice signals received over the subscriber's line 47 and impressed by the hybrid coil H_3 on the modulator of channel 2, are modulated therein with the carrier frequency received from the selective crystal 44, and both the resulting side-bands are transmitted through the carrier rejecting coupling C_2 to the common transmitting leg TC_1 . The side-bands of both channels pass directly from TC_1 through the hybrid coil H_E to the line L over which they are transmitted together with the carrier waves supplied by the associated generators G_1 , G_2 . . . to the distant carrier terminal.

The side-bands produced by the modulators in the corresponding channels at the distant terminals utilizing the particular carrier frequencies assigned to channels 1 and 2 at the east terminal illustrated, when received over the line L along with the carriers produced by the generators G_1 , G_2 pass through the hybrid coil H_E to the receiving leg RC_1 and after amplification by the amplifier 40 therein are impressed on the selective coupling networks C_3 and C_4 of channels 1 and 2. The networks C_3 and C_4 reject the carriers and selectively transmit all of the side-bands to the demodulators of the two channels. The two side-bands of one carrier will be demodulated in the demodulator of channel 1 by modulation with the corresponding carrier supplied from resonant crystal 43, and the side-bands of another carrier will be demodulated by modulation in the demodulator of channel 2 with the corresponding carrier supplied from resonant crystal 44, in the manner which has been previously described, to reproduce the signals of the different messages which in channel 1 are transmitted directly to the receiver 48 and in channel 2 are transmitted

through the hybrid coil H_3 to the subscriber's line 47.

The carrier terminal of Fig. 6 differs essentially from that of Fig. 5 merely in the arrangement for amplifying the received carriers. The amplification is provided by the single amplifier 49 of the booster circuit 50, the input of which works directly out of the high-frequency line hybrid coil H_2 , and the output of which connects through a second hybrid coil H_3 back to the line terminals of the first hybrid coil H_2 . The balance of the high frequency line L is provided by the balancing network 51 associated with the hybrid coil H_3 . In the direct connecting circuit between the hybrid coil H_3 and the line hybrid coil H_2 is an attenuation pad 52 shown as a pair of series resistances. The input of common receiving leg RC_1 leading to the demodulators of the several channels is connected to adjustable points on those two resistances so that the amplification provided in the receiving leg can be adjusted by varying the position of the sliders on the two resistances to make the amplification of the input waves supplied to the demodulators less than that given to the carriers. The received carriers are taken off from the sharply tuned crystal resonators 43, 44, 45 . . . connected in parallel to one of the windings of the hybrid coil H_3 as shown. Otherwise, the terminal of Fig. 6 is exactly like that of Fig. 5 and operates in a similar manner.

Of course, any of the arrangements illustrated in the drawings and described above may be modified to make use of each carrier only for transmission in one direction, with two distinct channels employed for effecting two-way operation in accordance with the well-known principle of "equivalent four-wire operation."

It will be apparent that instead of transmitting from a central supply all of the carriers as illustrated, the system may be operated on the basis of transmitting from the central carrier supply only the fundamental frequency, or of transmitting from it at a higher frequency two adjacent components of a harmonic series, from which the series may be derived at the two terminals by means of a harmonic generator controlled by the received frequencies, a different harmonic being utilized for each carrier desired. The supplying of the carrier fundamental from a single point should insure the tie-together of the frequencies at the two terminals and the maintenance of the requisite phase relations between the carriers and their respective side-bands.

It will be apparent also that the transmitting medium instead of being a high-frequency wire line may be a radio line and that thereby, by sharp selection of the carriers at the terminals and the proper choice of carrier amplitude in relation to side-bands, of adequate frequency spacing of the carriers and the use of appropriate types of modulator-demodulator elements—telephone transmission over the common wide-band medium of radio may be accomplished without the employment of band filters individual to each channel.

Various other modifications of the circuits illustrated and described which are within the spirit and scope of the invention will occur to persons skilled in the art.

What is claimed is:

1. In a high-frequency carrier telephone system, a source of high frequency carrier, a modulating device having an input circuit supplied with telephone signals and a side-band output

circuit, means for feeding said high frequency carrier from said source through said side-band output circuit to said modulating device to modulate therein with the supplied telephone signals to produce signal side-bands in said side-band output circuit, and means for preventing appreciable loss in the transmitted signal side-bands by interference from the carrier comprising an electromechanical element connected in the path of said carrier between said source and said side-band output circuit having a resonance to the carrier frequency which is so sharp that the lower edge of the side-band is not appreciably affected by the supplied carrier.

2. In a multichannel high-frequency carrier telephone system, a high-frequency transmission medium connecting stations, a plurality of modulators at each station, one for each channel, connected to said transmission medium without channel filters, means for supplying to said modulators over said medium individual high frequency carriers spaced from each other in the frequency spectrum at a frequency interval approximating the upper limit of audition, and means at said stations for amplifying the received carriers so that they are applied to the respective modulators at a level high compared to the level of the signal bands applied thereto.

3. The method of accomplishing multichannel carrier telephone transmission over a common medium connecting terminal stations each including modulating means for combining carriers with telephone signals to produce signal side-bands for transmission, without selecting by individual band the signal side-bands constituting individual channels, which consists in placing the carriers for modulating with the telephone signals at the terminal stations in the frequency spectrum at an interval approximating the upper limit of audition, supplying said carriers over said medium to said modulating means and discriminating between the channels at the terminal stations by carrier selection only.

4. A system for accomplishing multichannel carrier telephone transmission between stations over a common transmission medium without selecting by individual band the side-bands constituting the individual channels, comprising means for producing a plurality of carriers spaced in the frequency spectrum at a frequency interval approximating the upper limit of audition to enable the ready discrimination against beat frequencies between the carriers at the terminal stations, individual channel modulator-demodulators at the terminal stations connected to said medium, which are of the double balanced type possessing the characteristic of suppressing crossmodulation between two or more components impressed thereon simultaneously, and means for supplying said modulator-demodulators with the respective carriers at an energy level large compared with that of impressed signals or signal side-bands to produce signal side-bands for transmission, or to reproduce the signals for reception, said modulator-demodulators being connected directly to the common medium without the intervention of channel band filters.

5. In a multichannel carrier telephone transmission system, a carrier transmission medium connecting stations, a source of carrier supply applied to the transmission medium in common for both stations, a modulator-demodulator unit of the balanced type in each channel at the stations, connected to said transmission medium without the interposition of channel band filters,

an individual element for sharply selecting from the waves received over said medium and transmitting to the carrier terminals of the modulator-demodulator unit in each channel for modulation therein with the applied telephone signals or signal side-bands, the carriers of the particular frequency assigned to that channel, without interfering with the passage of the signal side-bands of the channel, and means for amplifying the carriers so that the energy of the carrier supplied to each modulator-demodulator unit is large compared to that of the side-bands.

6. In a multichannel carrier telephone transmission system, a high-frequency transmission medium extending between terminal points of the system, a source of carrier supply applied to the transmission medium in common for both terminals, means at the terminal points for selecting from the waves received over said transmission medium the carrier assigned to each channel so there is no interference with the passage of signal side-bands past the point of selection, low-frequency signal transmitting apparatus for each carrier channel at said terminal points, a modulator-demodulator of the double balanced type in each channel at the terminal points, having one set of terminals connected to the low-frequency signal transmitting apparatus of the channel and another set of terminals connected to said high-frequency medium, and means for applying the selected carrier for each channel to the modulator-demodulator therein at each terminal point so that second order demodulation products are eliminated from said one set of terminals and second order modulation components of the carrier itself are eliminated from said other set of terminals.

7. In a multichannel carrier wave signaling system, a carrier transmission medium extending between terminal stations, transmitting the carriers for the communication channels at the stations and the signal side-bands of the carriers between the stations, means at one or both stations for sharply selecting from the waves received over said transmission medium the particular carrier for each channel of transmission without producing appreciable distortion of the associated signal side-bands and without selecting the side-bands themselves, means at one or both stations to amplify the selected carriers to an energy level high compared with that of the side-bands, a modulator and demodulator of the double balanced type in each channel supplied with the selected carrier therefor thus amplified, means for applying low-frequency signals to each modulator to modulate therein with the supplied carrier, means to apply both side-bands only of the resulting modulation products of each modulator directly to said transmission medium for transmission thereover, means to apply the signal side-bands received over said line at each station directly to the demodulators thereat, and signal receiving means for the signals detected by each demodulator from the supplied side-bands associated with its particular carrier.

8. In a multichannel carrier signaling system, a high-frequency line connecting stations, a plurality of low-frequency signal circuits at each station, a corresponding number of balanced modulators respectively connected on one side individually with a different one of said signal circuits and on the other side in common to said line, means to supply a plurality of different high-frequency carriers over said line to both stations, sharply tuned resonant elements at each

station for respectively selecting a different one of the received carriers from the waves received over said line, means at each station for applying a different selected carrier to each modulator thereat to modulate with the signals applied to that modulator from the connected signal circuit, producing an upper and lower side-band for each carrier channel, or with the particular side-bands received over said line, produced by a carrier of corresponding frequency at the other station, to detect the modulating signals, the circuits connecting said line to said other side of each modulator at each station having a frequency transmission range sufficient to allow free transmission therebetween of all the signal side-bands received from said line or produced at the station.

9. In a multichannel carrier signaling system, a high-frequency line connecting a transmitting station and a receiving station, means for transmitting a plurality of high-frequency carriers generated at an intermediate point along said line to both stations over said line, said transmitting station including a plurality of sources of low-frequency signals, a corresponding number of transmitting channels each including a balanced modulator, a plurality of sharply tuned selective circuits for respectively selecting different ones of said carriers received over said line, means for applying each selected carrier to a different one of said balanced modulators to modulate therein with the signals applied thereto from the connected signal source to produce an upper and lower signal side-band for each carrier channel, and means for passing the produced side-bands freely to said line, said receiving station including a plurality of receiving channels each including a balanced demodulator, sharply tuned selective circuits for respectively selecting each of the carriers received over said line from the received waves, means for impressing all of the received side-bands on the demodulator in each of the receiving channels, means for impressing a different one of the selected carriers on each of said demodulators to combine therein with the impressed side-bands, and means connected to the output of each demodulator for selectively receiving the signals thereby demodulated from the impressed side-bands produced by the corresponding carrier frequency at the transmitting station.

10. In a multichannel carrier telephone system, a high-frequency line connecting stations, telephone signal transmitting and receiving apparatus at each station, a plurality of channels each including a bilateral modulator, at each station connected between said telephone signal transmitting and receiving apparatus and said line, a plurality of sources of high-frequency carrier waves connected to said line at an intermediate point so that said carrier waves are transmitted over said line to both stations, a plurality of resonant circuits at each station, respectively sharply tuned to the frequency of a different one of said carrier waves, for selecting a respectively different carrier wave from the waves received over said line, means at each station to apply the selected carrier waves respectively to the modulator in different channels thereto, to combine with the signals applied thereto from the associated signal transmitting apparatus to produce upper and lower signal side-bands of said selected carrier, or with the signal side-bands impressed thereon from line to demodulate the signal side-bands of the selected

carrier, the connections between said line and the bilateral modulator in each signal channel at the stations being such as to provide free transmission therebetween of all side-bands of said carriers and to substantially suppress the carrier frequencies.

11. The system of claim 10, in which said carrier waves supplied to said line are spaced far enough apart in the frequency spectrum so that any beat notes produced in the telephone receiving apparatus at the stations will be inaudible.

12. The system of claim 10, in which the carrier waves supplied to said line are spaced apart in the frequency spectrum by 10,000 cycles or more.

13. The system of claim 10 in which the high-frequency carrier wave generated by each of said sources is applied to said line through a resonant circuit sharply tuned to that frequency, so as to prevent any substantial interference with the signal side-bands transmitted over said line.

14. In a multichannel carrier telephone system, a high-frequency line connecting stations, a plurality of transmitting channels each including a balanced modulator and a plurality of receiving channels each including a balanced demodulator, at each station, means for coupling said transmitting channels and said receiving channels at each station in conjugate relation with each other and in energy transmitting relation with said high-frequency line, means for impressing a plurality of high-frequency carrier waves widely spaced in the frequency spectrum on said line for transmission thereover to said stations, a plurality of sharply tuned resonant circuits at each station for respectively selecting a different one of the carrier waves received from said line, auxiliary circuits for applying each selected carrier wave in common to a modulator in a different transmitting channel and a demodulator in a different receiving channel, to combine in the modulator with low-frequency telephone signals applied thereto to produce an upper and a lower signal side-band for transmission over said line, and in the demodulator with applied signal side-bands received from said line to demodulate the signals from the received side-bands of a carrier of corresponding frequency, means for suppressing from the outputs of the modulators in all transmitting channels at each station the carrier frequencies received over the line, while allowing free transmission of both side-bands produced by said modulator to the line, means for suppressing from the input of the demodulator in each receiving channel the carrier frequencies received from said line while allowing free transmission thereto of all side-bands received over said line, means for causing the carrier supplied to each modulator at the stations to be of high level compared with the level of the produced side-bands of said carrier to prevent interchannel

crosstalk, and means for insuring an out-of-phase relation of the side-bands received by the demodulators in the receiving channels at each station with respect to the carrier waves applied thereto.

15. In a carrier wave signaling system, a high-frequency two-way line connecting stations, low-frequency signal transmitting and receiving apparatus at each station, a circuit including a bilateral balanced modulator at each station connecting said signal transmitting and receiving apparatus to said line, a source of high-frequency carrier waves connected to said line for supplying said carrier waves over said line to the bilateral modulator at each station to modulate therein with low-frequency signal waves supplied by the associated signal transmitting apparatus to produce upper and lower signal side-bands for transmission to the line, or with the side-bands received over said line from the other stations to reproduce the signal waves therefrom for transmission to the associated signal receiving apparatus, the connections between the modulator and the line at each station having a transmission frequency range of sufficient width to pass both side-bands of said carrier, the connection between the said source and said line being sharply tuned to said carrier frequency to prevent interference with the transmitted side-bands.

16. In a multichannel carrier signaling system, a high-frequency line connecting stations each having a number of modulator-demodulator units corresponding to the number of channels, with associated signal transmitting and signal receiving apparatus, means to supply carrier waves of different high-frequencies to said stations over said line, sharply tuned resonant circuits at each station for respectively selecting a different one of the carrier waves received over the line, different auxiliary circuits for transmitting each selected carrier to a different one of said modulator-demodulator units to combine therein with the signal wave supplied from the associated signal transmitting apparatus to produce upper and lower side-bands of said carrier, or with the signal side-bands of corresponding carrier received from said line to detect the modulating signals therefrom, the connections between said modulator-demodulator units at each station and said line being such as to provide free transmission therebetween without the intermediary of band filters of both side-bands produced for transmission, or all side-bands received from said line, the values of the different carrier waves supplied over the line to said stations being such as to give a frequency spacing between carrier channels of at least 10 kilocycles, and means for making the amplitudes of the carrier waves applied to the modulator-demodulator units at the stations high in comparison with those of the side-bands of said carrier waves.

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