Jan. 7, 1930. E. M. DELORAINE ET AL 1,742,902

MULTICHANNEL RADIO COMMUNICATION SYSTEM

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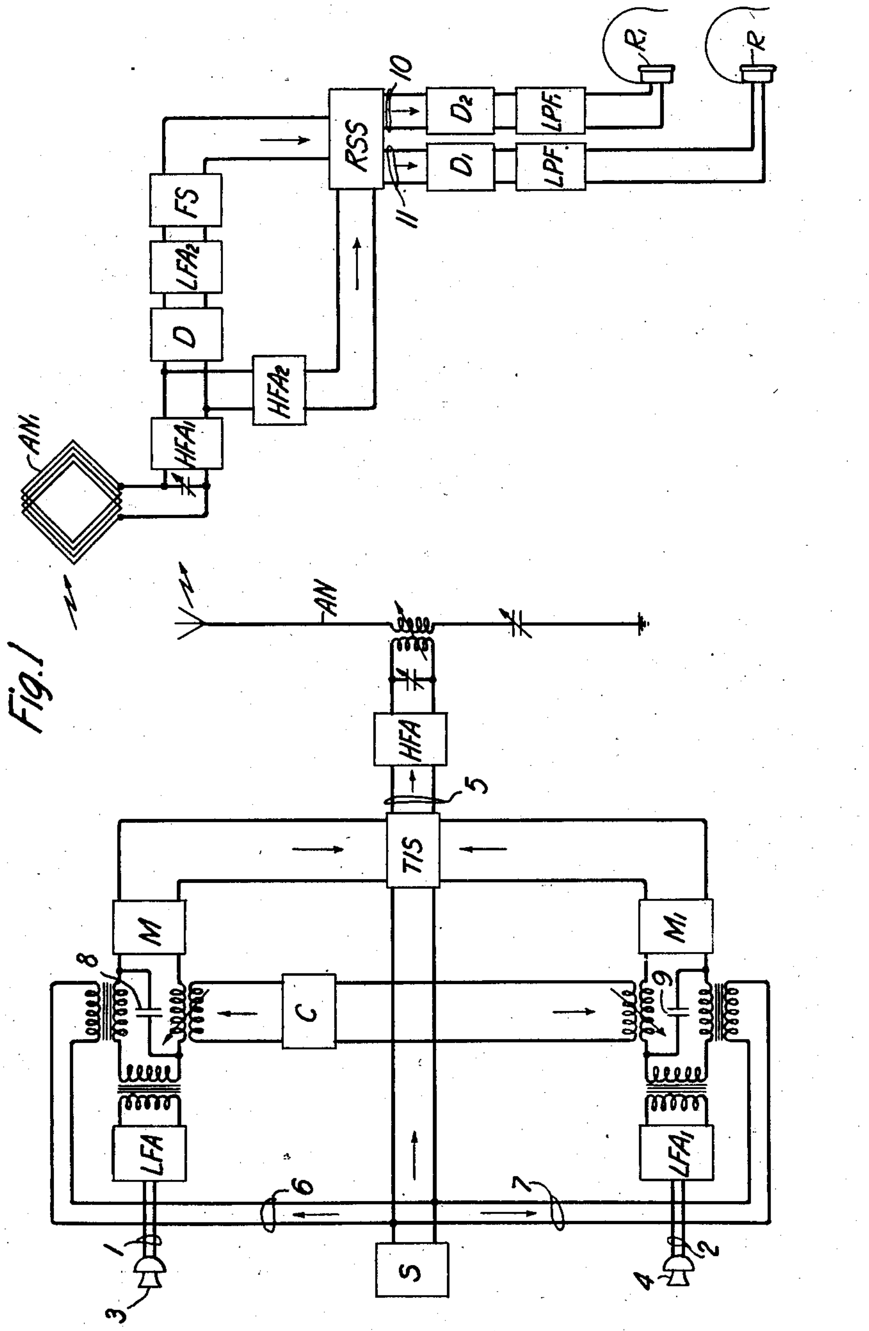

Fig. 1

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Fig. 2

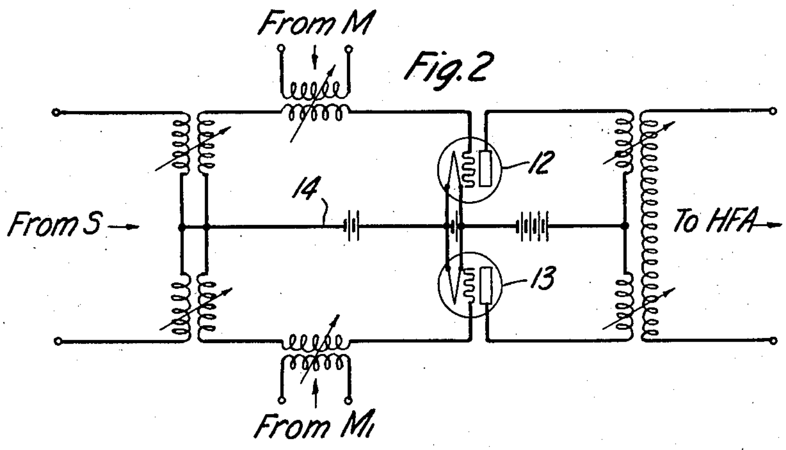


Fig. 3

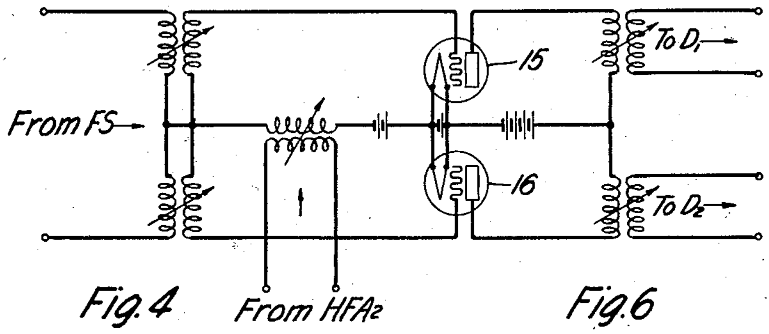


Fig. 4

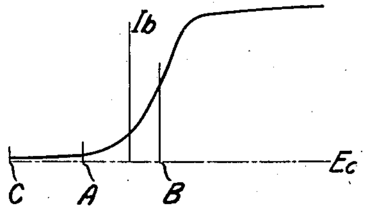


Fig. 5

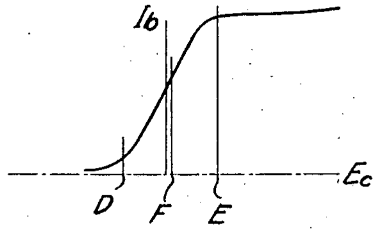
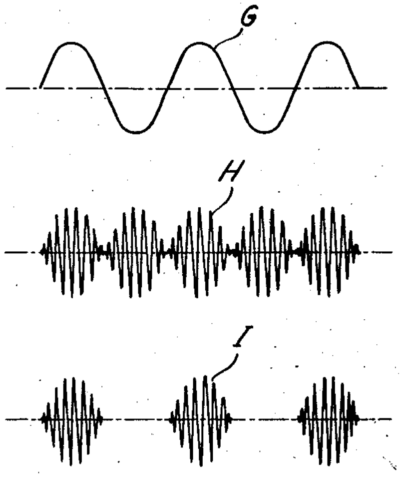


Fig. 6



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MULTICHANNEL RADIO COMMUNICATION SYSTEM

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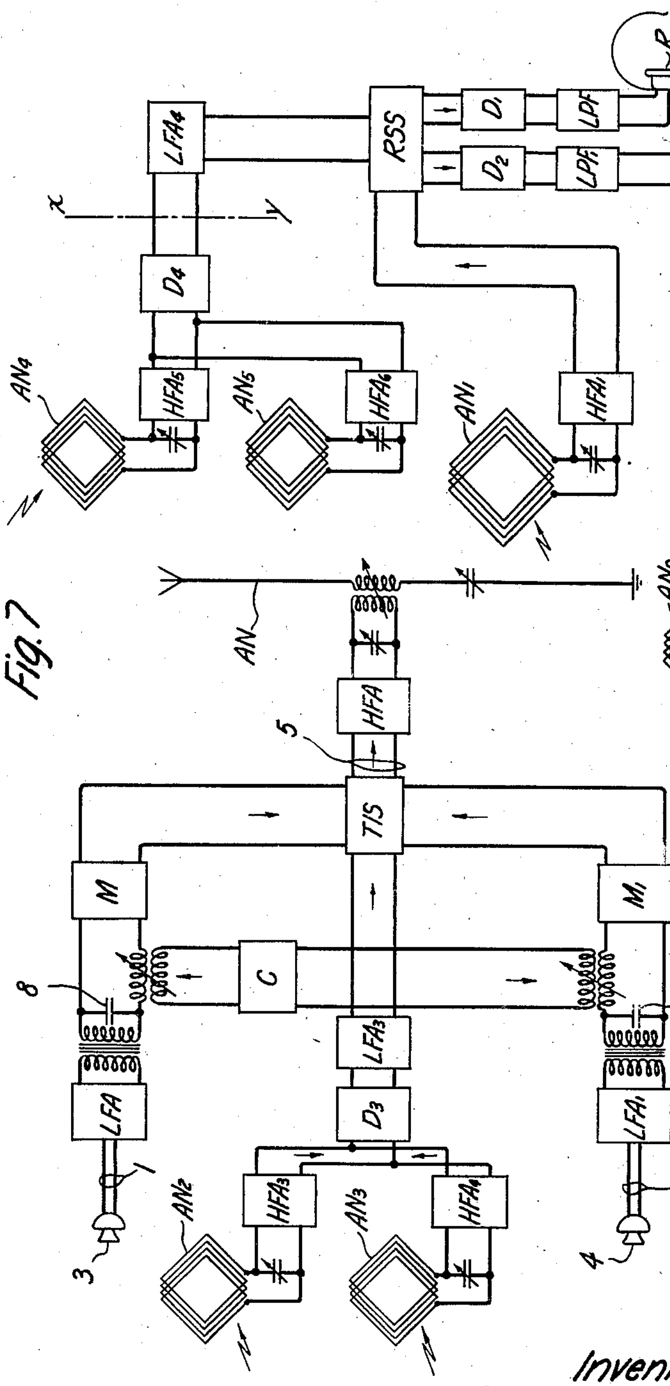

Fig. 7

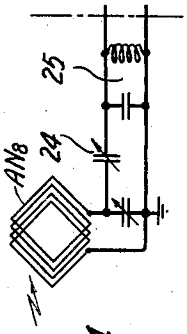

Fig. 14

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Fig. 8

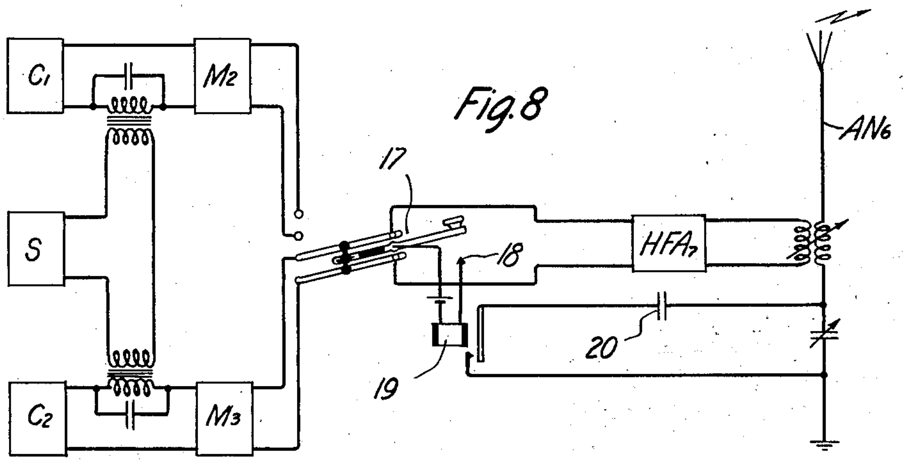


Fig. 9

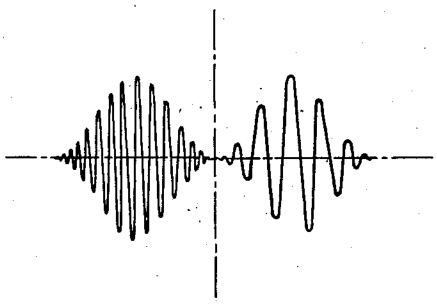


Fig. 15

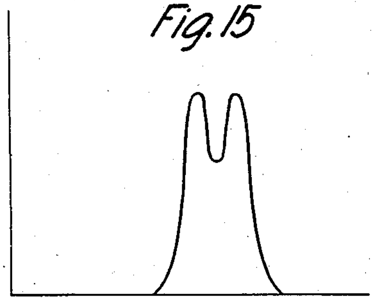
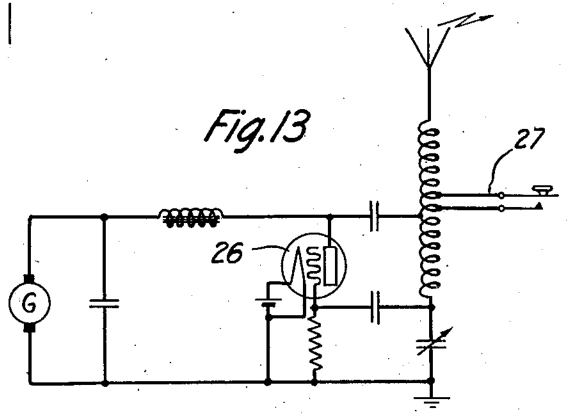


Fig. 13



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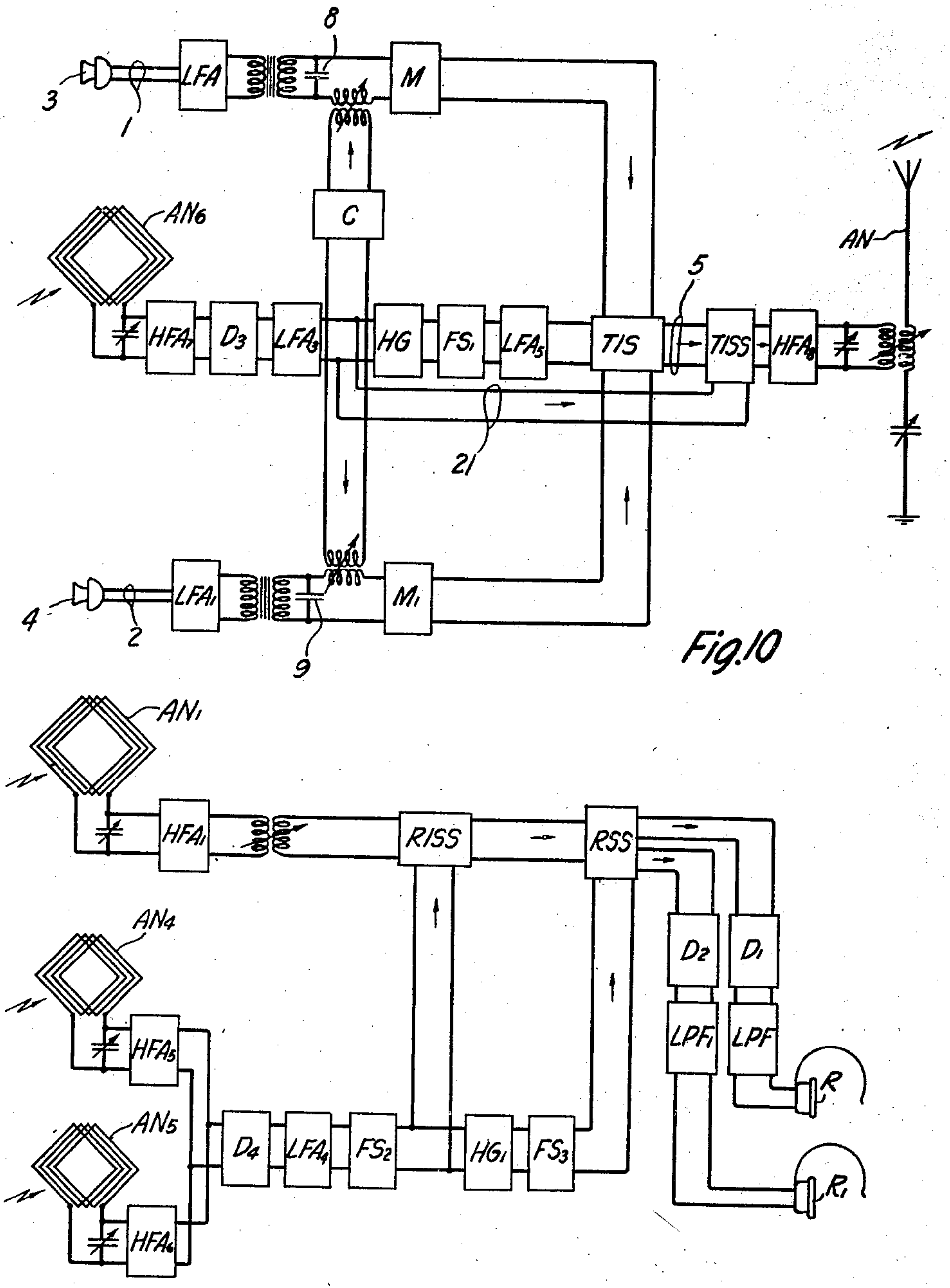

Fig. 10

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MULTICHANNEL RADIO COMMUNICATION SYSTEM

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Fig.11

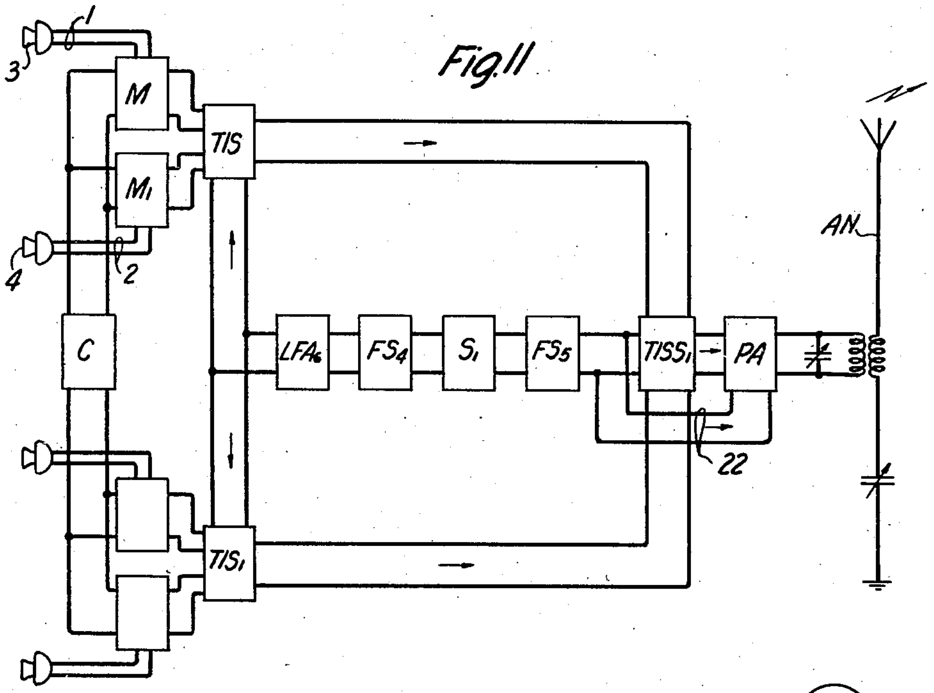
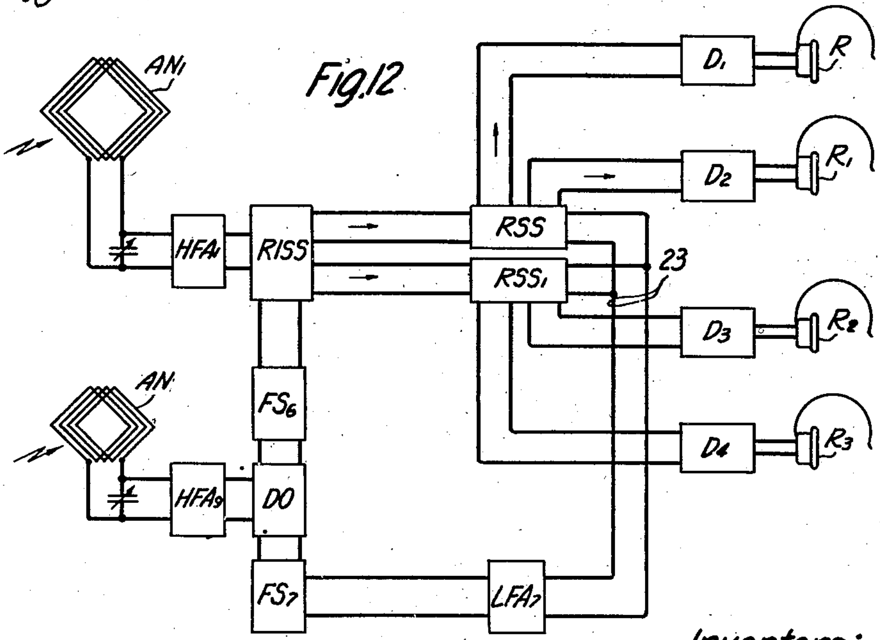


Fig.12



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Patented Jan. 7, 1930 **1,742,902**

# UNITED STATES PATENT OFFICE

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## MULTICHANNEL RADIO COMMUNICATION SYSTEM

Application filed February 14, 1925. Serial No. 9,199.

This invention relates to communication systems adapted for the simultaneous transmission of a plurality of waves in either one or both directions between two stations. The term "multiplex transmission" is used in the specification and claims to define, broadly, such communication systems. The invention relates especially to modulated carrier wave communication whether by means of an electric conductor, as in line-wire carrier wave, or through etheric space, as in radio carrier wave, communication.

An object of the invention is to provide methods of and means for multiplex communication whereby greatly increased economy of plant, energy and frequency range is secured, and especially as adapted for multiplex radio, instead of line-wire, carrier wave communication; since therein the urgency of economy of energy and frequency range is inherently relatively the greater.

This object is achieved in part by employing a single carrier frequency for all of the transmissions, message discrimination being effected on a time basis rather than on a frequency basis. A commutating means is employed to alternately paralyze all of the modulated carrier wave transmissions, except one, the commutation being effected at a super-audible frequency so that for any appreciable interval of time a plurality of separate messages employing the same carrier frequency, are, so far as may be determined by the senses, being simultaneously transmitted, although only one message is being transmitted at each instant of time. As has already been suggested this operation is without limitation as to the distribution of the transmissions between the two directions.

Since there is only one carrier frequency concerned in the transmitting function, frequency selection cannot be relied on at the distant receiving station for separating a plurality of message waves transmitted thereto in such manner. Since the message waves are differentiated only in the different times of arrival of their component parts, separation must be effected on a time basis. Accordingly, commutating or distributing means, the characteristic frequency of which is the same as that of the corresponding means at the other station, is provided at the receiving station.

It is desirable that all of the energy capable of being radiated from a given radio transmitting station of the invention be employed for message transmission, since the readability of the eventually demodulated signal depends in large measure on the ratio of signal energy level to interference energy level at the receiving antenna.

Accordingly, it is desirable to separately transmit the impulses necessary to insure the synchronous operation of the commutating and distributing means. In the operation of one form of system the synchronizing wave is separately transmitted to both stations from an independent third station.

An important feature of the invention is the utilization of the normal transmission from an independent signal transmitting station for the transmission of the synchronizing wave. A necessary condition is that the synchronizing wave must be transmitted continuously whether the station is transmitting a signal wave or not. This condition is satisfied in the operation of one modified system of the invention by utilizing a third station which transmits a telegraphic signal by a change of carrier frequency, the synchronizing wave being transmitted as a modulation of the outgoing carrier wave of changing frequency. By the use of this feature the synchronizing wave may be transmitted from the third station without increase of radiated energy and without interference with its signal transmission.

Under conditions where interference is less harmful, the multiplex signaling system itself can readily be adapted for transmitting the synchronizing wave, although from theoretical considerations it appears that the presence of interference limits the effective transmission to a distance materially less than where separate synchronization is used. However, the transmitting conductor of a multiplex transmitting station of the invention may also be used for transmitting the signal wave with its superposed synchronizing wave which waves would otherwise be transmitted from the third station, and with similar effect.

The invention attains its greatest efficiency where all of the transmissions are in one direction, since for this case the transmitting circuits would be used at all times, a particularly economic method of working, in view of the high cost of antenna structure. Duplex or quadruplex operation (respectively, one or two transmissions in each direction) would require that the circuits operate during only half of the time. One way working would be adapted for telegraphy, but not so well adapted for telephony. However, the economic advantages of one-way transmission, in the multiplex system of the invention, may be preserved and utilized in a two-way system by providing two such one-way systems for opposite directions of transmission, a different frequency being used for the two directions.

From the above brief description, it will be apparent that the invention provides methods of and means for multiplex operation using substantially the same amount of energy and frequency range as a single channel system.

Besides the features, as above described, relating to the basic principles of the invention, the invention, especially as embodied in radio systems, includes several novel elements and combinations, the use of which contributes to the efficient operation of the system as a whole. Included in this category are the following features:

1. Commutating means which produce the commutating effect without breaking the continuity of any circuit. The means comprises electric discharge devices having controlling means for varying the discharge in proportion to impressed electrical variations. The synchronizing wave is employed to produce these variations and thereby alternately reduce the discharge of all said devices, except one, to substantially zero. The signal modulated carrier waves are impressed on the devices and are accordingly correspondingly variably repeated.

2. In a self-synchronizing system, the synchronizing wave is transmitted as a modulation of the carrier wave used in the multiplex signal transmission. To insure that the synchronizing wave is transmitted at all times and in order to avoid the necessity of using a separate modulator for this wave, the synchronizing wave is simultaneously and at all times impressed on all the modulators used in the multiplex signal transmission.

3. The synchronizing wave may be transmitted directly, i. e. instead of as a modulation of the carrier wave. It may be transmitted from an antenna of the multiplex system or from a separate antenna. The separate antenna may be used additionally for telegraph signaling by change of frequency.

4. If a two-frequency synchronizing wave is employed as in the modification last described, its reception can be accomplished either by the use of two antennæ tuned to the respective frequencies, or by a single antenna loosely coupled to a tuned circuit, the antenna and tuned circuit preferably tuned to the same frequency. This frequency and the coupling are such that the two maxima of the resultant double-hump resonance curve of the combination have frequencies which are coincident with the two frequencies of the incident wave.

Other features and objects will be apparent after a reading of the following detailed description considered in connection with the accompanying drawing, in which:

Fig. 1 illustrates a diplex self-synchronizing system. The term "diplex" indicates that two messages may be simultaneously transmitted in the same direction;

Fig. 2 illustrates one form of commutating means for the transmitting station of the systems of Figs. 1, 7, 10 and 13. A commutating means having this function will be denominated in the specification and claims "transmitting intermixing selector";

Fig. 3 illustrates one form of the corresponding commutating means used at the receiving stations of Figs. 1, 7, 10 and 12. Commutating means having this function will hereinafter be denominated "receiving separating selector";

Fig. 4 comprises a characteristic curve of an electric discharge device used in the selectors of Figs. 2 and 3, and which is employed herein to explain one method of operating such selectors;

Fig. 5 comprises a characteristic curve of the devices used in the selectors of Figs. 2 and 3 and which is employed herein to explain a method of operating the selectors which is alternative to that for which the curve of Fig. 4 is used;

Fig. 6 comprises a set of curves that illustrate the wave forms of the waves occurring in various parts of the transmitting and receiving circuits of Fig. 1;

Fig. 7 illustrates a modified system similar to that of Fig. 1, but adapted for separate synchronization;

Fig. 8 illustrates a radio transmitting station which may be used in common for transmitting a telegraph signal and the synchronizing wave. This station may cooperate with either of the systems illustrated by Figs. 7 and 10;

Fig. 9 illustrates graphically the form of the wave radiated from the station of Fig. 8;

Fig. 10 illustrates one station of a quadruplex system of the invention, including both the transmitting and the receiving circuits;

Fig. 11 illustrates the transmitting station of a self-synchronization double-diplex system of the invention. The term "double-diplex" is used to designate a system or method employing four transmissions in one direction;

Fig. 12 illustrates a receiving station of a separate synchronization double-diplex system of the invention. The two systems of which Figs. 11 and 12 are each a part may be the same except that one is adapted for self-synchronization and the other for separate synchronization;

Fig. 13 illustrates a radio transmitting station adapted in common for transmission of a telegraph signal and for transmitting directly a synchronizing wave. This illustrates a method of generating a synchronizing wave alternative to that of Fig. 8. The method is used in the operation of the system of Fig. 7 modified by the substitution of the circuits of Fig. 14;

Fig. 14 illustrates a circuit that may be substituted for the portion of the receiving circuit of Fig. 7 at the left of line X—Y; and

Fig. 15 illustrates the double-hump resonance curve of the circuit of Fig. 14.

The elements of the circuits illustrated will be identified thereon by reference letters which are suggestive of their functions. For example, the labels S, M, AN, C, HFA, TIS, RSS, TISS, RISS identify elements whose functions relate respectively to a synchronizing wave, a modulator, an antenna, a carrier wave, a high frequency amplifier, a transmitting intermixing selector, a receiving-separating selector, a transmitting interspacing selector, and a receiving interspacing selector. The elements whose functions require the same literal designations will be differentiated by the use of different subscripts. The elements in similar systems or circuits which cooperate in an identical manner with the remaining elements in the respective systems will be given identical reference labels. Different reference labels will be applied to features which distinguish one system from another previously described, and the detailed description will be confined to these novel features.

Referring to Fig. 1, the portion at the left comprises the circuits at the transmitting station, and the portion at the right the circuits at the receiving station, of a diplex radio carrier wave signaling system arranged for self-synchronization.

The two transmissions are based on a single carrier wave supplied by carrier source C. The carrier wave is modulated by and in accordance with modulating currents produced in circuits 1 and 2 in modulators M and $M_1$ respectively, to produce the modulated carrier waves required for the two transmissions. The modulating currents may be amplified by low-frequency amplifiers LFA, and $LFA_1$ before being impressed on the respective modulators.

The modulating currents may be of any kind capable of being used in carrier wave signaling including speech or telegraphic code impulses. In the interest of uniformity of disclosure of the various systems, microphonic modulating current generating means 3 and 4 are indicated. However, the one-way systems of the invention, for example—the diplex and double-diplex systems, are probably better adapted for telegraphic than for telephonic operation.

The modulators may each be of any conventional type, for example, one type is described in U. S. patent to Van der Bijl, 1,350,752, August 24, 1920. The amplifier LFA and other amplifiers not yet described in this and other figures, as well as the other elements disclosed in diagrammatic form, are each well known in the art in many specific forms and are sufficiently described in this specification, by a statement of their respective functions, except where a detailed description is given.

The synchronizing wave is generated by local source S and is impressed on the transmitting intermixing selector TIS, in which the synchronizing and the two carrier modulated waves cooperate, to the end that the two modulated carrier waves are alternately impressed on output circuit 5. The intermixing selector is illustrated in detail in Fig. 2 and will be described later.

The resulting waves are amplified by high frequency amplifier HFA and transmitted by conductor AN. This conductor here takes the form of an antenna, typifying other means that could be employed, such as a line wire. The synchronizing wave is of super-audible frequency so that a receiving operator would not be conscious of the commutating operation except to the extent that the quality is slightly impaired by the deletion of half of the wave, in the form of elements minutely divided and uniformly distributed on a time basis.

The synchronizing wave, which is used at the receiving station in a manner analogous to the method of operation of the transmitting intermixing selector is continuously transmitted as a modulation of the carrier wave by utilizing the modulators employed in signal modulation, such wave being impressed on the respective modulators by circuits 6 and 7.

Condensers 8 and 9 have large impedance for the relatively low frequencies of the signal and synchronizing currents so as not to effect the coupling of the low frequency circuits to the modulators, but they have small impedance for the carrier current so as to be able effectively to by-pass this current around these circuits.

Refering now to the receiving station of Fig. 1, the complex incoming wave, comprising a carrier wave on which are impressed as amplitude variations the synchronizing wave and one or the other of the signal waves, depending on the instant of time considered, is received by antenna $AN_1$. The loop antenna typifies any known type of receiving antenna which may be used.

The received waves are amplified by high frequency amplifier $HFA_1$. One portion of the amplified wave is demodulated in demodulator D. Among the products of this operation is a reproduced synchronizing wave. This wave will be continuous, since each of the two signal modulated waves transmitted to this station carries a synchronizing wave as a modulation component. The reproduced synchronizing wave is selected from the other components, which include the reproduced superposed signal waves of all the channels, by selective circuit FS, amplified by low frequency amplifier $LFA_2$, and transmitted to the receiving separating selector. The circuit FS may comprise a series of coupled tuned circuits which are each tuned to the synchronizing frequency. Single frequency selective circuits of this kind are well known.

The remaining portion of the received wave is amplified in amplifier $HFA_2$ and impressed on the receiving separating selector RSS. The receiving separator selector is illustrated in detail in Fig. 3. Its function is complementary to that of the transmitting intermixing selector, that is, it distributes the intermixed carrier modulated waves between output circuits 10 and 11 so that each of these circuits contains only those portions corresponding to an individual one of the signaling currents produced in circuits 1 or 2 at the transmitting station. By separating the component parts of the received modulated waves in this manner intelligible reception and indication of the respective signal currents is made possible. These remaining steps comprise demodulation in devices $D_1$ and $D_2$ which are analogous in operation and may be similar in structure to modulators M and $M_1$, separation of the reproduced signal current from the reproduced synchronizing current by low pass filters LPF and $LPF_1$, and indication in telephone receivers R and $R_1$. The low pass filters may, for example, be of the type described in the U. S. patent to Campbell, 1,227,113, May 22, 1917.

Fig. 2 illustrates a transmitting intermixing selector. It comprises the two three-electrode electric discharge devices 12 and 13 and associated circuits. The labels identifying the circuits incoming to and outgoing from the devices indicate how the selector is used in a multiplex system of the invention. The circuit from each of the modulators is arranged with respect to its immediate associated device so as to cause said device to function like a conventional repeater. However, each of the devices is operated to repeat the impressed modulated carrier wave only during alternations of the synchronizing wave of a particular sign which is different for the two devices. This results from the mode of impressing the synchronizing wave which results in a variation of the control electrode potentials of the two devices in opposite senses with respect to their cathodes.

The operation of this selector can be better understood by reference to Fig. 4, the curve of which illustrates the well known control electrode potential-space current characteristic of a three-electrode electric discharge repeater. The labels $E_c$ and $I_b$ applied to the coordinate axes indicate respectively these two quantities. The potential of the control-electrode-biasing source 14 of Fig. 2 is adjusted to a value corresponding to the abscissa A of Fig. 4. The variation of potential produced at the synchronizing source has a magnitude A—B or A—C. Accordingly, when the polarity of the wave impressed from a synchronizing wave source tends to decrease the control electrode potential, the space current is reduced to substantially zero while during the alternations of opposite sign the normal space current is greatly increased. This means that the output currents of the two devices are commutated so that each is impressed on the transmitting antenna only during half of the time and at different times than in the case of the other. It is preferable, although not necessary, that the potential B correspond to the point on the curve where the slope, and hence the amplification, is the maximum.

Fig. 5 illustrates by means of the same characteristic curve as in Fig. 4, an alternative method of operating the intermixing selector. In this method the control electrodes are normally biased to potentials corresponding respectively to points D and E, as by means of separate batteries in the control electrode leads. The primary windings of the transformers for impressing the synchronizing wave are so related that the variations of control electrode potential of the two devices have the same phase. The variation of potential is sufficient to cause the resultant control electrode potential of one of the other device to have the value F, or the values for the two devices may be slightly different but close to this value, which corresponds to substantially the point of maximum slope of the curve. The synchronizing wave will in turn make the devices operative for repeating, to produce the same ultimate effect as in the other method of operation.

Fig. 3 illustrates a receiving separating selector which comprises an arrangement of two three-electrode electric discharge devices 15 and 16 and associated circuits, which is very similar to that of Fig. 2. The labels applied to the various circuits indicate how the selector is used in the multiplex systems of the invention. The arrangement of the circuits comprising the selector of Fig. 3 is identical with that of Fig. 2 except as modified by the fact that, from considerations of the basic functions of the two selectors, the two modulated waves in the intermixing selector must necessarily be impressed from different circuits and the resultant intermixed waves must be transmitted from it in a single circuit, while in the case of the separating selector, the converse operation and arrangement of circuits is necessary. The internal operations of the selectors are identical. Figs. 4 and 5 are each equally applicable to both selectors.

Fig. 6 illustrates certain practical features of operation of the system of Fig. 1. Curve G represents the synchronizing wave plotted to a time scale of abscissæ. Curve H represents the wave radiated from the transmitting antenna when the carrier wave is being transmitted by means of both channels. Curve I represents the same wave when the carrier wave is being transmitted by means of only one channel. Curve H accordingly is a composite of two curves each representing the carrier transmitted from an individual one of the channels, the transmissions for the two channels occurring, by reason of the function of the intermixing selector, during alternate periods of time. In order to avoid confusion, the variations of amplitude of the carrier waves of curves H and I illustrating the effects of telephone modulation thereof by the signal currents are not shown, but are capable of being represented in the conventional manner. For telegraphic operation waves of the form of curve I will be interrupted in accordance with a telegraph code. The curves also illustrate the similar quantities at the receiving station.

Obviously, the nearer the synchronizing wave approaches a rectangular form, as distinguished from the sine form for example, the nearer the operation approaches the condition in which commutation is attended by no other effect than the interruption of the modulated carrier. The faithfulness with which telephonic messages can be transmitted from the transmitting station and reproduced at the receiving station obviously is a direct function of the nearness of approach to this condition. The form of synchronizing wave is substantially immaterial in the case of telegraphic operation. As will be shown below the use of a rectangular wave form for the synchronizing wave is also conducive to efficiency of operation from an energy standpoint.

Fig. 7 illustrates a diplex system which differs from that of Fig. 1 to the extent required by the fact that it uses a synchronizing wave transmitted from a third station as a modulation of a changing frequency carrier wave. The form of this wave is indicated in Fig. 9, in which the two portions on either side of the dashed line exhibit different carrier frequency characteristics, the synchronizing wave being represented as the envelope of said double frequency carrier wave. There is no necessary relation between the duration of time when either of these carrier frequencies occur and the period of the synchronizing wave, since the change of frequency has to do only with the simultaneous operation of the circuit for signaling purposes.

The modulated changing frequency carrier wave of the form illustrated in Fig. 9, which is transmitted from the synchronizing station is received at the transmitting station of Fig. 7 on receiving loop antennæ $AN_2$ $AN_3$, which are, respectively, tuned to the two frequencies. The two portions are then amplified by amplifiers $HFA_3$ and $HFA_4$, combined and demodulated in demodulator $D_3$, amplified in amplifier $LAF_3$ and impressed on the transmitting intermixing selector TIS. The remaining portions of the transmitting circuit are the same as in the system of Fig. 1, except that the circuits for transmitting the synchronizing wave are dispensed with for obvious reasons.

Considering the receiving station of this system the antennæ $AN_4$ and $AN_5$, the high frequency amplifiers $HFA_5$ and $HFA_6$, demodulator $D_4$ and the low frequency amplifier $LFA_4$ function in the same manner as the corresponding elements $AN_2$, $AN_3$, $HFA_3$, $HFA_4$, $D_3$ and $LFA_3$ of the transmitting station, to reproduce the synchronizing wave. This wave is then impressed on the receiving separating selector. The remaining portions of the circuits at the receiving station are the same as in the receiving circuits of Fig. 1, except that, by reason of the separate transmission and reception of the synchronizing wave, the elements D, $LFA_2$ and FS of Fig. 1 are dispensed with.

Fig. 8 illustrates a type of radio station adapted to transmit a wave of the form disclosed in Fig. 9. It is adapted to cooperate with the system of Fig. 7 just described or with the quadruplex system of Fig. 10 to be described.

The circuit comprises in part sources $C_1$ and $C_2$ for simultaneously generating carrier waves of two different frequencies, high frequency amplifier $HFA_7$, a transmitting antenna $AN_6$, and the switching means 17 for alternately connecting the carrier sources to the amplifier and antenna in response to a telegraph code. These carrier waves are modulated in modulators $M_2$ and $M_3$, which are included in the circuits of the carrier sources, by synchronizing waves from source S. The modulators $M_2$ and $M_3$ may be of the Van der Bijl type disclosed in the above mentioned United States patent or any other type capable of accomplishing the same ultimate result.

The antenna circuit is normally resonant at the frequency corresponding to that of the carrier wave from source $C_2$. When switching means 17 is actuated to the position alternative to that illustrated so as to impress the wave from source $C_1$ on the antenna, a circuit is closed through contact 18 and relay 19, which connects condenser 20 in shunt to a portion of the antenna circuit and changes the resonant frequency of the antenna circuit to correspond with the frequency of the impressed wave.

Since examples of a self-synchronizing and a separate synchronizing diplex system have been described, there is a basis for a comparison of the effects of self- and separate synchronization with each other and with an ordinary simplex system.

As discussed with reference especially to Figs. 4 and 5 and as shown in Fig. 6, the amplitude of the synchronizing wave must be substantially equal to the amplitude of the carrier waves, or of the modulated waves if telephonic transmission, for example, is assumed. This means that in a self-synchronization system substantially half of the energy capacity of the system, particularly the antenna, is utilized for synchronization.

If W is the output energy capacity of a given station, $\frac{W}{2}$ is accordingly the energy available for signaling. In an ordinary simplex system the wave corresponding to curve I of Fig. 6 would have a substantially rectangular form. The form shown in curve I is due to the operation of the intermixing selector and results in a decrease of average amplitude by the factor $\frac{2}{\pi}$, assuming a sine wave form for the envelope of the wave. Accordingly, the energy received with a self-synchronization system of the invention, when both channels are in operation, would equal $\frac{W}{2}\times\frac{2}{\pi}$, as compared with $W$ for the operation of the ordinary simplex system, i. e., there is somewhat less than half of the available energy used for signaling. In a separate synchronization system the energy would correspondingly be $W \times \frac{2}{\pi}$, i. e. the greater proportion of the available energy is usefully employed for signal transmission. For each channel, of course, the corresponding quantities are ½ of those indicated above.

From the standpoint of energy used, as compared with ordinary simplex communication, there are advantages in the multiplex system of the invention, since with the same total energy twice as many channels of communication may be operated, although with some sacrifice of quality. From the standpoint of freedom from static and other interference, since the readability of the eventually reproduced signals is proportional to the ratio of the energy level of the transmissions and the static energy level, both at the receiver, the conditions favor a simplex system in the ratio $\frac{W}{W\times 1/2\times 2/\pi}$ or $\pi$, for each transmission for separate synchronization, and in the ratio $\frac{W}{W/2\times 1/2\times 2/\pi}$ or $2\pi$ in the similar case of self-synchronization. As a practical matter the effective ranges are correspondingly limited. This means that for the same total energy used, a greater range is possible with separate than with self-synchronization.

To the extent that the synchronizing wave can be made to approximate a rectangular form, the comparison is more favorable for the multiplex method, because it would result in the elimination of the factor $\frac{2}{\pi}$ in the above equations.

The use of a separate station for transmitting the synchronizing wave does not require the use of additional energy for that purpose, since the modulation of the carrier wave at this station does not increase the energy transmitted from that station over what can be usefully employed for signal purposes, i. e., the amplitude of the carrier waves at that station can be adjusted so that the amplitude of the resulting modulated wave is the same as the amplitude of the carrier wave that would otherwise be used.

Fig. 10 illustrates the circuits at either station of a quadruplex system embodying the same principles as have been applied in earlier described systems to one-way systems. Since the transmitting and receiving circuits may be identical at the two stations, the figure equally represents the circuits of either one-way branch of such systems, including both stations. The transmitting and receiving circuits of the figure differ only by the addition of certain elements, from the transmitting and receiving circuits of Fig. 7, for example. The description will be confined largely to these additional elements.

The principal characteristics that distinguish this system from the one-way systems already described are the use of four, instead of two transmissions, and the division of these transmissions between two directions. This requires that each transmission shall occur only one-fourth of the time. This is accomplished in the specific system of the figure by transmitting in one direction during the first and second quarters of a given unit of time and transmitting in the other direction during the third and fourth quarters of the unit. Different commutation means at each of the transmitting and receiving circuits effect the commutation between the transmissions in one direction and between the transmissions in opposite directions. Because the two transmissions in each direction must take place during one alternation of the commutating frequency used at the commutator which commutates between opposite directions, the commutating frequencies must have a harmonic relation.

In Fig. 10, a single synchronizing frequency is used. The first even harmonic is used for commutating between transmissions in the same direction and the fundamental frequency is used for commutating between transmissions in opposite directions. Since, even though the signal energy is radiated from each station during only one-half the time, the fundamental component of the synchronizing wave must be transmitted to the distant station all of the time, a self-synchronization system, at least of the type that has been described, cannot be used. A wave from a third station like that illustrated in Fig. 8 can be used and is here assumed.

The synchronizing wave is received by antenna $AN_6$, which is tuned broadly enough to efficiently receive both frequencies of the carrier wave. Two antennæ, as in Fig. 7, could equally well be used. The synchronizing wave is amplified in amplifier $HFA_7$ and impressed on demodulator $D_3$. Demodulator $D_3$ and amplifier $LFA_3$ function as do the similarly labeled elements in Fig. 7. The resultant synchronizing frequency is impressed on harmonic generator HG, in which there is produced a first even harmonic thereof. This harmonic generator may be an overloaded amplifier of the type described in U. S. Patent to Kendall 1,446,752, granted February 27, 1923. This harmonic is selected by selective circuit $FS_1$ and impressed on transmitting intermixing selector TIS, which functions as described above (Fig. 2).

The fundamental component is impressed through circuit 21 on the other commutating means, hereinafter denominated a "transmitting interspacing selector", TISS. This device functions on the same principle as the intermixing selector of Fig. 2 and may differ therefrom structurally to the extent that only one of the electric discharge devices 12 and 13 are used, since transmission occurs during only one-half of the time. The resultant wave is amplified in high frequency amplifier $HFA_8$, which functions in a similar manner to amplifier HFA of Figs. 1 and 7, and radiated from antenna AN.

In the receiving circuit of Fig. 10, the carrier wave modulated by the synchronizing wave is received on antenæ $AN_4$ and $AN_5$ and the synchronizing wave eventually reproduced by a series of steps similar to that used in the system of Fig. 7. A single antenna as in the transmitting circuit alternatively to the arrangement illustrated may be used, if desired. The reproduced synchronizing wave is selected by selective means $FS_2$ and amplified by low frequency amplifier $LFA_4$. A portion of it is then impressed on receiving interspacing selector RISS, which functions in identical manner as the transmitting interspacing selector. Care must be taken, as by proper poling of the transformers concerned in this function, to insure that this selector selects the currents corresponding either to the transmissions from the transmitting circuit of Fig. 10 or the transmissions in the opposite direction, dependent on whether the receiving circuit illustrated is that at the distant station or at the same station, respectively.

The other portion of the synchronizing wave is impressed on harmonic generator $HG_1$, which produces a first even harmonic in the same manner as the similar device HG of the transmitting circuit. Selective circuit $FS_2$ insures that the harmonic generator $HG_1$ is not affected by frequencies other than the synchronizing wave.

Selector circuit $FS_3$ selects the first even harmonic and impresses it on the receiving separating selector RSS. This selector and the elements associated with its output circuit are identical with the identically labeled elements in Fig. 7.

Although a quadruplex system makes possible the simultaneous transmission of four messages, as compared with two messages when using the systems of Figs. 1 and 7, it is less efficient from the standpoint of static elimination, if a given total energy capacity is assumed, since energy is being transmitted in either direction only one-half of the time.

Figs. 11 and 12 illustrate, respectively, a transmitting circuit and a receiving circuit of a double-diplex system, i. e., a system characterized by four simultaneous transmissions in one direction. Two systems each using a transmitting and a receiving circuit like Figs. 11 and 12, together would constitute the equivalent of two quadruplex systems, different carrier frequencies being used in the two directions. The same arrangement of the two commutating means described with reference to Fig. 10, are here used to insure proper commutation between the four frequencies transmitted in each direction. The principle of operation is the same. The interspacing selectors, however, must commutate between two groups of transmissions, so that an arrangement like that of Fig. 8 including both electric discharge devices must be used. The transmitting circuit of Fig. 11 is arranged for self-synchronization. The receiving circuit of Fig. 12 is capable of being used with the self-synchronization system of Fig. 11 or in a separate synchronization system accordingly the circuits of Figs. 11 and 12 may be considered either as parts of one complete double-diplex system or the transmitting and receiving portions of two distinct double diplex systems, either alternative to each other or constituting together a double quadruplex system.

Referring to Fig. 11, $S_1$ represents a means for generating a wave of the synchronizing frequency and the first harmonic thereof. It may, for example, comprise a combination of a synchronizing source, such as S of Fig. 1, and a harmonic generator, such as HG of Fig. 10. Selective circuit $SF_4$ selects the first even harmonic which is amplified by low frequency amplifier $LFA_6$ and impressed on transmitting intermixing selector TIS. The elements 1, 2, 3, 4, C, M, and $M_1$ are the same as the similarly labeled elements in the other figures and cooperate similarly with the intermixing selector TIS. A portion of the first harmonic also is impressed on transmitting intermixing selector $TIS_1$ which cooperates with elements similar to those just mentioned to similarly commutate between the other two transmissions.

The fundamental component of the synchronizing wave is selected by selective circuit $FS_5$ and impressed with the output currents from intermixing selectors TIS and $TIS_1$ on transmitting interspacing selector $TISS_1$. As a result of the operation of this selector, there is produced, and transmitted by means of power amplifier FPA and antenna AN, a wave which at equally distributed intervals of time comprises energies corresponding to the four transmissions.

In the self-synchronization system of Fig. 11, the synchronizing wave is transmitted directly, instead of as a modulated component of the carrier wave as in Fig. 1. This is accomplished by superposing on the message waves in the input of power amplifier PA the synchronizing wave, which is transmitted thereto by means of circuit 22. The antenna circuit is tuned broadly enough to radiate both the carrier and synchronizing frequencies.

Referring to Fig. 12, this figure illustrates the receiving circuits of a separate synchronization double-diplex system or of a self-synchronization system using the method of transmitting the synchronizing wave disclosed in Fig. 11. They may either be the receiving circuits at the distant station cooperating with the transmitting circuits of Fig. 11 or the receiving circuits at the same station as those transmitting circuits.

The synchronizing wave is received by antenna $AN_7$ and amplified by high frequency amplfier $HFA_9$. The fundamental as well as the first even harmonic of the frequency of this wave is required. Although a harmonic generator could be used to generate this first even harmonic as in Fig. 10, this figure illustrates an alternative means for accomplishing this result. Device DO is an oscillator which normally oscillates at a frequency very close to the fundamental frequency and the output wave of which has a pronounced first even harmonic. The oscillating condition of this oscillator, which may be of the electric discharge type, is such that this frequency is effected by the frequency of a strong oscillation impressed thereon. The synchronizing wave accordingly drives this oscillator, that is, causes it to oscillate at the impressed frequency.

This arrangement constitutes a means for greatly amplifying the received wave and for simultaneously producing an amplified first even harmonic thereof and is the full equivalent of the means which has been disclosed in other figures. However, a single frequency synchronizing wave is required so that a third station supplying this wave would not be well adapted for also producing a signaling wave as in the case of the circuits of Fig. 8.

The fundamental frequency is selected by selective circuit $SF_6$ and impressed on receiving interspacing selector RISS, on which is also impressed signaling waves received by antenna $AN_1$ and amplified by high frequency amplifier $HFA_1$. The resulting signaling waves are impressed on the receiving separating selectors RSS and $RSS_1$ on which is also impressed the first even harmonic of the fundamental frequency, selective circuit $FS_7$, low frequency amplifier $LFA_7$, and circuit 23. The finally separated signaling waves are demodulated by demodulators $D_1$, $D_2$, $D_3$, and $D_4$, and indicated in the telephone receivers R, $R_1$, $R_2$, and $R_3$, respectively. The operation of the various selectors in this figure is so nearly the same as that of the corresponding selectors in the transmittig circuit of Fig. 11 and in the circuits of the other figures that further explanation is not considered necessary.

Fig. 14 illustrates an arrangement for receiving a synchronizing wave which is alternative to that shown at the left of line X—Y of Fig. 7. The synchronizing wave assumed for the operation of this means is a changing frequency wave, such as may be produced by the circuit of Fig. 13, to be described. This method of transmitting a synchronizing wave, in which the carrier wave itself is the synchronizing wave, is contrasted with the method above described in which the synchronizing wave is transmitted as a modulated component of the carrier wave. The carrier wave may equally well, as in the previous example, be additionally used for signaling purposes.

This changing frequency wave is received on antenna $AN_8$ which is loosely coupled through condenser 24 to the tuned circuit 25. The tuning of the antenna and of the tuned circuit 25 is preferably the same and is such that when the coupling is adjusted so that the two humps of the resultant resonance curve are spaced apart by an interval corresponding to the spacing of the two carrier frequencies, the maxima of these two humps will be coincident with the two carrier frequencies. Fig. 15 illustrates the double hump character of the resonance curve. For a relatively loose coupling, so that the frequencies corresponding to the humps are relatively close together, the frequency of tuning of the antenna and of the resonant circuits will be substantially the arithmetic means of the frequencies of the humps. The phenomena accompanying the production of a double hump resonance curve are well known. For a theoretical consideration of the underlying principles, reference is made to Morecroft's "Principles of Radio Communication" pages 94 et seq. Obviously, the same principle could be used if the synchronizing wave were transmitted as a modulation of a double frequency carrier wave, in which case the arrangement of Fig. 14 could be used in the system of Fig. 7 in a similar manner except that it would be substituted for the receiving circuits of Fig. 7 at the left of the demodulator $D_4$ instead of at the left of line X—Y.

Fig. 13 illustrates a radio transmitting circuit which may be used to transmit the double frequency carrier wave used in the circuit of Fig. 14. The circuit comprises merely an electric discharge oscillator 26 oscillating into the antenna circuit the tuning of which determines the frequency of oscillation. This frequency may be changed in accordance with a telegraphic code by means of key 27. As in the case of the circuit of Fig. 8, the arrangement makes possible the simultaneous use of the circuit without increased energy consumption, for telegraphic signal transmission and for transmission of the synchronizing wave. Obviously the circuit of Fig. 8 could be made the functional equivalent of that of Fig. 13 by omitting the synchronizing source S.

It will be understood that details of the circuits and methods herein set forth may be embodied in organizations widely different from those illustrated without departing from the spirit of the invention which is defined by the following claims.

What is claimed is:

1. The method of multiplex carrier wave communication between two stations, which comprises simultaneously communicating between said stations by a plurality of modulated carrier waves employing the same carrier frequency and commutating all of such waves at a super-audible rate in such manner that at each instant of time, and in sequence, the waves corresponding to one and only one of the channels are transmitted between said stations.

2. The method of multiplex carrier wave communication between two stations employing terminal transmitting and receiving apparatuses individual to each of several modulated carrier wave communication channels, all of which use the same carrier frequency, and a transmitting path used in common for such waves between such transmitting and receiving apparatuses, which comprises simultaneously operating such apparatuses for all of said channels and at the same time commutating all of the resultant modulated carrier waves at superaudible frequency in such manner that at each instant of time only the transmitting and receiving apparatus individual to one channel are operatively connected to said path.

3. In a multiplex signaling system, means for generating and transmitting between two stations at least two carrier waves having the same frequency, means for modulating each of said waves at one station in accordance with a signal, corresponding means at the respective opposite stations for demodulating each modulated wave and commutating means at each station adapted to alternately provide a complete operative channel for each transmission, said commutating means being adapted to operate at a super-audible frequency.

4. In a multiplex signaling system, means providing the terminal equipment of at least two complete modulated carrier wave channels between two stations, said channels being adapted to use the same carrier frequency, and synchronously operated commutating means at the two stations whereby only one channel is operative for transmission between said stations at each instant of time, said commutating means being adapted to operate at a super-audible frequency.

5. In a carrier wave communication system in combination, terminal equipment at each of two stations for a complete multiplex signal modulated carrier wave system using the same carrier frequency for all channels, a transmitting path between said stations, and synchronously operated commutating means at each station adapted to alternately and at a super-audible frequency effectively connect the terminal equipment individual to each channel to the station terminals of said transmitting path.

6. The system of claim 5 in which the commutating means at each station comprises an electric discharge path in each channel and means whereby the discharge paths for the respective channels are alternately rendered conductive for discharge current in response to electric variations impressed on said discharge paths.

7. The system of claim 5, in which the commutating means at each station comprises electric discharge means between the terminal equipment of each channel and said path, and means whereby the impedance of said discharge means is varied in response to electric variations impressed thereon; said system including, additionally, means for transmitting a synchronizing wave to each of said stations for providing said electric variations.

8. The system of claim 5, in which the commutating means are responsive to electric variations impressed thereon; and including additionally a radio transmitting station for transmitting said electric variations to each station of the communication system.

9. The system of claim 5, in which the transmitting path comprises etheric space and in which the commutating means at each station comprises means responsive to electric variations; and including additionally a separate radio station comprising means for transmitting a separate telegraph signal by varying the frequency of a carrier wave, and means for impressing amplitude variations on said changing frequency carrier wave in response to the desired electric variations to be used in the multiplex system.

10. The system of claim 3 in which the commutating means are responsive to electric variations impressed thereon; and including, additionally, means for transmitting said electric variations as a modulated component of said carrier frequency.

11. The system of claim 3 in which the commutating means are responsive to electric variations impressed thereon; and including additionally means for generating said electric variations and for impressing them on each of said modulators whereby there is transmitted at all times with the commutated signal modulated waves the same carrier wave modulated in accordance with said variations.

12. A transmitting station of a multiplex one-way carrier wave system, comprising means for generating a plurality of carrier waves, all having the same frequency, means for modulating each of said waves in accordance with a signal, a transmitting conductor, and commutating means whereby the resultant signal modulated carrier waves are alternately impressed on said conductor, such alternations recurring at a super-audible frequency.

13. A transmitting station for a multiplex one-way radio carrier wave communication system, comprising means for generating a plurality of carrier currents all having the same frequency, means for modulating each of said waves in accordance with a signal, a transmitting antenna, and commutating mean whereby the resultant signal modulated carrier waves are alternately impressed on said antenna, such alternations recurring at a super-audible frequency.

14. A diplex radio communication system comprising a transmitting station, a receiving station, and means for impressing on each of said stations a synchronizing wave having a superaudible frequency, said transmitting station including in combination means for generating a carrier wave, means for simultaneously modulating said carrier wave in accordance with two distinct signal waves, a radiating means, means responsive to the alternations in sign of said impressed synchronizing wave to correspondingly alternately impress the two signal modulated waves on said radiating means and said receiving station including in combination a receiving conductor, a demodulator and an indicator corresponding to each of the two signal modulated waves, and means responsive to the alternations in sign of said synchronizing wave to correspondingly alternately impress the incident signal modulated waves on said demodulators.

15. A double-diplex radio communication system comprising a transmitting station, a receiving station, and means for impressing on each of said stations a synchronizing wave and a first even harmonic thereof; the transmitting station comprising in combination means for generating a carrier wave, means for simultaneously modulating said carrier waves in accordance with four distinct signal waves, means responsive to the alternations in sign of said harmonic wave to correspondingly effect the alternate transmission of two of the signal modulated waves, similar means responsive to the alternations in sign of said synchronizing wave to correspondingly effect the alternate transmission of the remaining two signal modulated waves, and means posterior to the last two mentioned means in the direction of transmission responsive to the alternations in sign of said synchronizing wave to correspondingly effect the alternate transmission of the above two groups of signal modulated waves, and means for radiating the resultant commutated signal modulated carrier wave; and said receiving station including in combination a receiving antenna, two receiving circuits associated therewith, means responsive to the alternations of sign of said synchronizing wave to correspondingly alternately impress the two groups of signal modulated waves incident on the receiving antenna on said receiving circuits, means in one of said receiving cricuits responsive to the alternations in sign of said harmonic wave to correspondingly effect the alternate transmission of the two signal modulated waves impressed on said circuit, similar means in the other receiving circuit responsive to the alternations in signal of the said harmonic wave to correspondingly effect the alternate transmission of the signal modulated waves of the other group, and a demodulator and an indicator for each of the resultant separated signal modulated carrier waves.

16. A quadruplex radio communication system comprising at each station, a transmitting circuit, a receiving circuit, and means for impressing on said transmitting and receiving circuits a synchronizing wave and the first even harmonic thereof; the transmitting circuits comprising in combination, means

for generating a carrier wave, means for modulating said carrier wave in accordance with two distinct signal waves, means responsive to the alternations in sign of said harmonic wave to correspondingly effect the alternate transmission of said signal modulated waves, means posterior to the last mentioned means in the direction of transmission responsive to the alternations in sign of said synchronizing wave to correspondingly effect the transmission of said signal modulated waves during alternations of one sign of said synchronizing wave, and means for radiating the resultant signal commutated signal modulated waves; and said receiving circuits comprising in combination a receiving antenna, a circuit associated therewith, means responsive to the alternations in sign of said synchronizing wave, to render said associated receiving circuits operative for transmission during the alternations of said synchronizing wave having a sign opposite to that correspondingly used at the transmitting circuits, two circuits branched from said associated circuit, means in said associated circuit responsive to the alternations in sign of said harmonic wave to correspondingly alternately make said branched circuits operative for transmission and a demodulator and an indicator in each of said branched circuits.

17. The system of claim 14 in which the means for impressing the synchronizing wave on said stations comprises in combination; a radio transmitting station having means for transmitting signals in accordance with a telegraph code by changing the frequency of the radiated wave, and means for modulating said change in frequency wave in accordance with the synchronizing wave; and at each of said stations antennæ respectively tuned to one of the frequencies of said changing frequency wave, demodulating means for combining the portions of the carrier wave received by said antennæ, and obtaining therefrom a reproduced synchronizing wave, and means for impressing said synchronizing wave on the circuits of said stations.

18. The system of claim 16 in which the means for impressing on the transmitting and receiving circuits at each of said stations the synchronizing wave and the first even harmonic thereof comprises in combination; a radio transmitting station including means for transmitting a telegraphic code signal by changing the frequency of a radiated carrier wave, and means for modulating said changed frequency carrier wave in accordance with the synchronizing carrier wave; and at each of said stations a means for receiving the changing frequency wave modulated by said synchronizing wave, means for reproducing the synchronizing wave therefrom, means responsive to said synchronizing wave for producing the first even harmonic thereof, and means for impressing said synchronizing wave, and the first even harmonic thereof, on the transmitting and receiving circuits of said station.

19. A system comprising means for controlling a wave-conveying-channel in accordance with the sign of impulses of an alternating current and additional means for controlling said channel in accordance with the sign of impulses of a current of multiple frequency derived from said alternating current.

In witness whereof, we hereunto subscribe our names this 26th day of January, A. D. 1925.

E. MAURICE DELORAINE.
EDWARD KENNETH SANDEMAN.