May 8, 1928. 1,668,637

L. ESPENSCHIED ET AL

DIRECTIVE RADIO REPEATING SYSTEM

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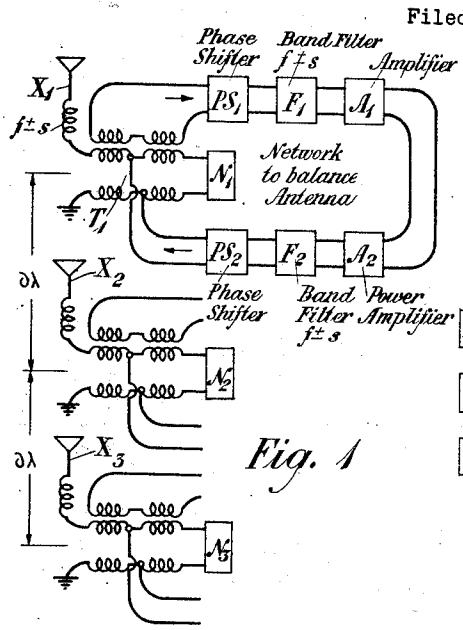


Fig. 1

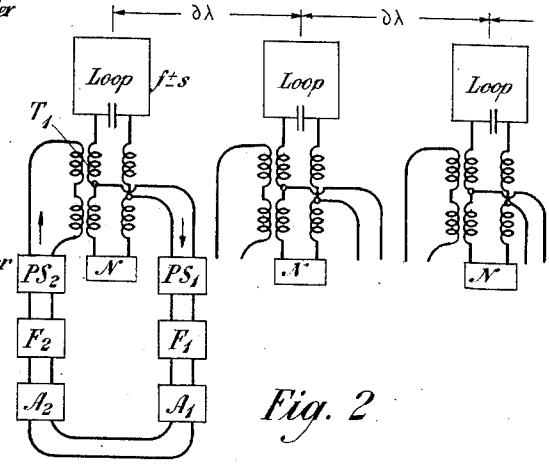


Fig. 2

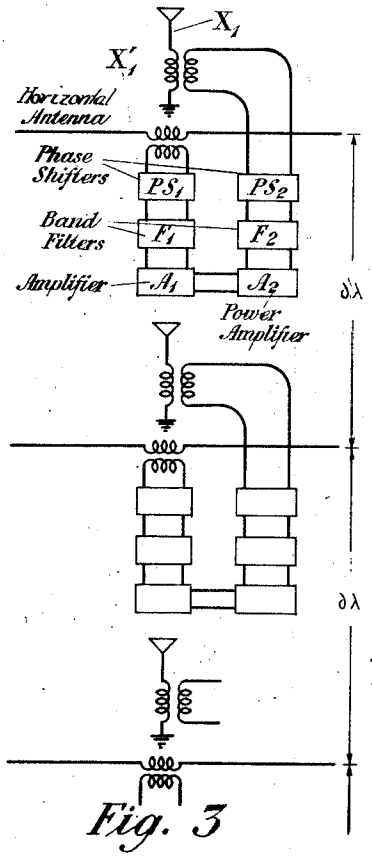


Fig. 3

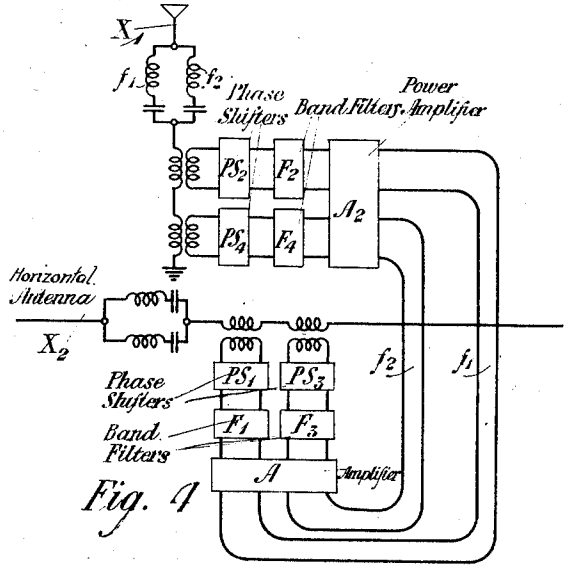


Fig. 4

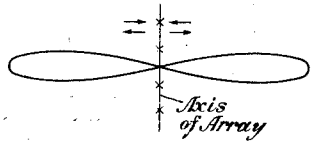


Fig. 4a

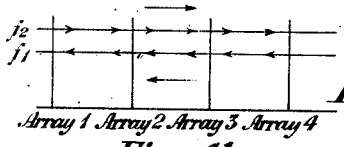


Fig. 4b

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4 Sheets-Sheet 2

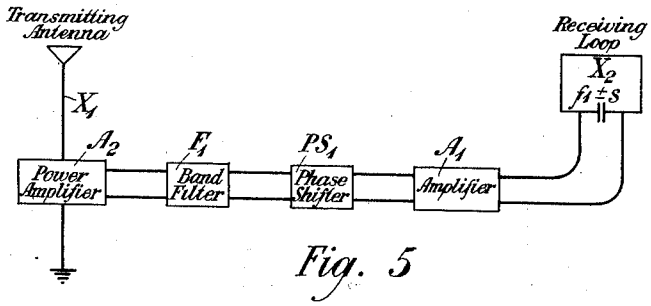


Fig. 5

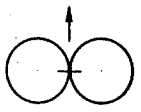


Fig. 5a

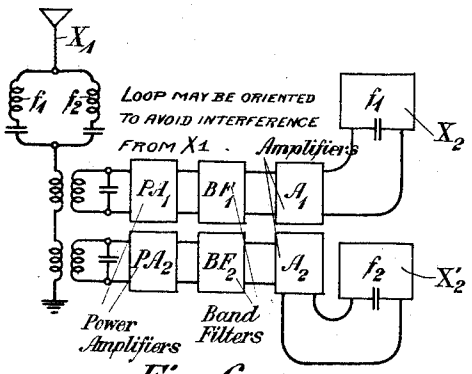


Fig. 6

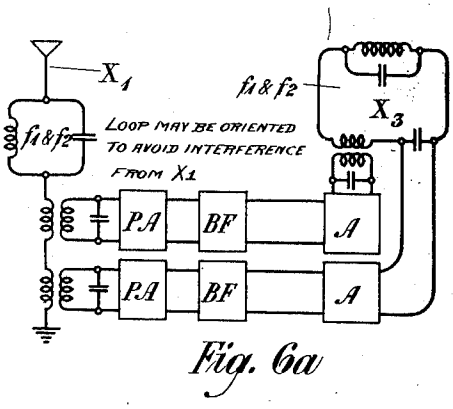


Fig. 6a

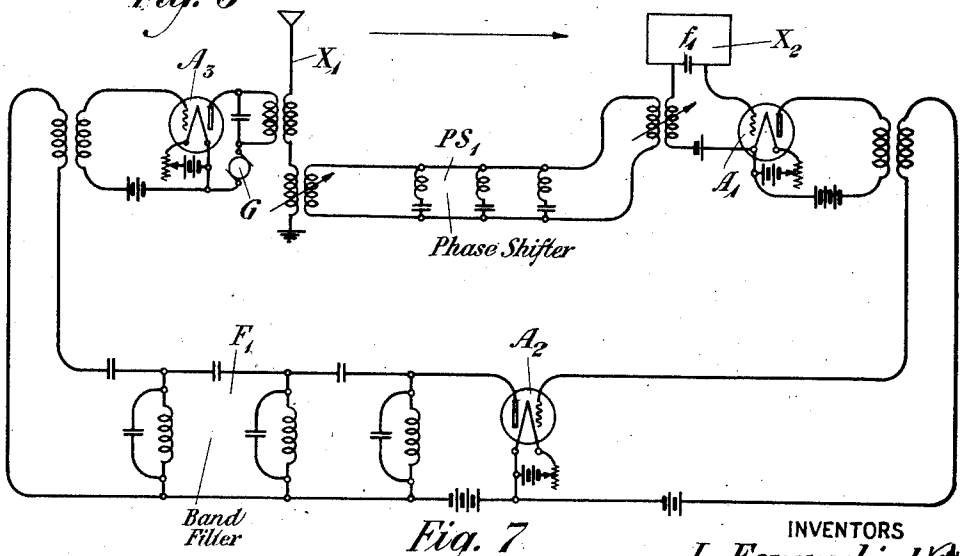


Fig. 7

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DIRECTIVE RADIO REPEATING SYSTEM

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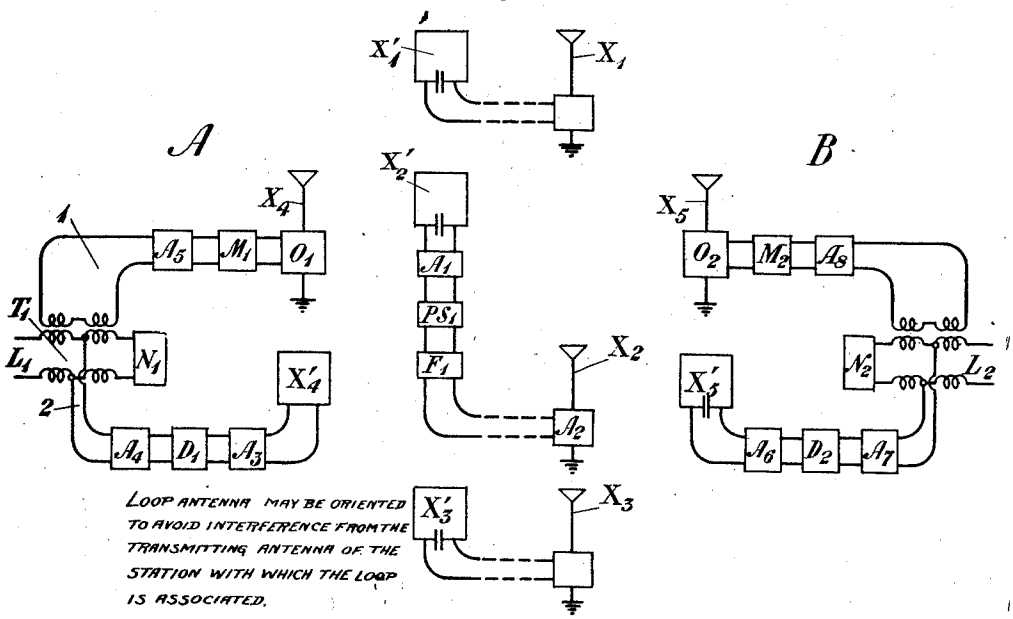


Fig. 8

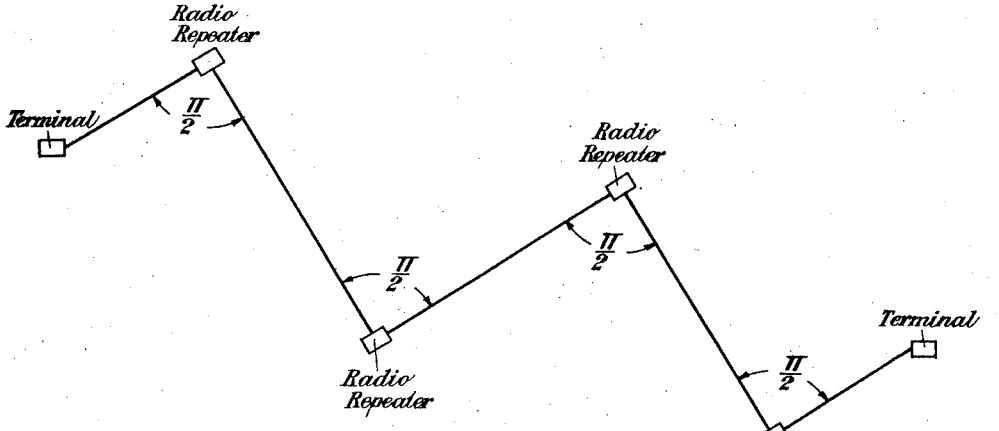


Fig. 10

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DIRECTIVE RADIO REPEATING SYSTEM

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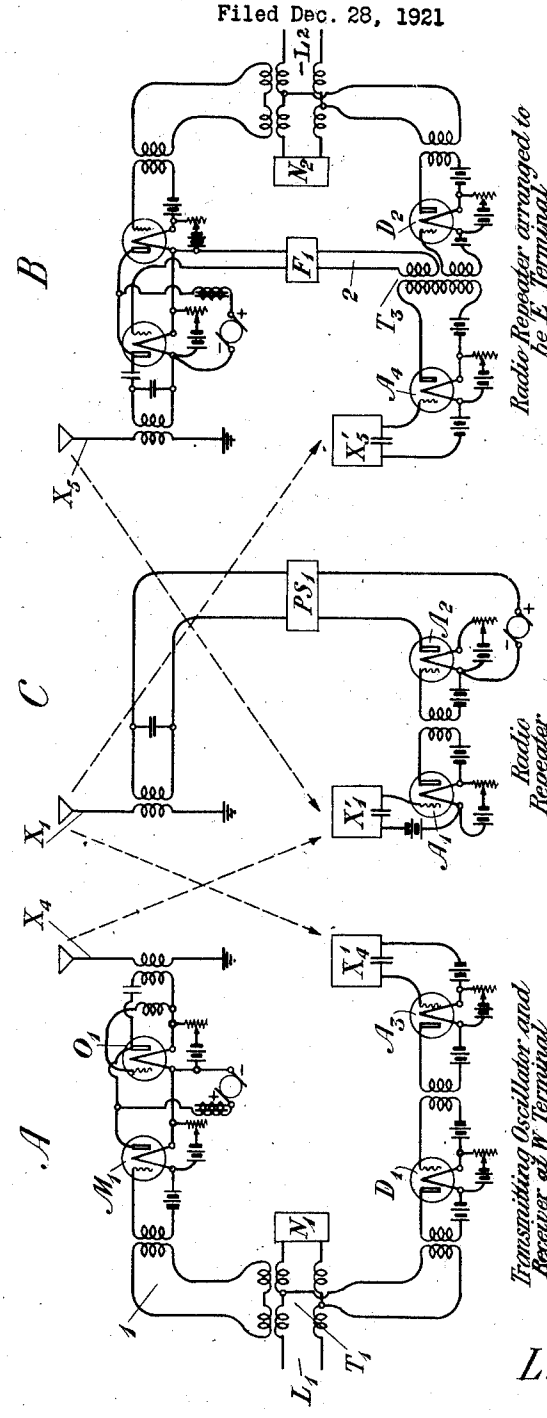


Fig. 9

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UNITED STATES PATENT OFFICE.

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DIRECTIVE RADIO REPEATING SYSTEM.

Application filed December 28, 1921. Serial No. 525,440.

This invention relates to directive radio repeating systems and particularly to that type of system adjusted to have a bilateral receiving and transmitting characteristic and in which transmission and reception occur at the same frequency.

The radio repeating systems heretofore designed comprise a single antenna and an amplifying circuit connected therewith which were adapted to amplify waves received from any direction and transmit the amplified waves in all directions. Not only were these systems inefficient because of the lack of a directional characteristic in receiving and sending but also the degree of amplification was somewhat low, being limited by the tendency of the repeater to sing.

One of the objects of this invention is to provide a repeater system having controllable directivity, and balanced so that great amplification can be obtained without producing singing in the repeater circuit and thereby rendering it inefficient.

Another object of this invention is to provide a system suitable for long distance signaling in which the effects of static are minimized by the use of short waves, which, as is well known, are less affected by static than are long waves. Furthermore, the effect of static may be minimized by sustaining throughout the course of transmission the ratio of the signaling energy to static, which result may be attained by spacing the directive repeating stations at certain predetermined points, depending upon the drop in the energy level between the successive repeating stations.

By the use of repeating stations embodying directive antenna arrays such, for example, as are described in the copending application of G. A. Campbell, Serial No. 327,553, filed September 30, 1919, and properly designed and adjusted amplifying circuits, the course of transmission of signals between widely separated terminals may be controlled, since it is practicable, by properly locating the repeating stations, to direct the transmission either along a straight line between the two terminals, or along a more devious course. This feature of our invention becomes important when it is desired to avoid objects lying between the two terminals which would tend to interfere with the propagation of electro-magnetic waves, or when, for traffic or other reasons, it would be desirable to transmit the signals over the more indirect route.

Further objects of this invention will be apparent from the following description, when read in connection with the attached drawing, of which Figures 1 and 2 show broadly the principles of this invention, the former being characterized by a vertical antenna array and the latter by a loop antenna array; Fig. 3 shows a balanced arrangement using horizontal and vertical antennæ: Fig. 4 shows an arrangement using horizontal and vertical antennæ adapted for duplex operation; Fig. 4^a shows the radiation characteristic of the arrangements shown in the foregoing figures and Fig. 4^b is a frequency chart of Fig. 4; Fig. 5 shows an arrangement for receiving by a loop antenna and transmitting by a vertical antenna, the characteristic of the loop antenna being shown in Fig. 5^a; Figs. 6 and 6^a show other forms of circuits similar to Fig. 5, but adapted for the duplex operation; Fig. 7 shows a circuit having separate receiving and transmitting antennæ and characterized by a connecting circuit between the transmitting and receiving antennæ to prevent interference between them; Figs. 8 and 9 show complete radio systems embodying a directive repeater for relaying the signals between the terminal stations, Fig. 9 being distinguished from Fig. 8 by the use of a single source of carrier oscillations for modulation and demodulation at both terminals; and Fig. 10 shows a method for arranging repeater stations to prevent singing between adjacent ones.

In Fig. 1, X_1, X_2 and X_3 represent three antennæ of an array, which are spaced a definite part of a wave length apart. Each antenna has connected thereto an amplifying circuit having a phase shifting device PS_1 a band filter F_1 and an amplifier A_1 in the input side of the amplifying circuit, and a power amplifier A_2, a band filter F_1 and a phase shifting device PS_2 in the output side of the said circuit. The antenna X_1 is connected with the amplifying circuit by means of the multi-winding transformer T_1 with which is also connected a network N_1 designed to balance the antenna X_1. The an-

tennæ X_2 and X_3 are connected with amplifying circuits similar to that shown in connection with the antenna X_1.

Oscillations set up in the antennæ as the result of an electromagnetic wave will be impressed by the transformers upon the input side of the amplifying circuits. Thus, for example, oscillations set up in antenna X_1 will be impressed by the transformer T_1 upon the amplifying circuit. The phase of the current will be changed by the phase shifting device PS_1, and the current will then pass through the band filter F_1, which is preferably designed to transmit a band of frequencies represented by the carrier frequency plus the signaling frequency or the carrier frequency minus the signaling frequency. The current traversing the band filter will be amplified first by the low power amplifier A_1 and then by the high power amplifier A_2. The resultant current will be transmitted through the band filter F_2 having the same characteristic as the filter F_1. The phase shifting device PS_2 is designed to control the phase of the current applied to the antenna X_1 for transmission therefrom. By properly spacing the antenna constituting the array and by the proper control of the amplitude and the phase of the currents applied to the individual antenna of the array according to the principles set forth in the copending application to G. A. Campbell, Serial No. 327,553, filed September 30, 1919, we may obtain, for example, the bilateral radiation characteristic shown in Fig. 4^a. This characteristic indicates maximum receiving and transmitting efficiency along the axis of the characteristic, which is perpendicular to the axis of the array. It will accordingly be seen that by means of the repeater arrangement shown in Fig. 1, adjusted so as to have the characteristic shown in Fig. 4^a, it is practicable to receive signals from both directions perpendicular to the axis of the array and to transmit amplified signals in both directions from the axis of the array. The frequencies of the received signals depend, of course, upon the tuning of the antennæ and also upon the frequency range of the band filters. Since reception and transmission are effected on the same frequency, it is necessary to balance the individual antennæ by means of a balancing network such as N_1 shown in connection with the X_1 in order to prevent the continuous circulation of energy within the repeater circuit, known as singing.

The arrangement shown in Fig. 2 is in general similar to that shown in Fig. 1, excepting that loop antennæ take the place of the vertical antennæ shown in Fig. 1. The characteristic of loop antenna, shown in Fig. 5^a, indicates maximum reception and transmission of energy along an axis lying within the plane of each antenna constituting the array. The loops are adjusted for the reception and transmission of signals of the same frequency. The current set up in the loop by the high frequency wave will be impressed upon the input branch of the amplifying circuit passing through the phase shifter PS_1, the band filter F_1, and low power amplifier A_1 then through the high power amplifier A_2, a second band filter F_2 and a second phase shifter PS_2, which controls the phase of the current applied through the transformer T_1 to the loop antenna. By proper spacing of the loops and by proper control of the amplitude and phase of the current applied to each antenna of the array, the direction of reception and transmission of signals may be controlled. The advantage of using the loop array is that the same degree of directive transmission or reception may be obtained with fewer units than with the vertical array. Since transmission and reception are effected by the same carrier frequency, singing is prevented by the proper balancing of the loops by the networks N as shown in the figure.

Fig. 3 shows a repeater, adjusted for receiving and transmitting upon the same frequency, in which signals are received by a horizontal antenna which is balanced with respect to the vertical antenna which transmits the amplified signals. In this arrangement each unit comprises a horizontal antenna, a vertical antenna and an amplifying circuit. Although in the figure the vertical and horizontal antennæ of each unit are shown in close proximity to each other, and the various units are spaced at definite fractions of a wave length apart, it is desired to point out that all of the vertical antennæ may be arranged in a group, each located at the proper distance from the others, and similarly all of the horizontal antenna may be grouped together, each located at the proper distance from the others. This necessitates, however, that the respective amplifying circuits must extend from a horizontal antenna to its corresponding transmitting antenna located in the other group, which may be some distance away. The amplifying circuit itself comprises phase shifting devices, band filters and amplifiers similar to those described in connection with the previous figures. In a radio relay of this type, received signals set up currents in the horizontal antenna which are transmitted through the phase shifting device PS_1, the filter F_1 and the low power amplifier A_1, thence through the power amplifier A_2, the filter F_2 and the phase shifting device PS_2, to the transmitting antenna X_1. Although reception and transmission are effected upon the same frequency singing is prevented through the balanced relationship of the

horizontal antenna to the vertical antenna. By proper spacing of the antennæ and by proper control of the amplitude and phase of the currents applied to the individual antenna of the array, radio signals may be relayed and the direction of transmission may be controlled.

The arrangement shown in Fig. 4, while operating upon the principle of transmission and reception of signals upon the same frequency, is designed for the simultaneous transmission of two channels either in the same or in opposite directions. The antenna structure is of the balanced type shown in Fig. 3, with the exception that both the ground antenna and the vertical antenna have two degreees of freedom. In the operation of the arrangement shown in this figure, if a wave representing a band of frequencies such as f_1+s or f_1-s strikes the horizontal antenna, oscillations within the band of frequencies will be set up in the horizontal antenna. The current within this band of frequencies will be transmitted through the phase shifting device PS_1 and through the band filter F_1 to the amplifier A_1, thence through the power amplifier A_2 and the second band filter F_2, which is adapted to pass the same range of frequencies as F_1, and then through the phase shifting device PS_2 to the vertical antenna X_1 which as stated, is adapted to oscillate at the same frequencies as X_2. Since the antenna X_1 occupies such a position with respect to the horizontal antenna X_2 as not to create oscillations in X_2 when X_1 is radiating, relatively high amplification can be obtained without producing singing of the repeater. In a similar manner if a wave representing a band of frequencies f_2+s or f_2-s strikes the ground antenna X_2, oscillations of the same band of frequencies will be set up in the said antenna. These oscillations will be transmitted through the phase shifting device PS_3 and the band filter F_3 which is designed to transmit the range of frequencies represented by f_2+s or f_2-s. The current within this band of frequencies will be amplified by the low power amplifier A_1 and also by the high power amplifier A_2, and the resultant amplified current will be transmitted through the band filter F_4 and then through the phase shifting device PS_4 to the antenna X_1 which will oscillate at the transmitted frequencies. Although the amplifiers A_1 and A_2 are represented as being common to the paths of the two channels, it is, of course, apparent that separate amplifiers of both types individual to the paths of the two channels could be used.

The arrangement shown in Fig. 4 constitutes only a single unit of a radio repeating system, but it is to be understood that there will be a plurality of such units constituting a repeating station in which the adjacent receiving antennæ will be spaced at a definite fraction of a wave length apart in the manner described in connection with Fig. 3, and the transmitting antennæ will be similarly spaced. By properly controlling the phase and the amplitude of the received and transmitted current on each unit circuit of an array, the direction of transmission and reception may be readily controlled.

Fig. 5 shows a unit circuit of a repeating station characterized by separate receiving and transmitting antennæ, the receiving antenna being of the loop type and the transmitting antenna being vertical. Oscillations of the frequency f_1+s or f_1-s received by the loop antenna X_2 will be transmitted through the amplifier A_1 and the phase shifting device PS_1 and the band filter F_1 to the power amplifier A_2 connected with the transmitting antenna X_1. Since the radiation and reception characteristic of a loop antenna is, as shown in Fig. 5a, such that the maximum efficiency is along a line coinciding with the plane of the loop and the minimum efficiency along the axis perpendicular to the loop, interference from the oscillations transmitted by antennæ as X_1 can be substantially prevented by adjusting the phase shifting device PS_1 so that the transmitting antenna will have a characteristic for example, such as is shown in Fig. 4a with the major axis of the characteristic perpendicular to the plane of the receiving loop. Accordingly interference may be substantially prevented even though the two antennæ are responsive to the same frequencies. The arrangement shown in Fig. 5 constitutes but a single unit of the radiating system and it is to be understood that there will be a plurality of antennæ arranged in an array with suitable local circuits individual to each pair of receiving and transmitting antennæ.

Figs. 6 and 6a are modifications of the form shown in Fig. 5, the modification consisting in arranging a structure for the simultaneous reception and transmission of two channels. Thus the loop X_2 is responsive to carrier frequency f_1 and the loop X_2' is responsive to the carrier frequency f_2. In Fig. 6a a single loop X_3 having two degrees of freedom such as the frequencies f_1 and f_2 takes the place of the two loops in Fig. 6. The transmission of currents at these frequencies through the local circuits to the transmitting antenna X_1 is similar to that described in connection with Fig. 5. The circuit arrangements shown in Figs. 6 and 6a are units of a radio repeater system and there would be, of course, a plurality of such circuits having the adjacent receiving antennæ (and similarly the transmitting antennæ) spaced at a predetermined fraction of a wave length apart. By proper control of the phase of the transmitted currents in each unit circuit, the radiation may be given

the directional characteristic shown in Fig. 4ª.

Fig. 7 is a variation of the idea embodied in Fig. 5. The repeater circuit illustrated by Fig. 7, which represents one unit of a directive repeating station, is intended for the transmission of amplified signals having the same frequency as the received signals. The circuit contains a receiving loop X_2 for receiving oscillations of the frequency f_1, which are amplified by the low power amplifiers A_1 and A_2, and impressed upon the band filter F_1. Current of the frequencies transmitted through the band filter F_1 will be amplified by the power amplifier A_3 and impressed upon the transmitting antenna X_1. Freedom from interference from the transmitted oscillations is obtained partly by proper orientation of the loop antenna and partly by feeding from the transmitting antenna to the circuit of the loop antenna a certain amount of current, the phase of which as applied to the loop circuit is controlled by the phase shifting device PS_1. The phase angle of this transmitted current, which may be termed the neutralizing current, when applied to the loop circuit is such as to neutralize currents set up in the said loop as the result of direct radiation from the transmitting antenna thereto. The arrangement shown in Fig. 7 represents but a single unit of an array, and there would, of course, be a plurality of antennæ suitably spaced and having a local connecting circuit individual to each pair of receiving and transmitting antennæ.

Fig. 8 represents a complete system comprising two terminal stations A and B, and a repeater station C intermediate the said terminal stations. The repeater station comprises an array of transmitting antennæ X_1, X_2 and X_3, and also an array of receiving antennæ represented as loops and X_1' X_2' and X_3'. Each pair of transmitting and receiving antennæ is connected by a local circuit, such for example, as that shown connecting the antennæ X_2 and X_2' containing a low power amplifier A_4, a phase shifting device PS_1, a band filter F_1 and a power amplifier A_2. At each of the terminal stations a low frequency signaling circuit L_1 is connected with the terminal circuit by means of a triple winding transformer T_1 which has associated therewith a network N_1 designed to balance the line L_1. The input side of the terminal circuit comprises a receiving loop X_4' an amplifier A_3, a detector D_1 and a second amplifier A_4. The output branch of the said terminal circuit comprises an amplifier A_5, a modulator M_1 and an oscillator O_1 which is connected with the transmitting antennæ X_4. The apparatus constituting the terminal station B is similar to that at terminal station A and needs no further explanation. Low frequency signals arriving over the line L_1 will be impressed by the transformer T_1 upon the output branch 1 of the terminal station A. These low frequency signals will be amplified by the amplifier A_5 and will modulate in the modulator M_1 the high frequency oscillations set up by the oscillator O_1. The modulated oscillations when radiated by the directive array of which antennæ X_4 is a part will be received by the loop antennæ X_1', X_2', and X_3' constituting part of an array of the repeating station C, which are tuned for the reception of oscillations of the frequency transmitted by the power oscillator O_1. These received oscillations will be amplified by the amplifier A_1 and the current in each local circuit will be adjusted in phase by the phase shifting device PS_1 so as to retain the proper directional characteristic of the array. The current will be transmitted through the band filter F_1 and when amplified by the power amplifier A_2 will be transmitted by the transmitting antennæ X_1, X_2 and X_3. The array of which the latter antennæ form a part is designed to direct its energy toward the receiving loop X_5' of the station B, which is tuned for receiving oscillations of the frequency transmitted by the repeater station. The received oscillations will be amplified by the amplifier A_6 detected by the detector D_2, and again amplified by the amplifier A_7. The resultant low frequency signals will be impressed across the low frequency signaling circuit L_2. In similar manner low frequency signals arriving over the line L_2 will be transmitted from the station B by the transmitting antennæ X_5. These signals will be relayed by the repeating station C and impressed upon the terminal station A.

Fig. 9 shows a complete system which differs from that disclosed in Fig. 8 primarily for the reason that the carrier oscillations, generated at station A, are transmitted together with the side bands to the repeating station C where both the carrier and the side band frequencies are amplified and are then transmitted to the terminal station B where the received carrier is used not only for the detection of the received side band frequencies, but it also serves as the carrier of signal frequency from station B to station A. At station C, X_1 represents a transmitting antenna of an array and X_1' represents a receiving loop of an array. A_1 represents a low power amplifier and A_2 a high power amplifier whose output side is connected with a phase shifting device PS_1, which is coupled to the transmitting antenna X_1. The receiving loop X_1' is designed to receive the carrier and side band frequencies. The received current will be amplified by the amplifier A_3 and will be detected by the detector D_1. The resultant

low frequency signaling current will be transmitted over the line L_1.

Low frequency signals arriving over the line L_1 at the station A will be impressed by the transformer T_1 upon the output circuit 1. These currents will serve to modulate the high frequency oscillations set up by the oscillator O_1 which operates in conjunction with the modulator M_1. The resultant side bands of oscillations, together with the carrier, will be radiated by the antenna X_4 and will be received by the loop X_1' at the relay station. Both the carrier and the side band frequencies will be amplified at the relay station and will be transmitted from the antenna X_1. Due to the directive qualities of the array, of which antenna X_1 is a unit, the oscillations of the carrier and the side band frequencies will be received at the loop X_5' located at station B. Currents of all frequencies will be amplified by the amplifier A_4, and the signal frequency will be detected by the detector D_2 and impressed upon the line L_2. A part of the energy of the carrier frequency will be transmitted by the transformer T_3 to the branch circuit 2 and will be impressed upon the filter F_1, which is designed to transmit the carrier frequency. Current of the carrier frequency will pass through the filter F_1 and will be modulated by the signal frequencies arriving over the line L_2 for transmission from the antenna X_5. It will be seen that the arrangement disclosed in Fig. 9 is adapted for the repeating of messages in each direction using the same frequency for receiving and transmitting at the repeating station. Although a particular form of repeating circuit is shown, it is to be understood that any forms shown in the preceding figures may be used in the system shown in Fig. 9.

Fig. 10 shows the geographical distribution, for example, of four repeaters located between two terminal stations. Any form of the antenna may be used for receiving and transmitting. It is necessary only that the direction of reception and transmission shall be perpendicular to each other so as to avoid singing of the repeaters.

This invention is broadly directed to the combination of repeating circuits with directive antenna arrays. From the foregoing descriptions it will be seen that the objects, set forth in the beginning, may readily be obtained by the means described and illustrated. Furthermore, it should be clearly stated that the amplifying circuits are in reality translating circuits capable of modifying the current in a variety of ways apart from amplifying, such as frequency selection by filters and phase control by the phase shifting devices. It is also desirable to make definite that the amplifiers may be either a single stage or multi-stage arrangement, and may be of the thermionic vacuum tube or other well known type.

It will, of course, be apparent that the invention is not limited to the particular forms and arrangements shown in the aforedescribed figures, since it is capable of embodiment in a variety of other and different forms within the spirit and scope of the appended claims.

What is claimed is:

1. In a radio repeating system the combination with an antenna array for the reception and transmission of signals, of a plurality of amplifiers connected therewith, means to control the phase of the currents applied to the antennæ of the said array, and means to control the phase of the currents received from the said antennæ and applied to the said amplifiers.

2. In a radio repeating system the combination with an antenna array of a plurality of repeating circuits individual to the antennæ of the said array including frequency selecting means, means to control the phase of the currents received by the antennæ of the said array and means to control the phase of the currents applied to the antennæ of the said array for transmission therefrom.

3. In a radio repeating system the combination with an antenna array for the reception and transmission of signals of a plurality of repeating circuits each individual to an antenna of the said array and each having its input and its output circuits connected with its respective antenna, and means associated therewith to prevent singing of the said repeating circuits.

4. In a radio repeating system the combination with an antenna array for the reception and transmission of radiant energy of a plurality of local amplifier circuits each individual to and having its input and its output ends connected with one antenna of the said array, the said local circuits having associated therewith devices for controlling the phase of the received and the transmitted energy.

5. In a radio repeating system the combination with a repeating station comprising a directive antenna array having amplifiers associated therewith for the amplification of signals transmitted thereto of a plurality of terminal circuits adapted to work in conjunction with the said repeating circuit, one of said terminal circuits having a source of carrier oscillations, and having its antennæ tuned to transmit carrier oscillations to the second terminal circuit to be used therein for the purpose of detecting received signals, the said second terminal station having means to utilize a portion of the said carrier oscillations as the carrier of signals to the said first terminal station.

6. In a radio repeating system the com-

bination with an antenna array comprising a plurality of antennæ each for the reception and transmission of signals, of a plurality of amplifiers, and a plurality of circuits each including one of said amplifiers, and each of said circuits having its input end and its output end connected with one of said antennæ.

7. In a radio repeating system, the combination with an antenna array comprising a plurality of antennæ each for the reception and transmission of signals, of a plurality of translating circuits, each having its input end and its output end conjugately connected with one of said antennæ whereby singing of each of said circuits is prevented, and each of said circuits having an amplifier and means to control the phase of the output current.

8. In a radio repeating system, the combination with an antenna array comprising a plurality of antennæ each for the reception and transmission of signals, of a plurality of translating circuits, each having its input end and its outpnt end conjugately connected with one of said antennæ whereby singing of each of said circuits is prevented, and each of said circuits having an amplifier, means to control the phase of the current applied to the said amplifier, and means to control the phase of the current applied by the said amplifier to its antenna.

9. In a radio repeating system, the combination with an antenna array comprising a plurality of antennæ each for the reception and transmission of signals, of a plurality of translating circuits, each having its input end and its output end conjugately connected with one of said antennæ whereby singing of each of said circuits is prevented, and each of said circuits having an amplifier, means to select from the received currents those of a particular frequency or band of frequencies, and means to control the phase of the output current of the amplifier as applied to its antenna.

10 In a radio repeating system, the combination with a plurality of antennæ constituting an array for the transmission and reception of signals, of a plurality of amplifiers, each cooperating with one of the said antennæ, a plurality of circuits each including one of said amplifiers to connect the input side and the output side of its amplifier with the antenna with which the said amplifier is intend to cooperate.

11. In a radio repeating system, the combination with a plurality of antennæ constituting an array for the transmission and reception of signals, of a plurality of amplifiers having input and output circuits, each cooperating with one of the said antennæ, a plurality of coupling means each connected with one of said antennæ and also with the said input and output circuits of the amplifier cooperating with the same antenna, the said coupling means being so designed and the connections being so effected that the output currents produce no effect upon the input circuit and likewise the input current no effect upon the output circuit.

In testimony whereof, we have signed our names to this specification this 27th day of December, 1921.

LLOYD ESPENSCHIED.
DE LOSS K. MARTIN.