May 8, 1928. 1,669,123

L. ESPENSCHIED ET AL

DIRECTIVE RADIO REPEATING SYSTEM

Filed Dec. 28, 1921 3 Sheets-Sheet 1

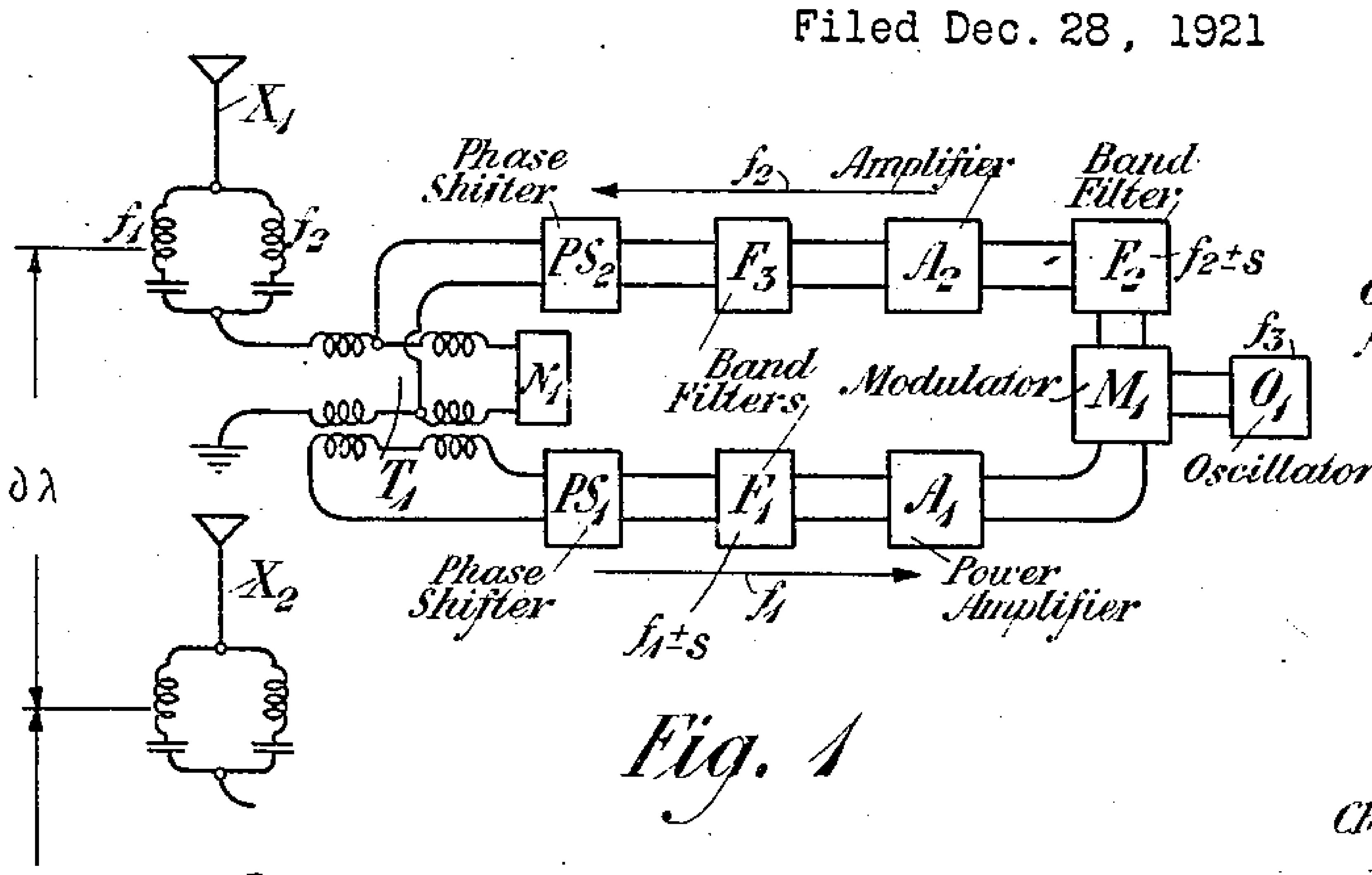

Fig. 1

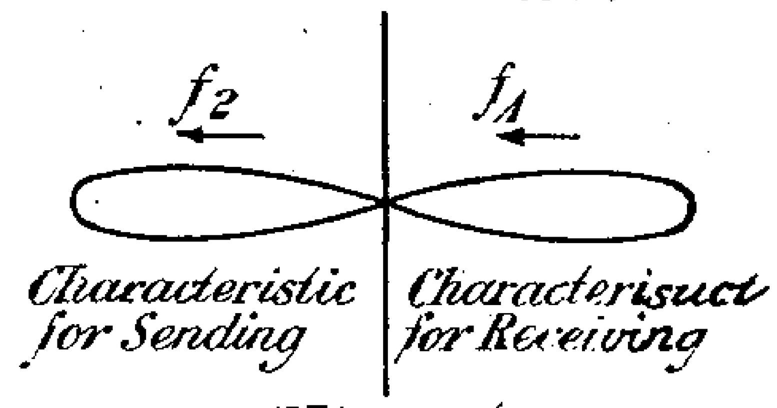

Fig. 1a

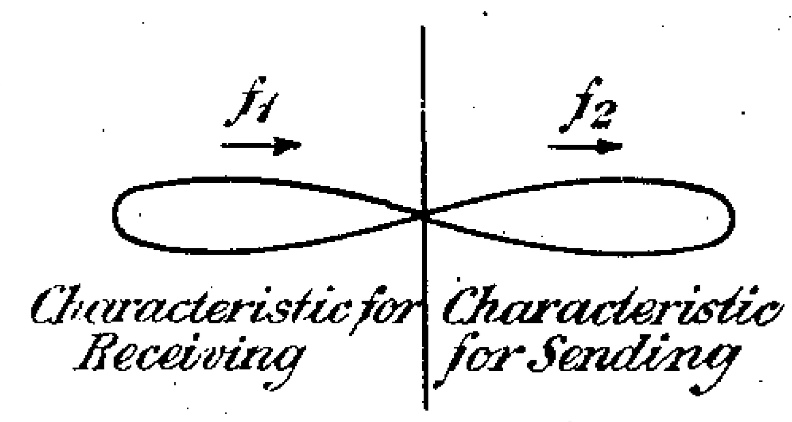

Fig. 1b

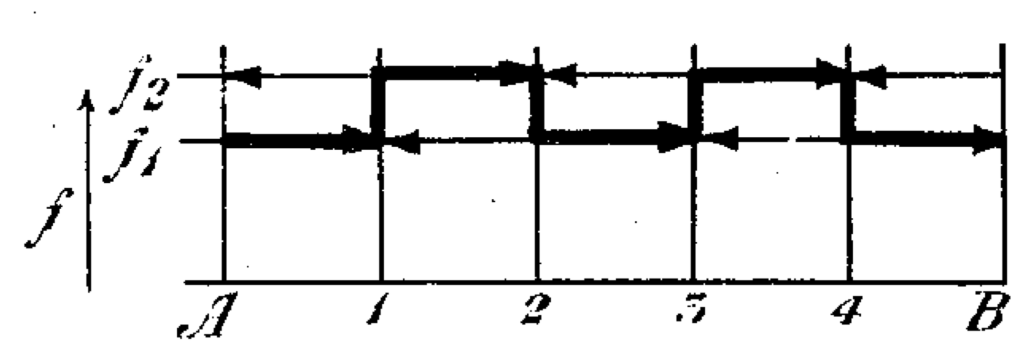

Fig. 1c

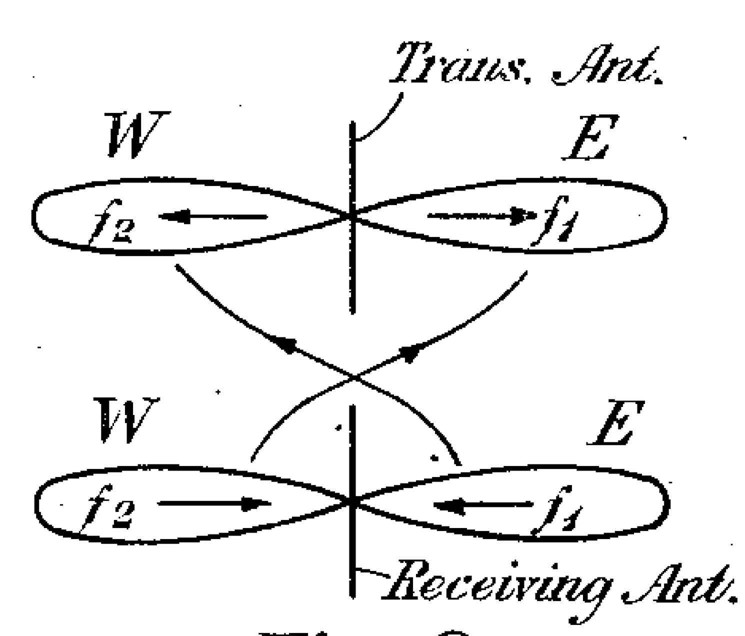

Fig. 2a

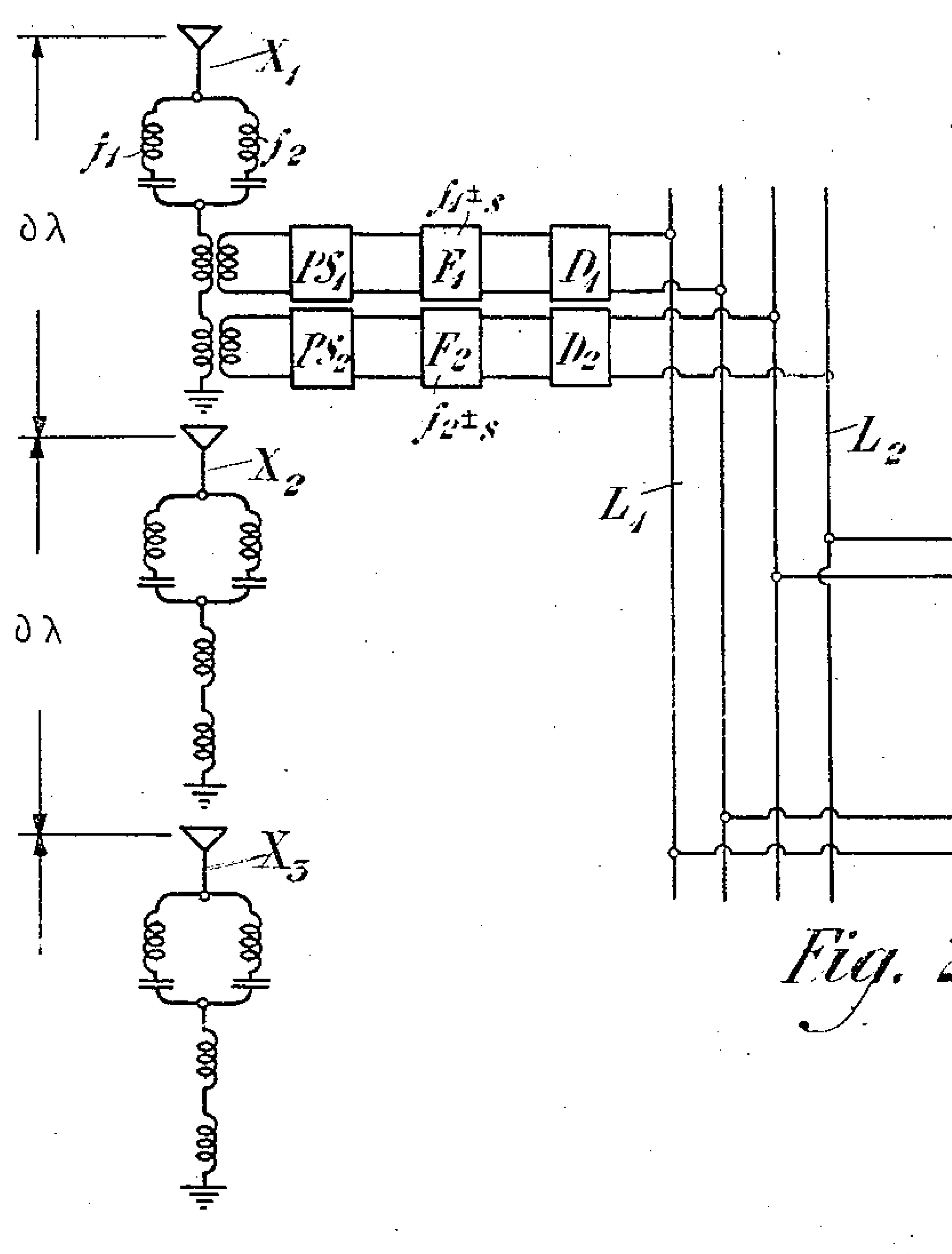
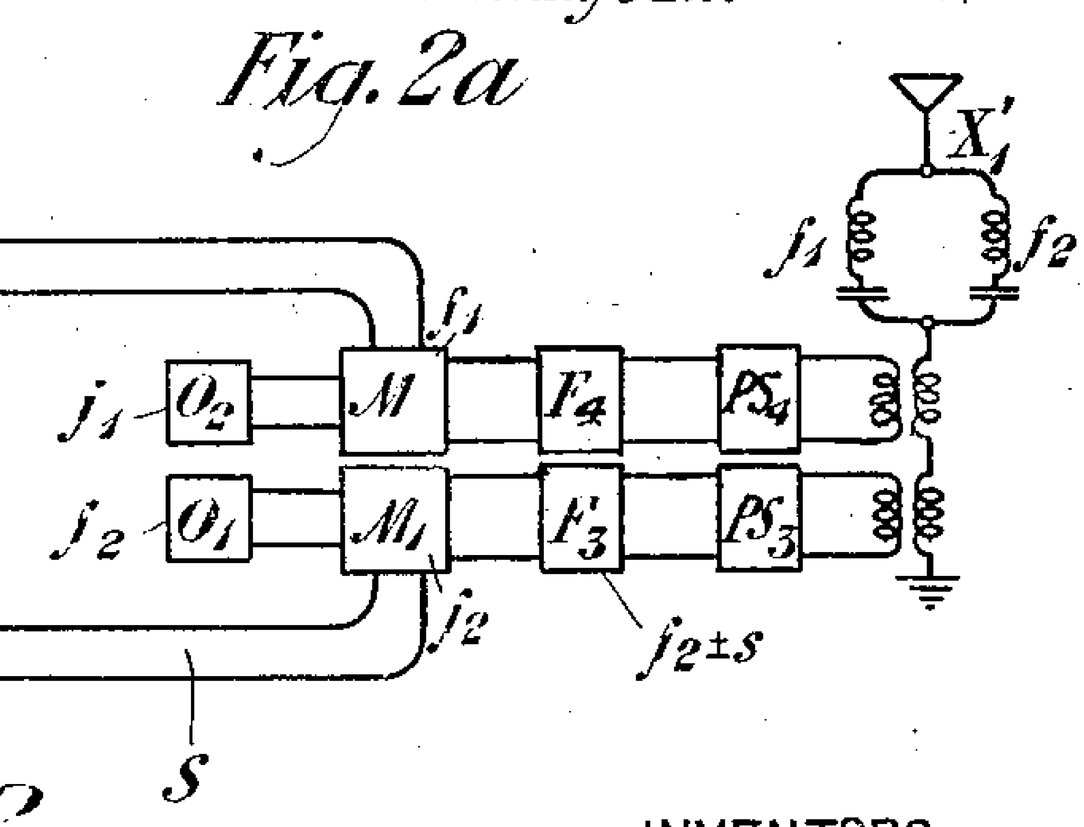

Fig. 2

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Filed Dec. 28, 1921 3 Sheets-Sheet 2

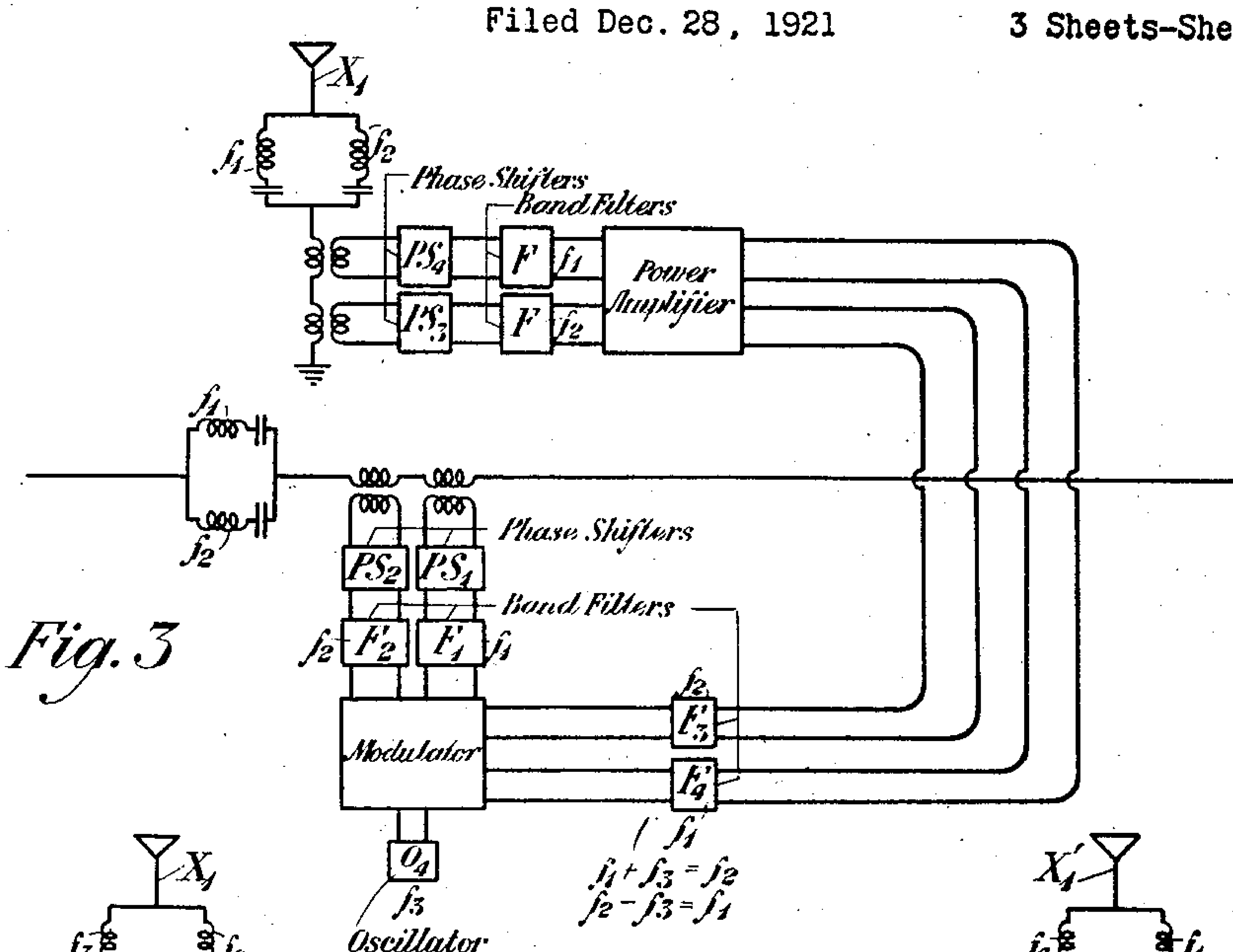
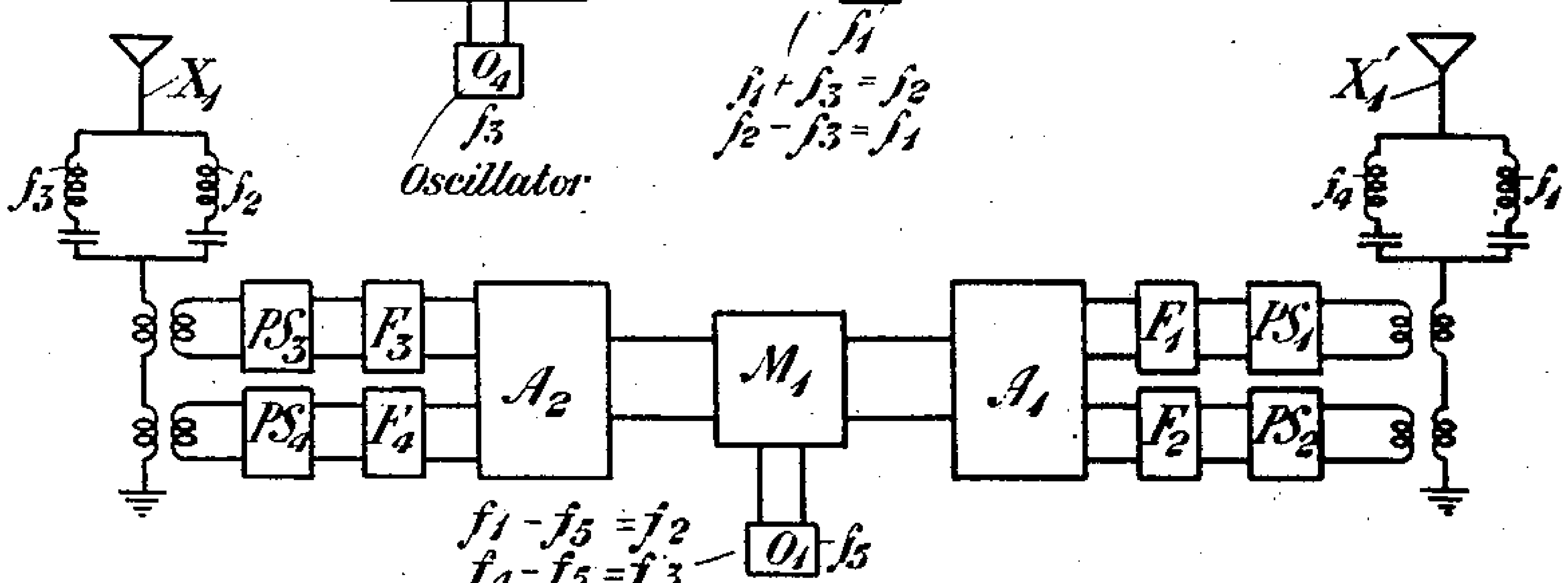


Fig. 3



Radiation and Reception from both directions

Fig. 4

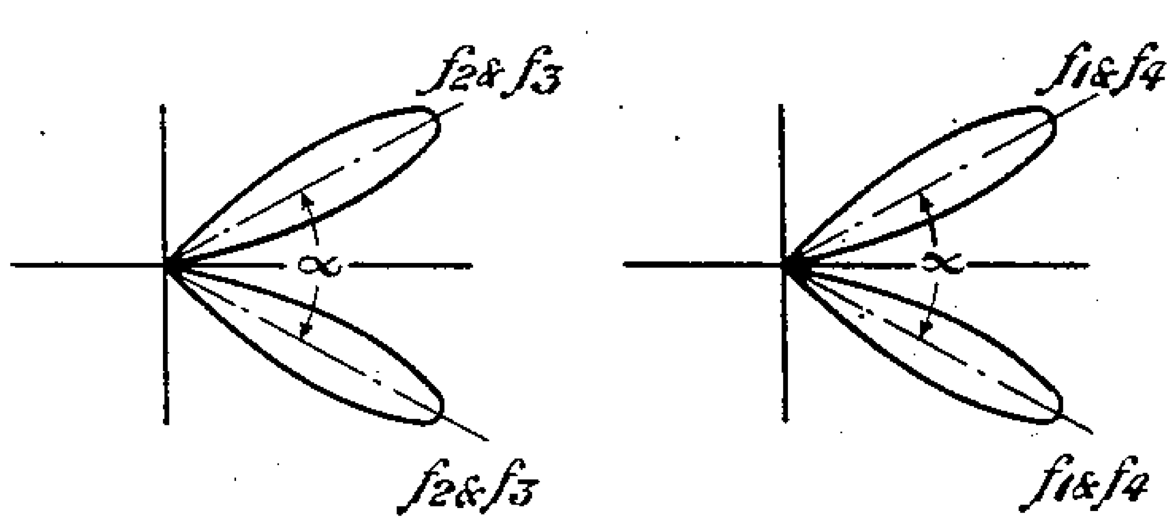


Fig. 4a

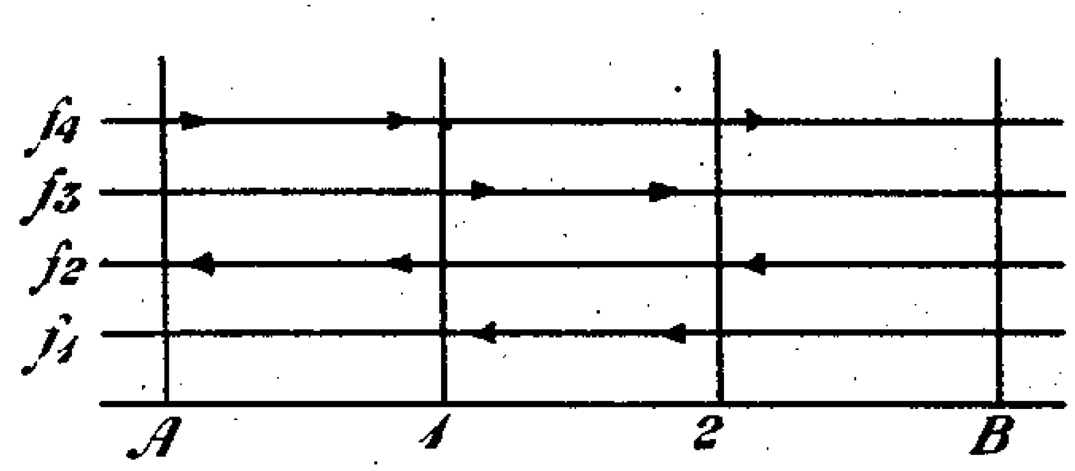


Fig. 4b

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DIRECTIVE RADIO REPEATING SYSTEM

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3 Sheets-Sheet 3

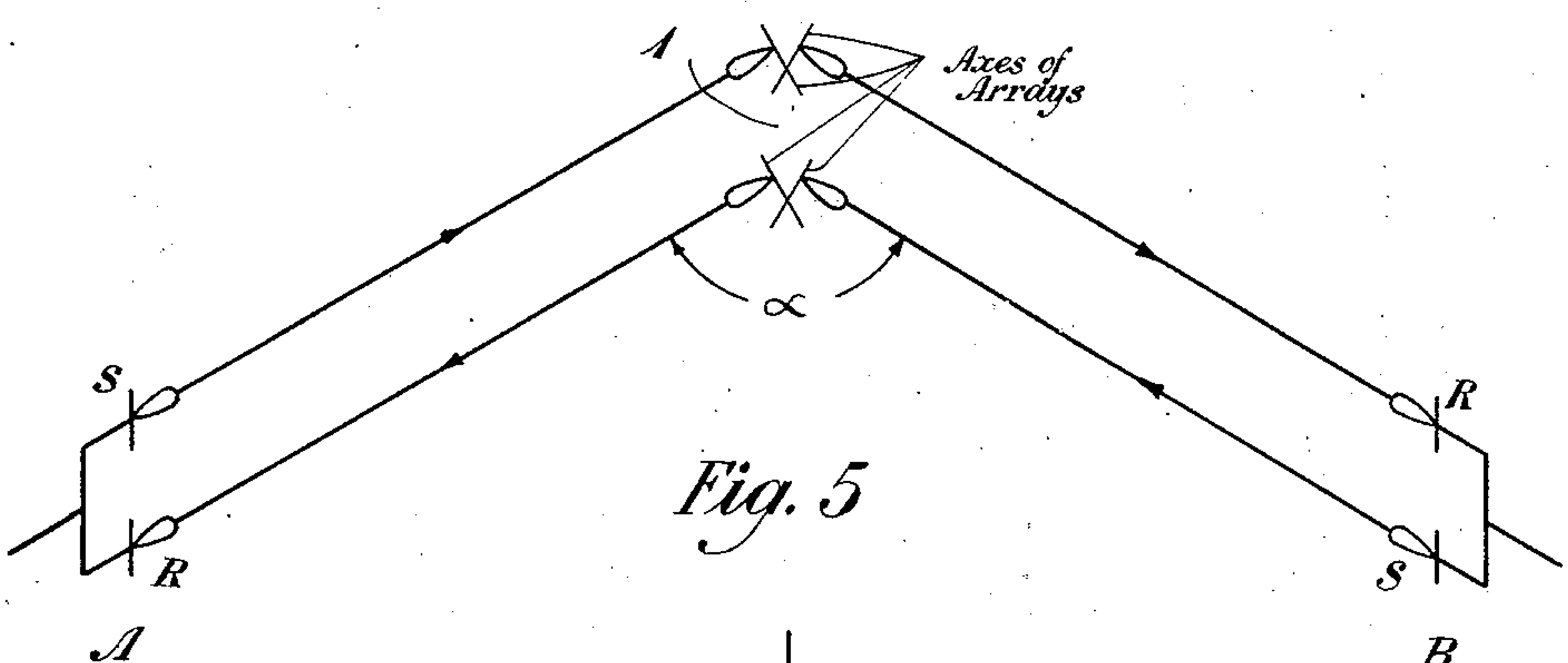

Fig. 5

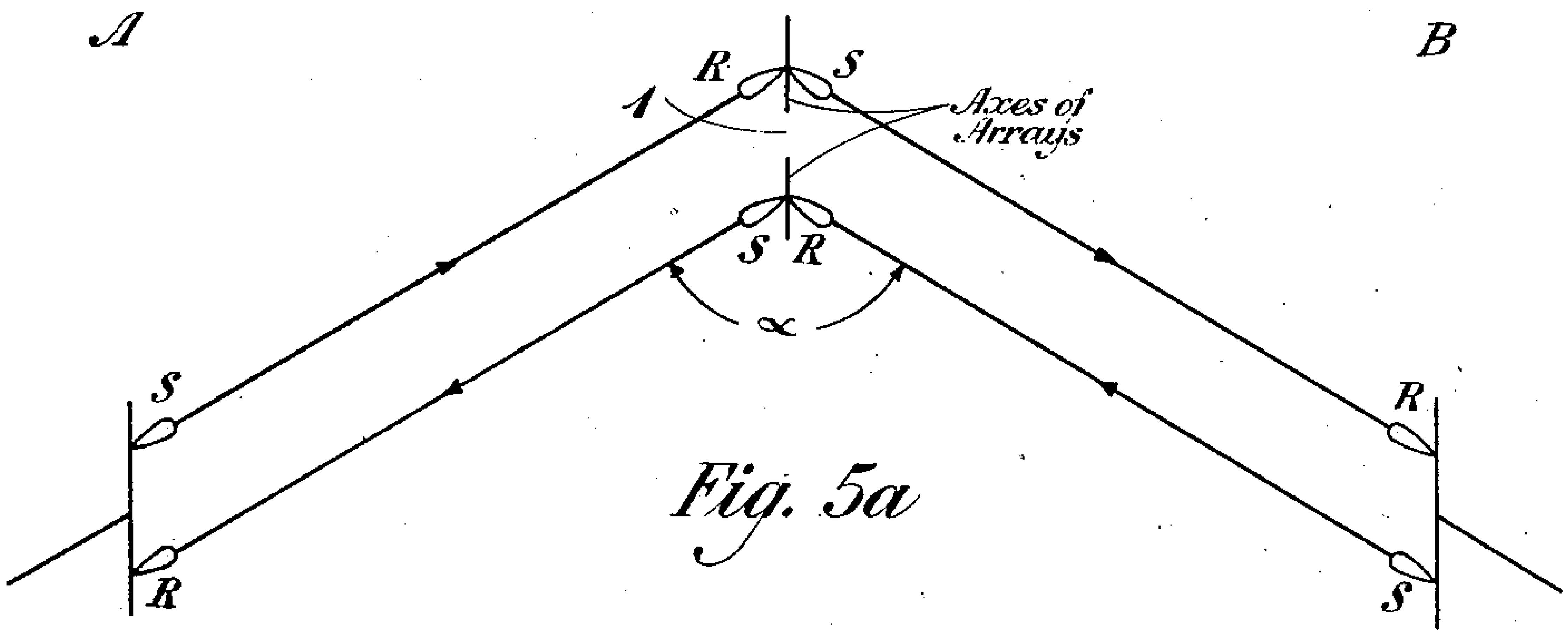

Fig. 5a

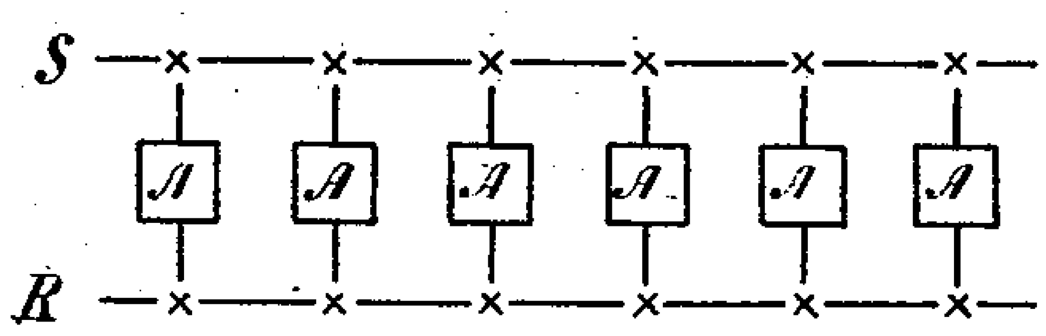

Fig. 5b

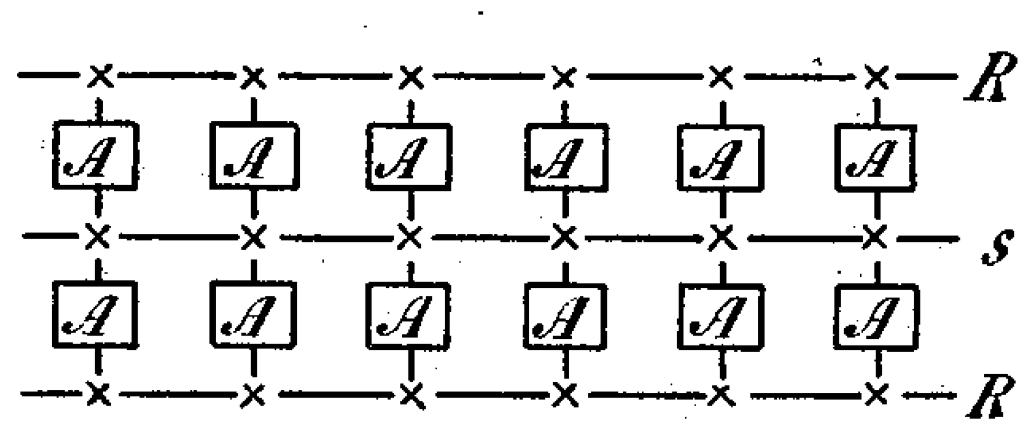

Fig. 5c

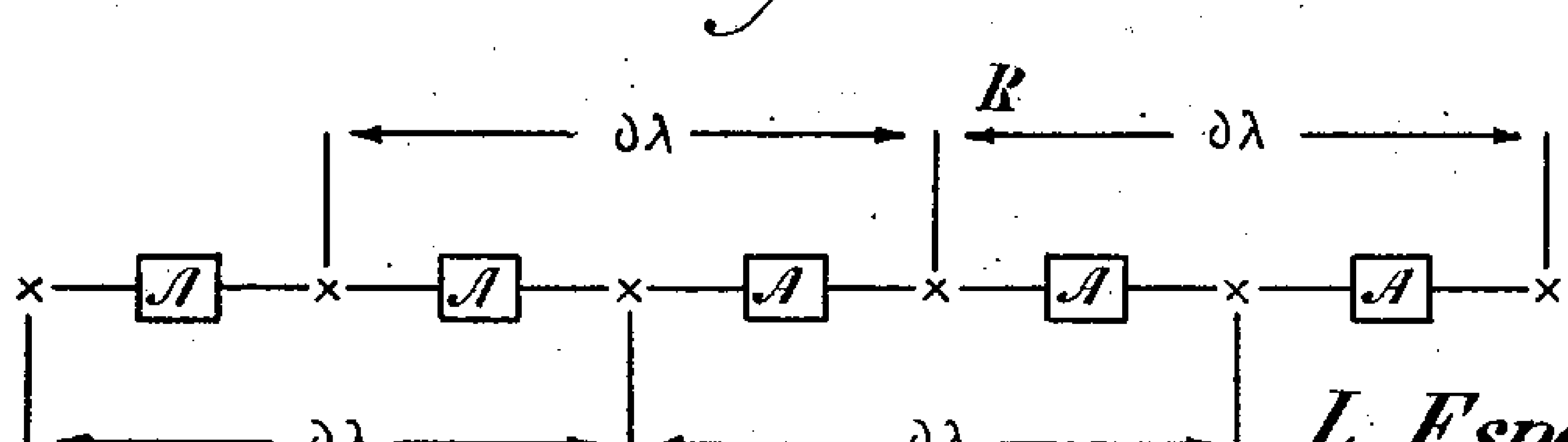

Fig. 5d

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UNITED STATES PATENT OFFICE.

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DIRECTIVE RADIO REPEATING SYSTEM.

Application filed December 28, 1921. Serial No. 525,443.

This invention relates to radio repeating systems and particularly to systems of the type employing directive antenna arrays adjusted for unilateral and duolateral reception and transmission of signals.

In our copending application, Serial No. 525,442, filed December 28, 1921, there is disclosed means for the directive relaying of radio signals which are characterized by the change of frequency at the repeating point so that the transmitted frequency is different from the received frequency of any given channel, and further characterized by bilateral reception and transmission By bilateral is meant equal reception or transmission efficiency in two directions diametrically opposite to each other.

It is the object of the present invention to provide an arrangement for relaying radio signals in which reception is efficient from one direction only, and likewise, transmission is efficient in one direction only. Another object of this invention is to provide an arrangement for the efficient relaying of radio signals, the angular difference between the direction of reception and transmission being less than 180 degrees.

By the use of repeating stations embodying directive antenna arrays and their associated 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 more 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 drawings, of which Figure 1 represents an antenna array for the reception and transmission of signals with a single local circuit shown completely for illustrative purposes; Figs. 1^a and 1^b represent two unilateral characteristics of the array shown in Fig. 1, and Fig. 1^c shows the frequency distribution throughout such a repeating system; Fig. 2 shows another form of repeating station employing two antenna arrays, and Fig. 2^a represents the characteristics of such a system; Fig. 3 shows another form of unit of an array employing a ground antenna for receiving and a vertical antenna for transmitting; Fig. 4 shows an arrangement employing two arrays and four frequencies to effect simultaneous radiation and reception from both directions, the system having a duolateral characteristic as shown in Fig. 4^a and having the frequency distribution as shown in Fig. 4^b; Figs. 5 and 5^a illustrate ways for effecting an indirect course of transmission between terminals; and Figs. 5^b, 5^c and 5^d show various arrangements of the antennæ and the individual amplifying circuits of such arrays.

In Fig. 1, X_1, X_2 and X_3 represent three antennæ of an array, each responsive to two frequencies f_1 and f_2, together with any side bands of frequencies that may be superimposed thereon as may be represented by f_1+s and f_2+s. The adjacent antennæ are separated geographically as shown in the figure a definite fraction of a wave length apart. The antenna X_1 is connected by means of the triple winding transformer T_1 with its local amplifying circuit containing a phase shifting device PS_1, a band filter F_1 adapted to transmit frequencies $f_1 \pm s$, a low power amplifier A_1, a modulator M_1 having associated therewith an oscillator O_1 producing unmodulated oscillations of the frequency f_3, another band filter F_2 adapted to transmit the frequencies $f_2 \pm s$, a power amplifier A_2, a third band filter F_3 transmitting the same frequencies as F_2, and a second phase shifting device PS_2. It is to be understood that similar local amplifying circuits are connected with the antennæ X_2, X_3, etc., of the array. Oscillations of the frequencies $f_1 \pm s$, which are received by the antenna X_1, for example, will be impressed by the transformer T_1 upon the local circuit. Current at that frequency will be given a certain phase adjustment by the phase shifting device PS_1 and transmitted through the band filter F_1 and will be amplified by the amplifier A_1. The amplified current of the frequency $f_1 \pm s$ will be impressed upon the modulator M_1, together with current of the frequency f_3 from the local source O_1. The currents of these frequencies will be beaten together in the modulator M_1 and the resultant currents of the frequencies represented by the band $f_2 \pm s$ where f_2 may $=(f_1+f_3)$ or $=(f_1-f_3)$ will be transmitted through the filter F_2 and amplified to the requisite degree by the power amplifier A_2. The resultant amplified current will be transmitted through the band filter F_3 and given the proper phase adjustment by the phase shifting device PS_2 before impressing it upon the antenna X_1, which as stated, is adapted to respond to the frequencies $f_2 \pm s$. Similar action takes place in the local circuits connected with the antennæ X_2, X_3, etc., of the array.

By proper spacing of the antennæ of the array and by proper adjustment of the phase of the current in each local circuit by means of the phase shifting devices PS_1 and PS_2, etc., and by suitable control of the amplitude of the oscillations by means of the amplifiers in the manner clearly set forth in the application of George A. Campbell, Serial No. 327,553, filed September 30, 1919, unilateral reception and transmission of signals may be effected. Fig. 1ᵃ represents the characteristic of the system when it receives most efficiently signals at the frequency f_1 from the right and transmits signals at the frequency f_2 along a narrow strip towards the left. In a system having this characteristic, which is a theoretically perfect situation, no signals of the frequency f_1 will be received from the left nor will signals of the frequency f_2 be transmitted towards the right. A system having this characteristic would be adapted for one-way transmission only and in order to effect two-way transmission it would be necessary to adjust the phase shifting devices and perhaps the amplitude of the current in the local circuit in order to give the system the characteristic shown in Fig. 1ᵇ in which reception at the frequency f_1 is efficient from the left and transmission at the frequency f_2 is efficient towards the right. Fig. 1ᶜ shows the distribution of frequency at the various repeaters represented by the numerals 1, 2, 3, etc., located in a system between the terminal stations A and B. Thus, signals of the frequency f_1, transmitted from station A to relay station 1, will be changed to the frequency f_2 and transmitted to the relay station 2, where they will be changed again to frequency f_1 and transmitted to station 3. Here the frequency will be stepped up to f_2 and transmitted to station 4 where the frequency will be stepped down again to f_1 and transmitted to the terminal station B. Transmission in the opposite direction from station B to station A at originating frequency f_2 is indicated by the light solid line.

Fig. 2 shows an arrangement employing two arrays, one for receiving, the other for transmitting, whereby simultaneous two-way operation of the system is effected. In this figure X_1, X_2 and X_3 represent three receiving antennæ, each responsive to the frequencies f_1 and f_2, (and their respective side bands $\pm s$). The antenna X_1, for example, is shown connected with two branch circuits, the upper one containing the phase shifting device PS_1, a band filter F_1 transmitting frequencies $f_1 \pm s$, and a detector D_1. The lower branch circuit contains similar apparatus but the filter F_2 is adapted to transmit frequencies $f_2 \pm s$. These branch circuits are connected to transmission conductors L_1 and L_2, which are common to the respective upper and lower branch circuits of each of the other antennæ of the system X_2, X_3, etc. The transmission conductors L_1 and L_2 are connected respectively with the lower and upper branch circuits connected with the antenna of the transmitting array, of which X_1' is an example. The lower branch circuit of the transmitting antenna X_1' contains an oscillator O_1 generating a frequency f_2, a modulator M_1 for modulating frequency f_2 with the band frequencies s, a filter F_3 adapted to transmit frequency $f_2 \pm s$, which is the resultant frequency range of the modulator M_1, and a phase shifting device PS_3 designed to control the phase of the current supplied by this branch circuit to the transmitting antenna X_1'. Similar apparatus is connected with the upper branch circuit of the transmitting antenna, excepting that the band filter F_4 is designed to transmit frequency $f_1 \pm s$, which is the resultant range of frequencies of the modulation of the band s from line L_2, with the oscillations of the frequency f_1 from the oscillator O_2.

Oscillations of the frequency $f_1 \pm s$ set up in the receiving antenna X_1 by the waves of that frequency will be transmitted through the upper branch circuit, being given a suitable phase angle by the phase shifting devices PS_1. These frequencies will be detected by the detector D_1 and the resultant low frequency oscillations will be transmitted over the line L_1 to the modulator M_1 connected with the output branch of the system. Here they will be beaten with the oscillations of the frequency f_2 and converted to a high frequency band represented by $f_2 \pm s$. These oscillations will be transmitted through the filter F_3 and after being given the proper phase angle by the phase shifting device PS_3 to insure proper directivity of the array, they will be transmitted from the antenna X_1'. The characteristic shown in Fig. 2ᵃ shows that the system can be made effective for simultaneous two-way operation by the proper adjustment of the phase shifting devices. Thus, in Fig. 2ᵃ, the lower pair of loops represents two unilateral characteristics of the receiving antenna and the upper pair of loops represents two unilateral characteristics of the transmitting antenna. Thus, by the proper adjustment of the phase shifting device PS_1 and similar devices in the similar branch circuits connected with the other receiving antennæ X_2, X_3, etc., of the array, oscillations of the frequency F_1, (together with its side bands $\pm s$), will be efficiently received from the right. These oscillations are detected and the side band frequencies s transmitted over the line L to the transmitting branch of the system, where they will modulate the frequency f_2 and will be given the proper phase by the phase shifting device PS_3 (and similar devices connected with similar circuits of the transmitting array), and will be radiated in a narrow band toward the left, as shown in the upper characteristic of Fig. 2ª. The system can be made responsive to oscillations of the frequency f_2 received from the left by the proper adjustment of the phase shifting device PS_2 (and similar parts of the other receiving antenna) and it can be adjusted to transmit oscillations of the frequency f_1 toward the right, as shown in the upper characteristic of Fig. 2ª by suitable adjustment of the phase shifting device PS_4 (and similar parts of the other transmitting antenna).

Fig. 3 shows a unit of a repeating station employing two arrays, one consisting of ground antennæ for receiving and the other consisting of vertical antennæ for transmitting. A repeating station made up of units as shown in Fig. 3 may be adapted for simultaneous two-way relaying of signals. Directivity of reception can be obtained by the proper adjustment of the phase shifting devices PS_1 and PS_2 and similar phase controlling devices on the other circuits of the antenna array. In like manner directivity of transmission can be effected by the proper adjustment of the phase shifting devices PS_3 and PS_4 and similar devices in similar circuits of the array. Thus, for example, the phase shifting device PS_1 and the correspondingly located phase shifting devices of all the other local circuits connected with the other receiving antennæ of the system may be adjusted so that reception of the frequency f_1 will be most efficient along a narrow band from the left, and by similar adjustment of the phase shifting device PS_2 and its other corresponding devices, efficient reception of the frequency f_2 may be effected along a narrow strip from the right. The phase shifting device PS_3 and its corresponding associates in the other circuits would be adjusted to give directivity of transmission along a narrow band toward the right and the phase shifting device PS_4 and its corresponding associates would be adjusted to give directivity of transmission of the frequency f_1 toward the left. The oscillator O_1 is designed to generate a frequency f_3 which, when beaten with the frequency f_1, will produce f_2, and in like manner when beaten with the frequency f_2 will produce f_1. These output frequencies will be selected by the suitable band filters F_3 and F_4 and when given the proper phase angle by the phase shifting devices PS_3 and PS_4 will be radiated from the antenna X_1. The characteristic of such a system is that shown in Fig. 2ª.

Fig. 4 shows, as stated, an arrangement for duolateral transmission and reception of signals. The receiving antenna X_1' is responsive to the frequencies f_1 and f_4 and the transmitting antenna to the frequencies f_2 and f_3. It is to be understood that a band of frequencies such as $f_1 \pm s$, etc., can be received and transmitted from these antennæ. The received frequencies would pass into their respective branch circuits which are coupled with the receiving antennæ, depending upon the transmission characteristics of the filters F_1 and F_2. The phase angle of the received current of each frequency in each local circuit of a repeating station would be controlled by the phase shifting devices PS_1 and PS_2. The currents would be amplified by the amplifier A_1 and modulated in the modulator M_1 with current of the frequency f_5 obtained from the source O_1. The frequencies selected as a result of modulating the frequency f_1 with f_5 is the frequency f_2 and in like manner the frequency selected as a result of modulating f_4 with f_5 is the frequency f_3. Currents of these resultant frequencies would be amplified by the power amplifier A_2 and transmitted into their appropriate branch circuits, depending upon the transmission characteristics of the filters F_3 and F_4. The resultant currents would be given in each local circuit the proper phasing by means of the phase shifting devices PS_3 and PS_4, and transmitted from the antenna X_1. Fig. 4ª shows the characteristics of a system which is adjusted to receive simultaneously from two directions which are separated by the angular distance α and designed to transmit simultaneously in two directions which are separated by the same angular distance as are the received waves. Fig. 4ᵇ represents the frequency distribution in a duolateral system having two repeating stations 1 and 2 interposed between the terminal stations A and B. Thus, station 1 is intended to receive frequencies f_1 and f_4 and to transmit frequencies f_2 and f_3, that is to say, the frequency f_1 would be received simultaneously from two directions separated by the angular distance α and also the frequency f_4 would be received from the same two directions. In like manner, frequency f_2 would be transmitted simultaneously in two directions separated by the angular distance α and also the frequency f^3 would be transmitted in the same way.

The application of either the unilateral or the duolateral system is clearly shown in Figs. 5 and 5^a wherein it is desired to relay the received signals, giving the transmitted waves a different direction from the received waves. Thus, in Fig. 5, A and B represent two terminal stations having a relay station 1 located between them. At station 1, the difference in direction of the received and transmitted waves is represented by the angle α. Fig. 5 shows the use at the repeating station 1 of two arrays each designed to have a unilateral characteristic, one for receiving and the other for transmitting the signals. In Fig. 5^a, a single array is used which is designed to have a duolateral characteristic whereby transmission and reception can be effected at the proper angular difference. Figs. 5^b, 5^c and 5^d represent three possible forms of antenna arrays. Thus, in Fig. 5^b the upper array is intended for transmitting and the lower array for receiving, the pairs of receiving and transmitting antennæ being connected by the local circuits designated A. Fig. 5^c represents an arrangement employing two receiving arrays and a common sending array. The corresponding pairs of receiving and transmitting antennæ are connected as shown by the local circuits designated A. Fig. 5^d represents an arrangement in which the antennæ of the receiving array are along the same axis as antennæ of the transmitting array. The adjacent antennæ of the receiving array are spaced at a definite fractional wave length apart in a manner similar to that in which the antennæ of the transmitting array are spaced. The corresponding pairs of transmitting and receiving antennæ are joined by the local circuits, as shown, designated A.

It will be seen that by means of the foregoing arrangements, signals may be received efficiently from any one direction and transmitted efficiently in any other direction without producing undesirable reaction at the repeating station. Also by the duolateral type, signals may be received efficiently from two directions less than 180 degrees apart and transmitted in two directions also less than 180 degrees apart, without producing undesirable reaction at the repeating station.

Although this invention has been disclosed as embodied in specific forms and arrangements of parts, it is to be understood that it is capable of embodiment in other and different forms without departing from the spirit and scope of the appended claims.

What is claimed is:

1. In a radio repeating system characterized by directive control of received and transmitted waves, the combination with a receiving antenna array tuned to a definite frequency of a transmitting antenna array balanced with respect to the receiving antenna array and tuned to a different frequency, and a plurality of amplifying circuits individual to and connected with a pair of antennæ, one from each array, having frequency changing means, amplifying means connected therewith, and means connected with each of said other means to adjust the phase of the received and transmitted currents to produce unilateral reception and radiation.

2. In a radio repeating system characterized by directive control of received and transmitted waves, the combination with a receiving antenna array tuned to a definite frequency of a transmitting antenna array tuned to a different frequency, means to reduce the frequency of the received waves, means to amplify the said waves, means to increase the frequency of the said waves before radiation, and means to adjust the phase of the currents resulting from said waves for unilateral reception and transmission.

3. In a radio system characterized by directive control of received and transmitted waves, the combination with a receiving antenna array tuned to a definite frequency of a transmitting antenna array tuned to a different frequency, means to reduce the frequency of the received waves, means to amplify the said waves, means to increase the frequency of the said waves before radiation, and means to adjust the phase of the currents resulting from said waves, to control the direction of reception and transmission.

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

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