L. ESPENSCHIED ET AL

DIRECTIVE RADIO REPEATING SYSTEM

Filed Dec. 28, 1921 3 Sheets-Sheet 1

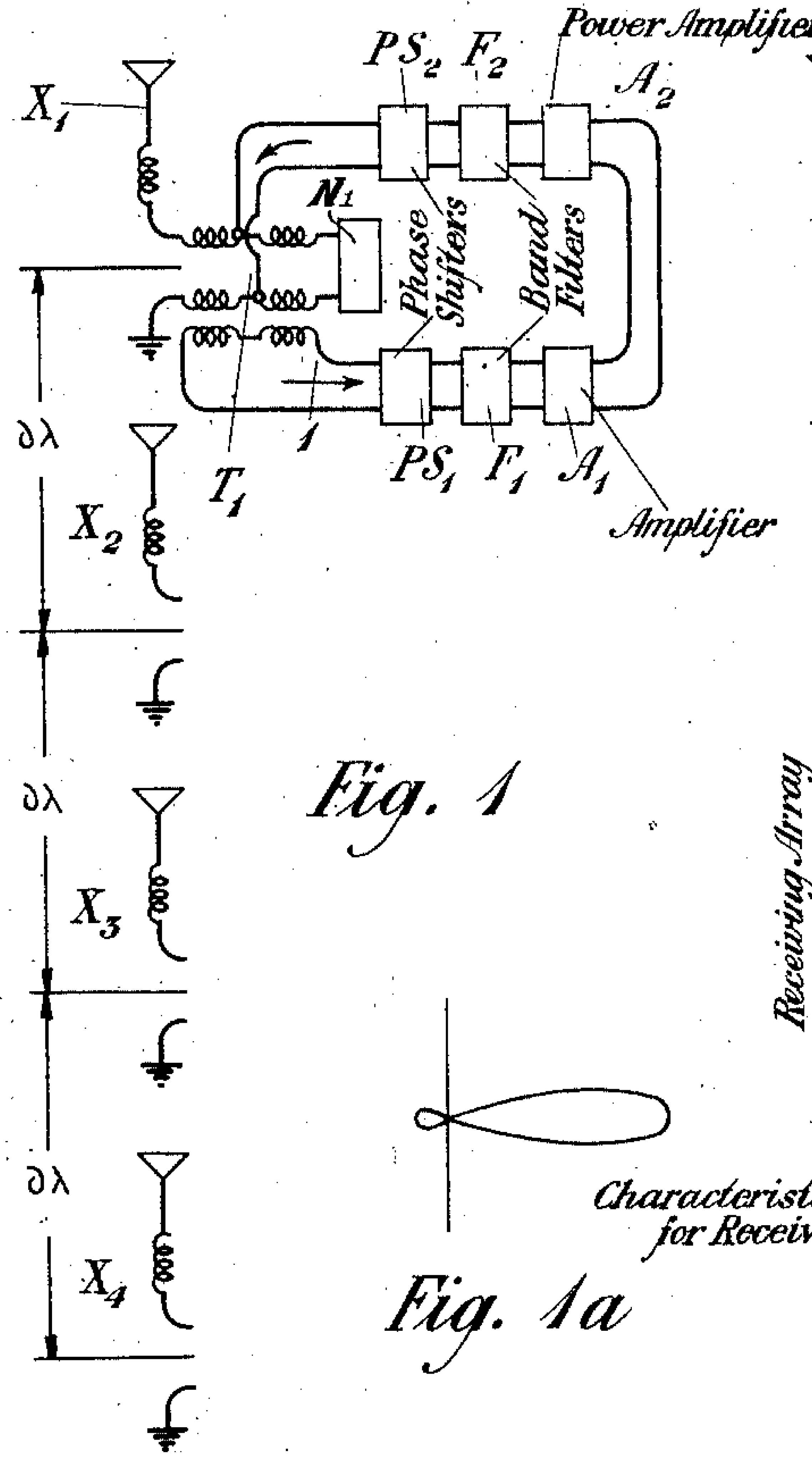
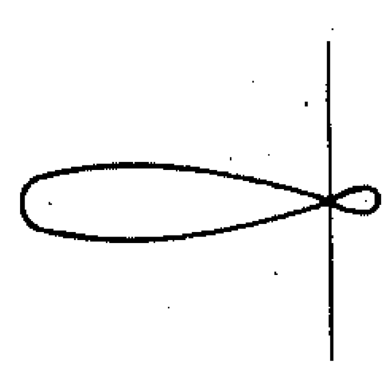


Fig. 1

Array with Unilateral Characteristic

Characteristic of Array for Receiving

Fig. 1a



Characteristic of Array for Sending

Fig. 1b

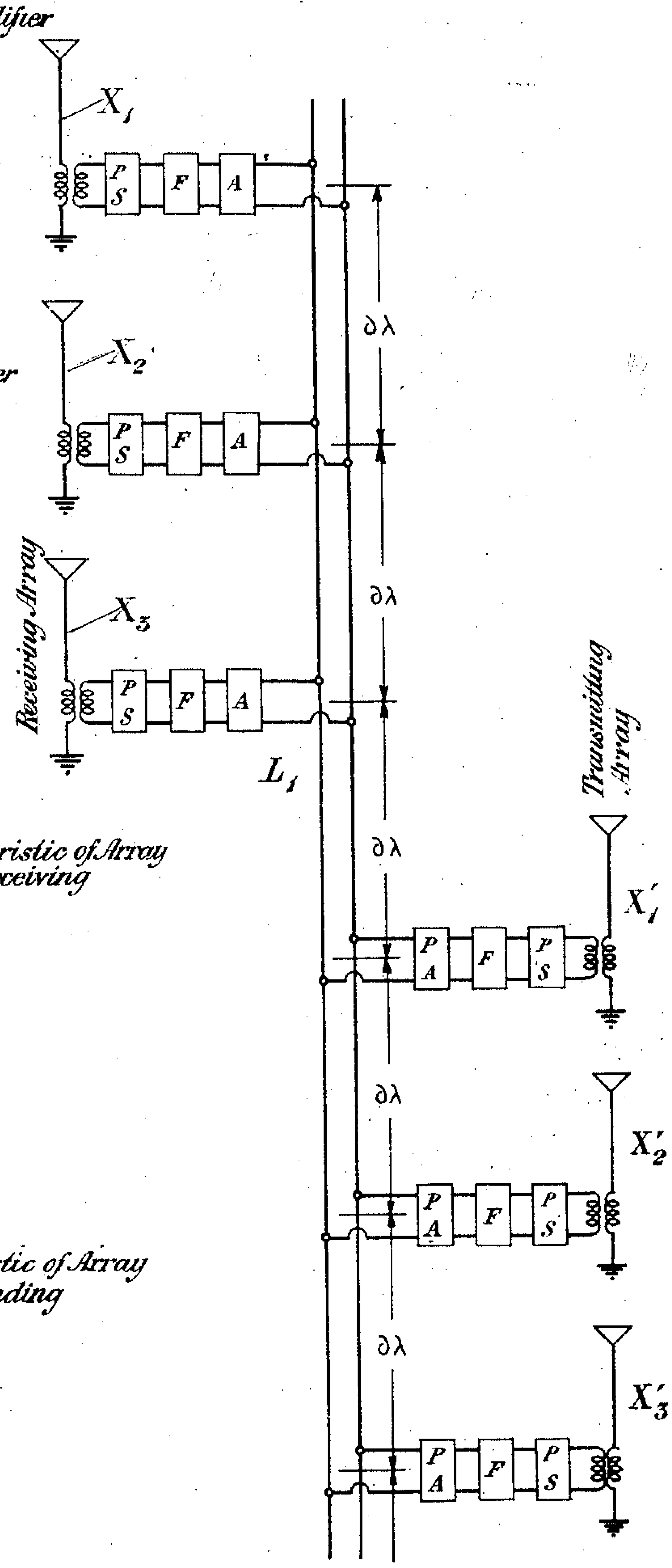


Fig. 2

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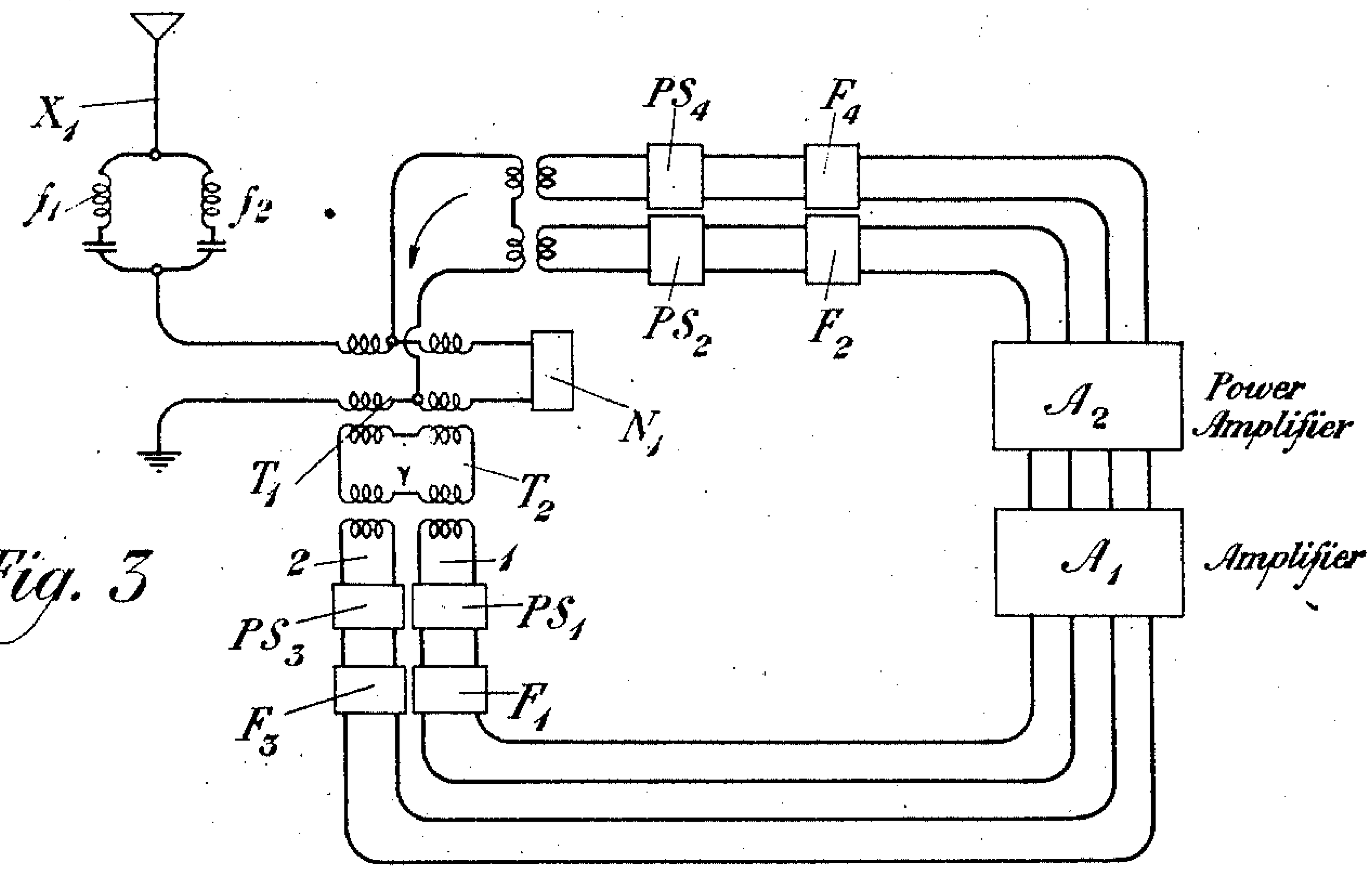
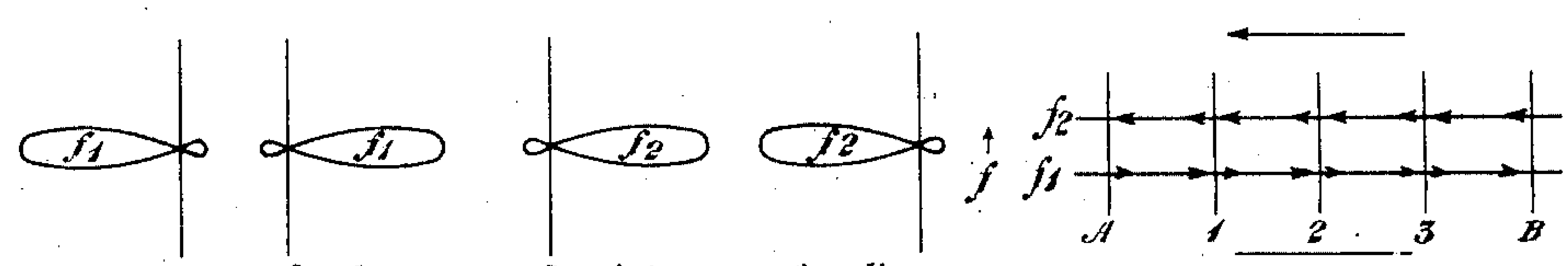


Fig. 3

Array with Unilateral Characteristic



Receiving Fig. 3a Sending Fig. 3b Receiving Fig. 3c Sending Fig. 3d

Characteristics of Array

Fig. 3e

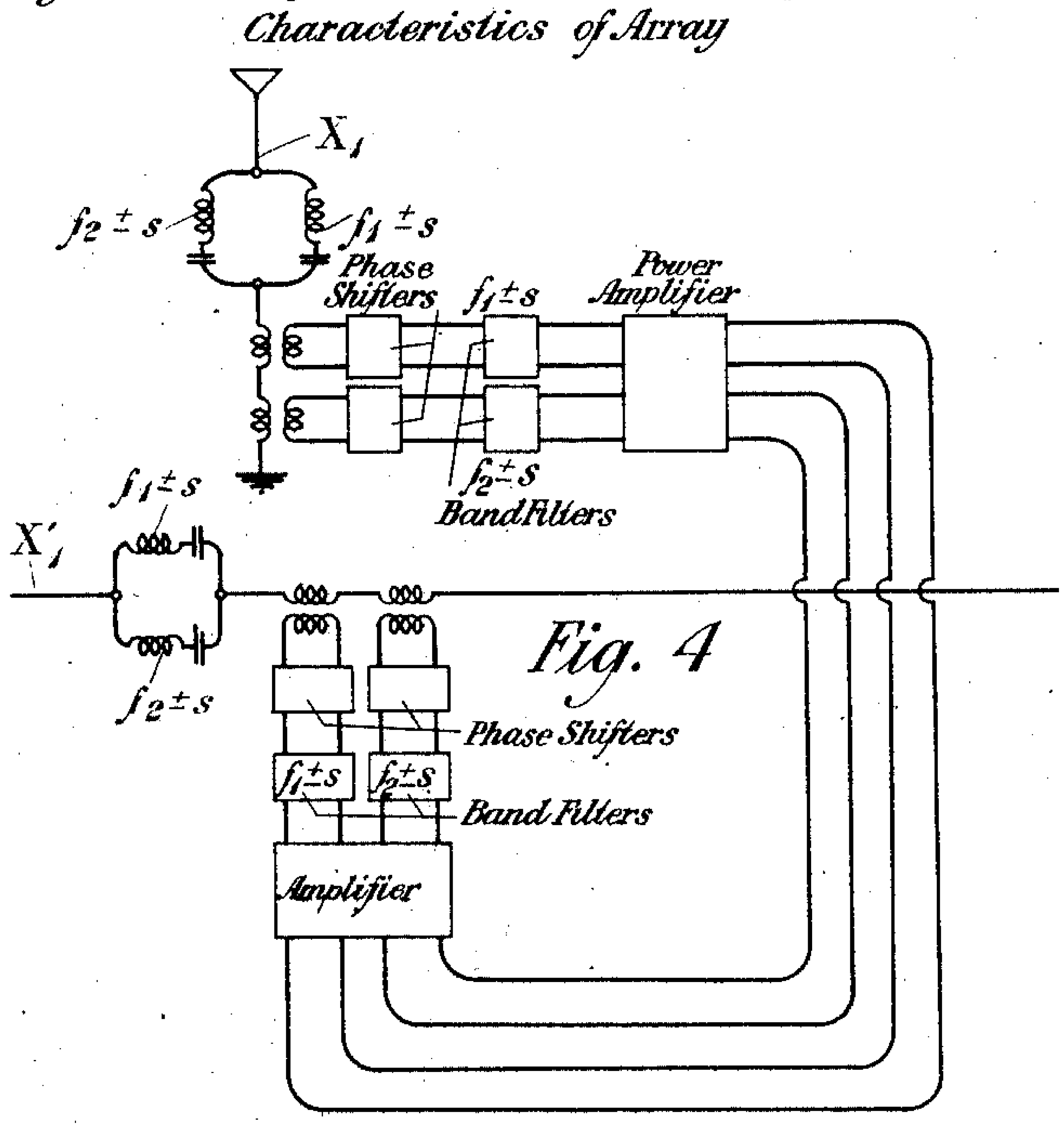


Fig. 4

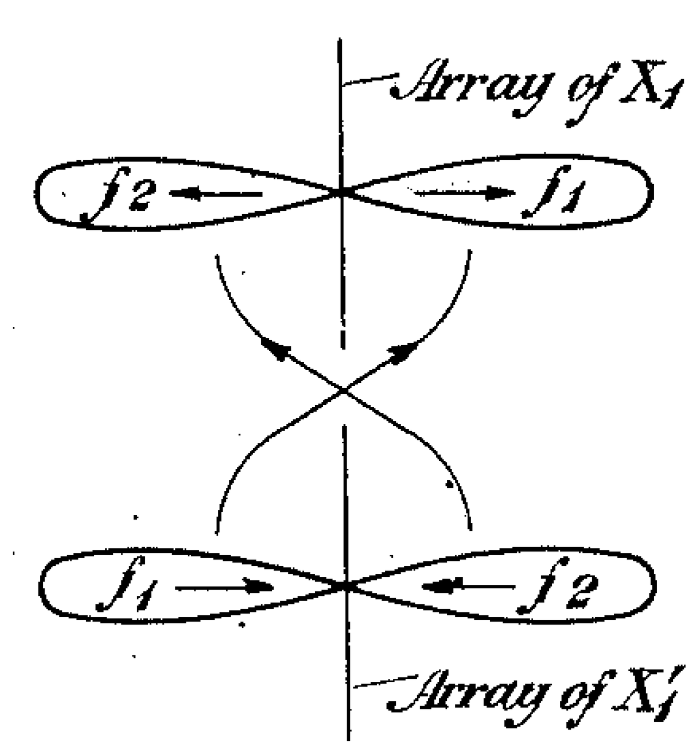


Fig. 4a

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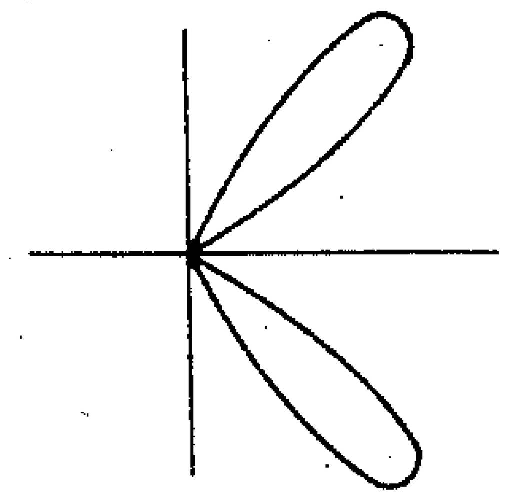


Fig. 5

Optional Arrangements of axis
of array at turning point

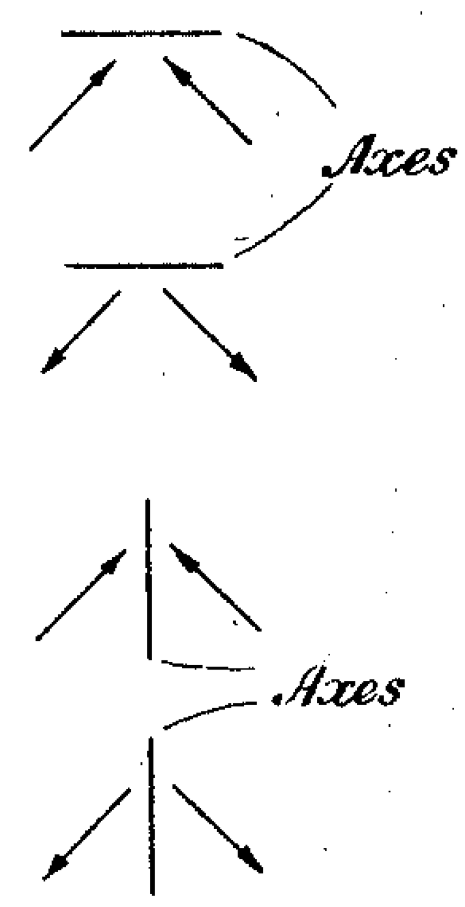


Fig. 5a

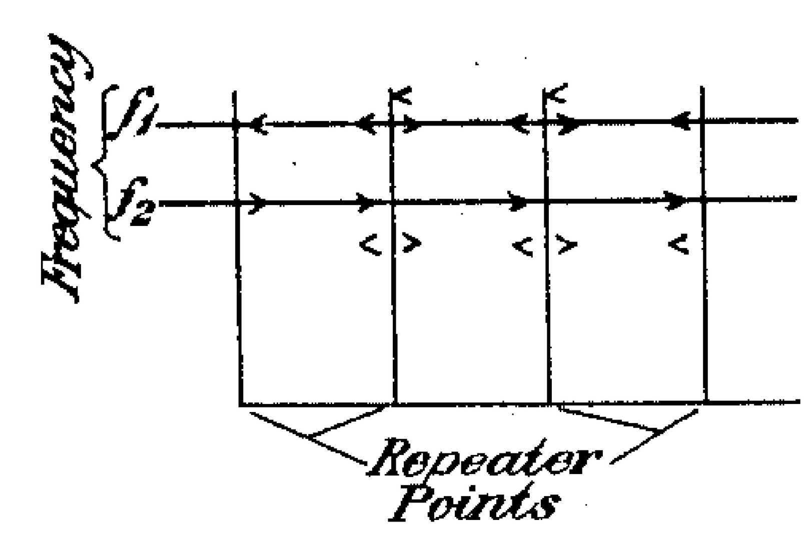
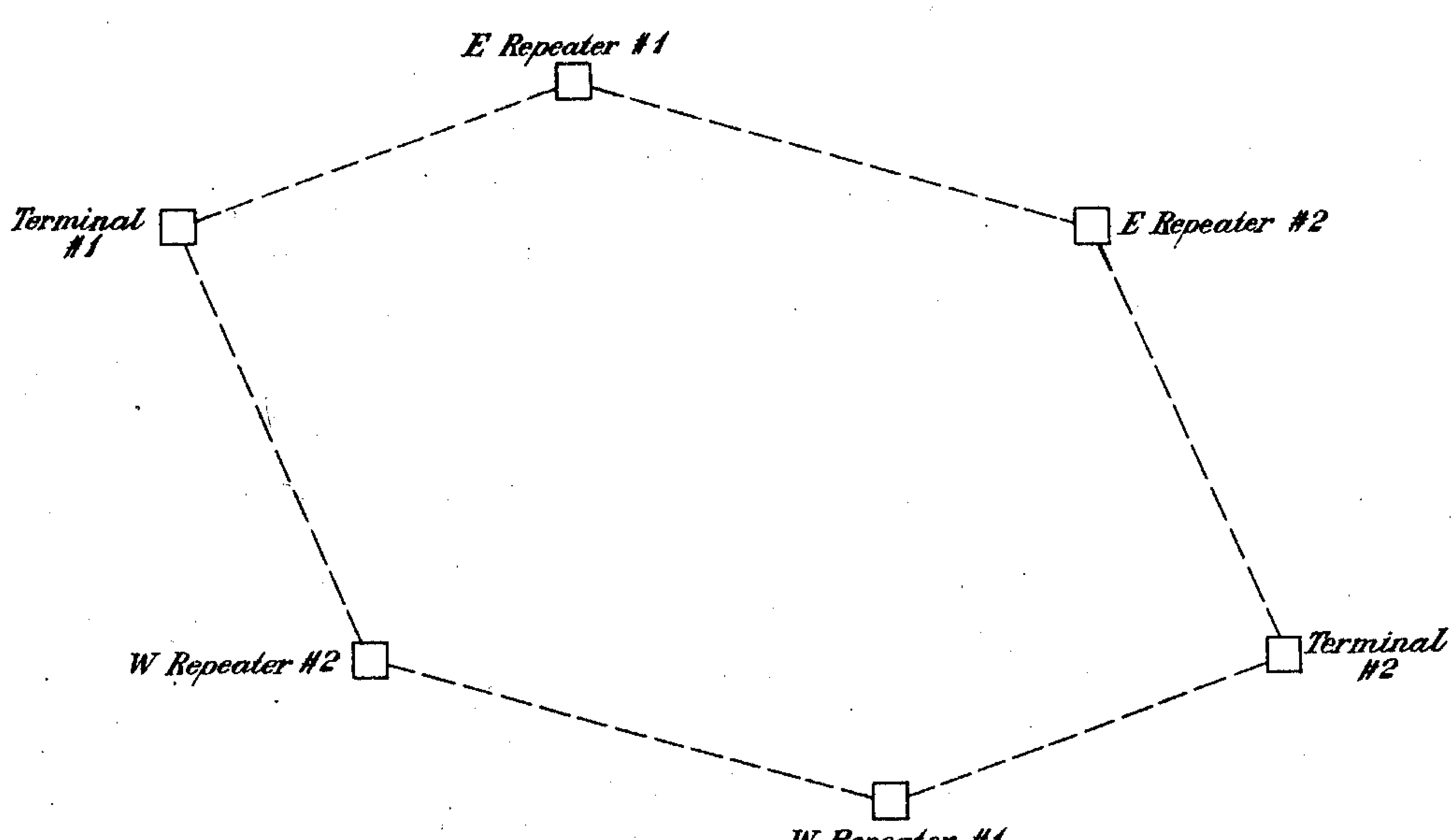


Fig. 5b



Geographical Separation used to Eliminate Singing between
Talking Channels

Fig. 6

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UNITED STATES PATENT OFFICE.

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DIRECTIVE RADIO REPEATING SYSTEM.

Application filed December 28, 1921. Serial No. 525,441.

This invention relates to directive radio repeating systems and particularly to that type of system in which transmission and reception are effected at the same frequency.

In our copending application, Serial No. 525,440 filed December 28, 1921, various forms of circuits are shown for relaying radio signals in which transmission and reception are effected at the same frequency. In the forms shown in the said copending application, the direction characteristic of the antenna arrays is of the bilateral type in which both reception and transmission of energy is effected in two diametrically opposite directions from the array.

It is one of the objects of the present invention to provide a radio relay adjusted to have a direction characteristic which is either unilateral or duolateral. "Unilateral" means that the antenna array is capable of receiving efficiently from only one direction, and, likewise of transmitting efficiently in only one direction; and "duolateral" means reception from two directions less than 180 degrees apart, and, likewise, transmission from two directions less than 180 degrees apart.

Another object of this invention is to provide a long distance signaling system 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 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 important when it is desired to avoid objects lying between the two terminals which would tend to interfere with the propagation of electromagnetic waves, or when, for traffic or other reasons, it would be desirable to transmit the signals over the more indirect route.

This invention will be better understood from the following description when read in connection with the attached drawing, of which Figure 1 shows an arrangement in which reception and transmission are effected by the same antenna array and Figs. 1^a and 1^b represent characteristics of the array; Fig. 2 shows an arrangement employing two arrays of antennæ; Fig. 3 shows a unit circuit of an array adapted for duplex operation, Figs. 3^a to 3^d inclusive, are characteristics of the array and 3^e represents graphically the frequency distribution throughout the system; Fig. 4 shows a unit circuit of an array using balanced vertical and ground antennæ for duplex operation, and Fig. 4^a is a characteristic of the array; Fig. 5 is a duolateral characteristic of a system such as Fig. 4, under proper adjustment; Fig. 5^a shows optional arrangements of the array, and Fig. 5^b shows graphically the frequency distribution; and Fig. 6 shows a method for separating the repeating stations, which is rendered possible by directive control of radiation and reception, whereby singing between channels is prevented.

In Fig. 1, X_1, X_2, X_3 and X_4 represent four vertical antennæ which are spaced apart a definite fraction of a wave length, as shown in the drawing. Connected with the antenna X_1 by means of a triple-winding transformer or hybrid coil T_1, is a local circuit comprising a phase shifting device PS_1, a band filter F_1, a low power amplifier A_1, a power amplifier A_2, another band filter F_2, and another phase shifting device PS_2. This local circuit is connected with the windings of the transformer T_1 in a manner well known to those familiar with the art, and the said transformer has also connected thereto a network N_1, which is designed to balance the antenna X_1. Each antenna of the array has connected thereto a circuit similar to and embodying the same apparatus as that described in connection with the antenna X_1.

In the operation of the system shown in this figure, when oscillations of the frequency of $f_1 \pm s$ are set up in each of the antennæ of the array, as for example X_1, the current at this frequency will pass into the input branch 1 of the repeater circuit and will be impressed upon the phase shifting device PS_1, which is designed to control the phase of the current applied to the subsequent amplifying devices in this local circuit. Current of the frequency of $f_1 \pm s$ will pass through the band filter F_1 and be amplified by the low power amplifier A_1. This amplifier may be a single stage type, although it is customary and undoubtedly desirable to use a plurality of stages in order to build up the potential applied to the power amplifier A_2. The output current of the latter amplifier is transmitted through a band filter F_2, having preferably the same frequency transmission range as F_1, and is then passed through the phase shifting device PS_2 which controls the phase at which the current is applied to the antenna X_1 for radiation therefrom. It is to be understood that similar action is going on simultaneously in the other antennæ, constituting the array, and in the local circuits individual to the said antennæ. By controlling the phase of the current by means of the phase shifting devices PS_1 and PS_2 associated with the local circuits of each antenna in a manner fully described in the copending application of George A. Campbell, Serial No. 327,553, filed September 30, 1919, it is possible to control the efficiency of reception and transmission. This is clearly shown in Figs. 1^a and 1^b, the former representing the characteristic for receiving and the latter for sending. It will be seen that in accordance with Fig. 1^a, the system receives most efficiently waves advancing from the right and transmits most efficiently towards the left.

Since the arrangement shown in Fig. 1 is adjusted for reception from only one direction and for transmission in the opposite direction, it is obvious that it is useful only for one-way transmission of signals. For practical operation it would, of course, be necessary to have two of these, in one of which the receiving and sending characteristics would be opposite to those of the other. Such a system is shown in Fig. 6, in which the upper dotted line between the two terminals represents the direction of transmission from terminal 1 to terminal 2, and the lower dotted line represents the direction of transmission between terminal 2 and terminal 1. In this arrangement the east repeater #1 would be operated so as to receive most efficiently along the line connecting the repeater with the terminal 1 and transmitting most efficiently along the line extending from the east repeater #1 to the east repeater #2. If the transmission between the two terminals is effected by the same frequency, singing between the repeaters may be greatly minimized by wide geographical separation of the repeaters, as shown in Fig. 6.

The arrangement shown in Fig. 2 is differentiated from that shown in Fig. 1, however, by the use of separate arrays of antennæ for receiving and sending. Thus, the antennæ X_1, X_2 and X_3 belong to the receiving array and antennæ X_1', X_2' and X_3' belong to the transmitting array. It may be stated that although the axes of the two arrays, as shown in the figure, are along different lines, the arrays may be arranged so that their axes will coincide. The characteristic of the receiving array is that shown in Fig. 1^a, and the characteristic of the transmitting array is as shown in Fig. 1^b. Oscillations set up in the antennæ X_1, X_2 and X_3 are transmitted through the phase shifting devices, and the band filters, and the low power amplifiers of the local circuit and are impressed upon the common transmission line L_1, that connects the circuits of the receiving antenna with the circuits of the transmitting antenna. The currents transmitted over the line L_1 are amplified by the power amplifiers and after passing through the band filters are given the proper phase adjustment before being applied to the transmitting antennæ X_1', X_2', and X_3'. In the arrangement shown in Fig. 2, singing is prevented by the directive characteristics of the two arrays.

The arrangement shown in Fig. 3 is adapted for the simultaneous transmission and reception of two signaling channels. The antenna X_1 is designed for the reception of two channels, one represented by $f_1 \pm s$, and the other represented by $f_2 \pm s$. A band of frequencies represented by $f_1 \pm s$ received from the direction represented by the major axis of the loop characteristic 3^a will be impressed upon the local amplifying circuit connected with the antenna X_1 by means of the transformer T_1. The current resulting therefrom will be impressed by the transformer T_2 upon the circuit 1, which has connected therewith a phase shifting device PS_1 and a band filter F_1, which latter device is adapted to transmit a band of frequencies represented by $f_1 \pm s$. The current of the frequencies within the said band will be amplified first by the low power amplifier A_1 and then by the power amplifier A_2. The amplified current of this frequency range will pass through the band filter F_2 and through the phase shifting device PS_2 and will be impressed upon the antenna by the transformer T_1 for transmission at the frequency of $f_1 \pm s$. Simultaneously with the amplification of the signals represented by the band $f_1 \pm s$, other signals within the range $f_2 \pm s$ may be received, amplified and transmitted from this repeater device. Let it be assumed that signals based upon the carrier frequency f_2 are received along the line of major axis of the characteristic 3^c, which direction is opposite to that in which the signals were received as represented by Fig. 3[a]. The current resulting therefrom will be impressed upon the input circuit 2, which has associated therewith a phase shifter PS_3 and a band filter F_3, adapted respectively to control the phase of the received currents, and to limit the range of frequencies to a band represented by $f_2 \pm s$. Currents passing through the filter F_3 will be amplified, first by the low power amplifier A_1, and then by the high power amplifier A_2, and the resultant amplified current will pass through the band filter F_4. By means of the phase shifting devices such as PS_4 associated with the antenna X_1, and similar devices of the other antennæ of the array, the wave will be radiated therefrom along the line represented by the characteristic of Fig. 3[d]. It will be seen that in the arrangement shown in Fig. 3 reception and transmission is effected at the same frequency in each direction, that is to say, the wave arriving from the east at the frequency f_1 will be radiated to the west at the same frequency and the wave arriving from the west at the frequency f_2 will be radiated to the east at the frequency f_2. Singing through each unit circuit is prevented by means of the balancing network N_1, and similar net-works of the other unit circuits.

The arrangement shown in Fig. 4 differs from that shown in Fig. 3 principally in the use of a ground antenna for receiving in connection with a vertical antenna for transmission. In this way, singing of the amplifying circuit is prevented by the balanced relation of the two antennæ instead of by using a balancing network such as shown in Fig. 3. Furthermore, both antennæ of Fig. 4 have two degrees of freedom, thereby rendering the circuit adapted for duplex operation. The reception frequency and transmission frequency for each individual channel is the same. This is clearly shown in Fig. 4[a], which represents four unilateral characteristics and not two bilateral ones. Thus, as shown in the latter figure, signals of the frequency f_1 received from the west by the array of X_1' are amplified and transmitted towards the east at the same frequency by the array of X_1; and in similar manner signals of frequency f_2 received from the east by the array of X_1' are transmitted at the same frequency towards the west by the array of X_1.

The arrangement shown in Fig. 4 may be adapted by the proper spacing of the antennæ and by the proper adjustment of the amplitude and phase of the received and transmitted current to have, what is termed, the duolateral characteristic for receiving and transmitting, as shown in Fig. 5. Thus, for example, the signals based on the carrier frequency f_1 may be efficiently received from that direction coinciding with the axis of the upper characteristic and may be efficiently transmitted in the direction of the axis of the lower characteristic; and, similarly, signals based upon the carrier frequency f_2 may be efficiently received from that direction coinciding with the axis of the lower characteristic and efficiently transmitted in the direction of the axis of the upper characteristic; or signals may be efficiently received simultaneously from two directions coinciding with the two axis of the characteristics, and simultaneously transmitted in the same two directions away from the central point.

It will therefore be apparent to those familiar with the art that by means of the arrangements set forth in the foregoing described figures, not only can radio signals be relayed or amplified but also that the direction of reception and transmission may be controlled so as to provide minimum interference with other signals in transmission and also to produce the greatest efficiency of operation.

By means of the invention, which has been described in some of its various forms, the course of transmission of signals may be readily controlled, so that, if it is desirable to use an indirect route between two terminals, in order to avoid an obstacle to electromagnetic waves or for any purpose whatsoever, we may effect the desired result with the minimum loss of energy.

Likewise we can efficiently use short wave lengths for long distance transmission and can reduce the effect of static interference by the proper location of repeating stations embodying the principles of our invention.

Although this invention has been described as embodied in a certain form and arrangement of parts, it is to be understood that it is capable of embodiment in 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 a receiving antenna array of a transmitting antenna array, each comprising a plurality of antennæ, and a plurality of connecting circuits each extending from an antenna of one array to an antenna of the other array, the said circuits containing means to amplify and means to change the phase of the currents in the said circuits to effect unilateral directivity of the reception and transmission of radio signals.

2. In a radio repeating system the combination with a receiving antenna array of a transmitting antenna array, each of said arrays comprising a plurality of antennæ, and both of said arrays designed to respond to the same frequency and a plurality of connecting circuits, each extending from an antenna of one array to an antenna of the

other array, said circuits containing means to amplify and means to change the phase of the currents in the said circuits to effect unilateral directivity of the reception and transmission of radio signals.

3. In a radio receiving system adapted to receive and transmit signals at the same frequency the combination with a receiving array of a transmitting array and a plurality of circuits individual to each pair of receiving and transmitting antennæ having means associated therewith to amplify the received currents and means to control the phase of the currents transmitted in order to effect unilateral directivity of transmission.

4. In a radio repeating system adapted to receive and transmit signals at the same frequency the combination with a receiving array of a transmitting array and a plurality of circuits individual to each pair of receiving and transmitting antennæ having means associated therewith to amplify the received currents and means to control the phase of the received currents in order to effect unilateral reception and means to control the phase of the transmitted currents in order to effect unilateral transmission.

5. In a radio repeating system adapted for the simultaneous reception and transmission of a plurality of signaling channels the combination of a receiving antenna array responsive to two frequencies, a transmitting antenna array also responsive to two frequencies and a plurality of circuits connecting each pair of receiving and transmitting antennæ adapted to control the phase of the received currents of each channel to effect unilateral reception and to amplify the said currents.

6. In a radio repeating system adapted for the simultaneous reception and transmission of a plurality of signaling channels, the combination of a receiving antenna array responsive to two frequencies, a transmitting antenna array also responsive to two frequencies and a plurality of circuits connecting each pair of receiving and transmitting antennæ adapted to amplify the received currents and to control the phase of the amplified currents of each channel to effect unilateral transmission of each channel from the said array.

7. In a radio repeating system adapted for the simultaneous reception and transmission of a plurality of signaling channels the combination of a receiving antenna array responsive to two frequencies, a transmitting antenna array also responsive to two frequencies and a plurality of circuits connecting each pair of receiving and transmitting antennæ having means associated therewith to control the phase of the received currents and also having means to control the phase of the transmitted currents in order to effect unilateral reception and transmission, and means to amplify the currents traversing the said circuits.

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

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DE LOSS K. MARTIN.