

May 8, 1928.

1,668,638

L. ESPENSCHIED ET AL

DIRECTIVE RADIO REPEATING SYSTEM

Filed Dec. 28, 1921

4 Sheets-Sheet 1

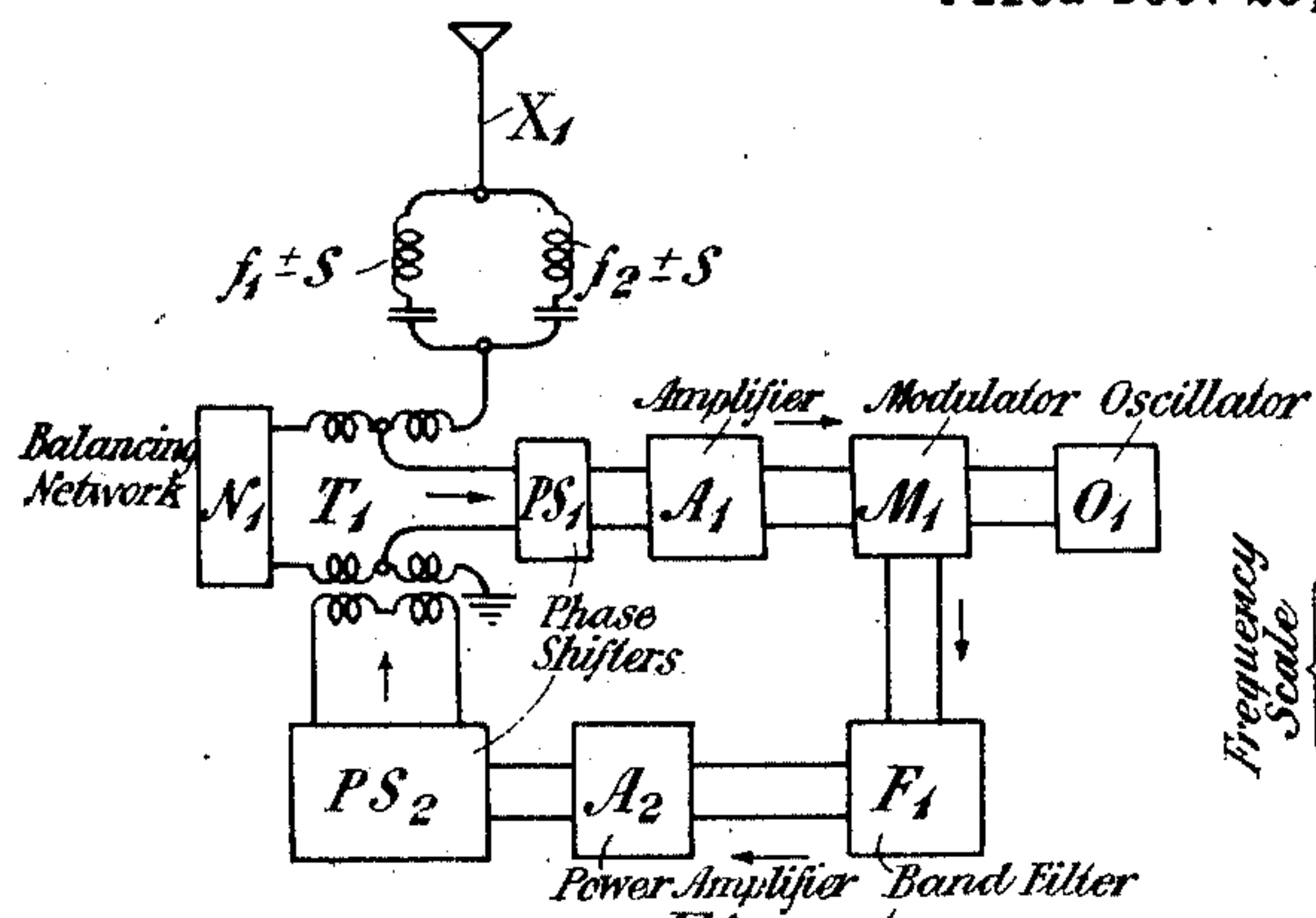


Fig. 1

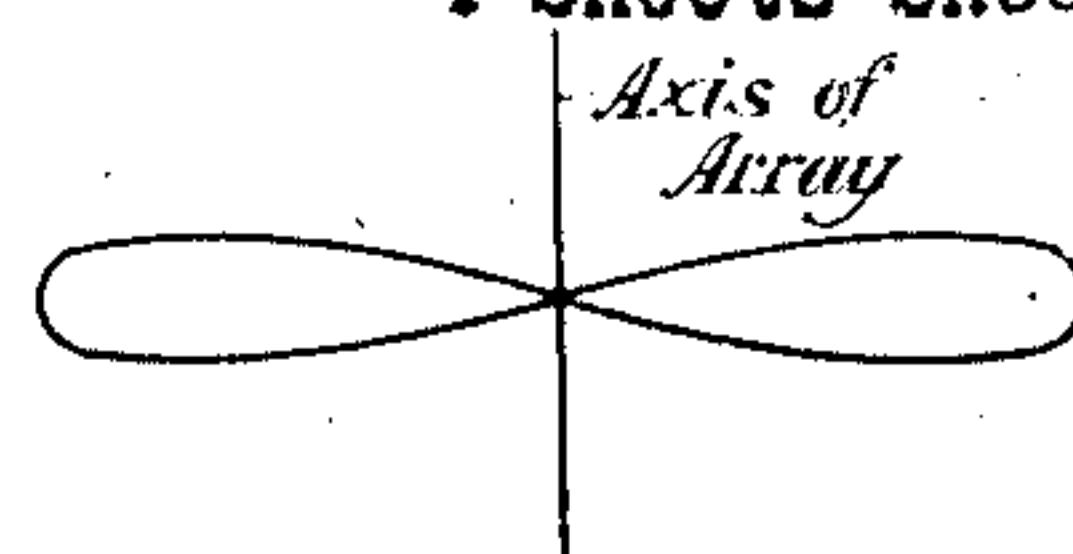


Fig. 1a

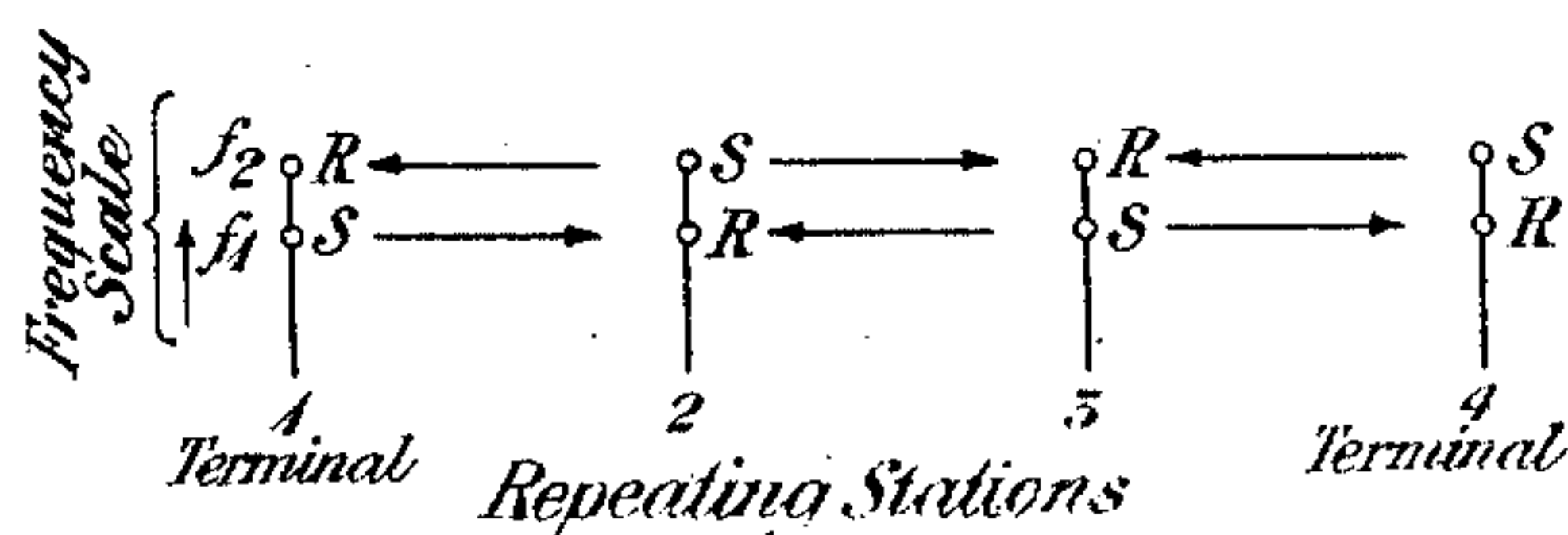


Fig. 1b

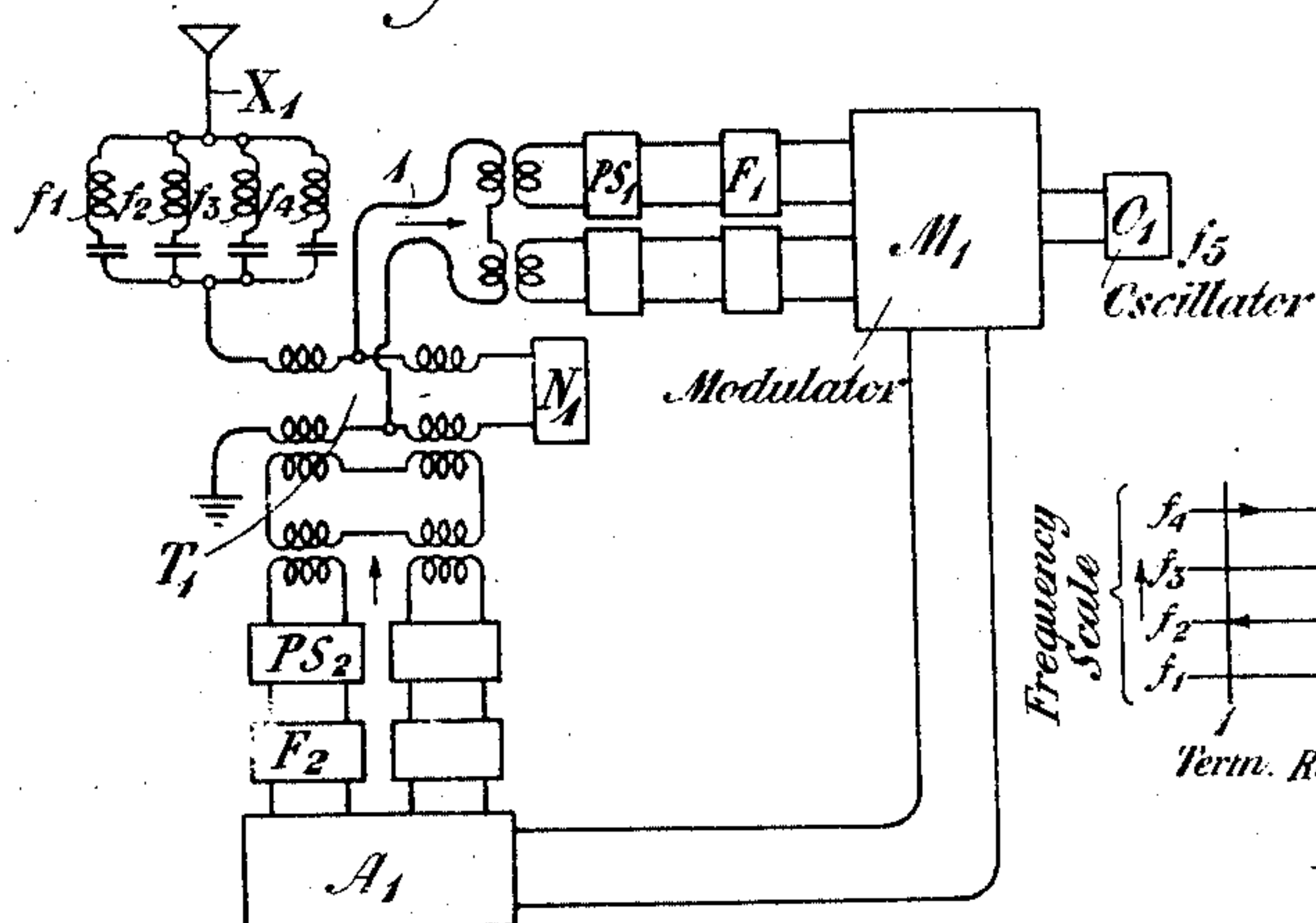


Fig. 2

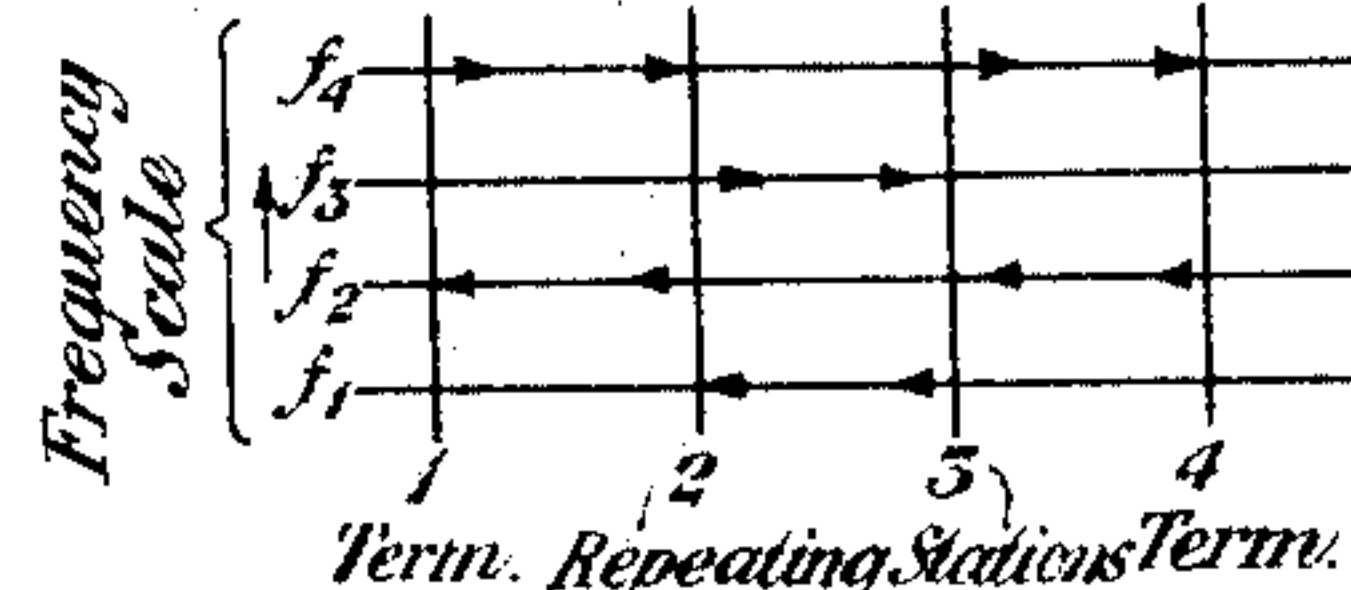


Fig. 2a

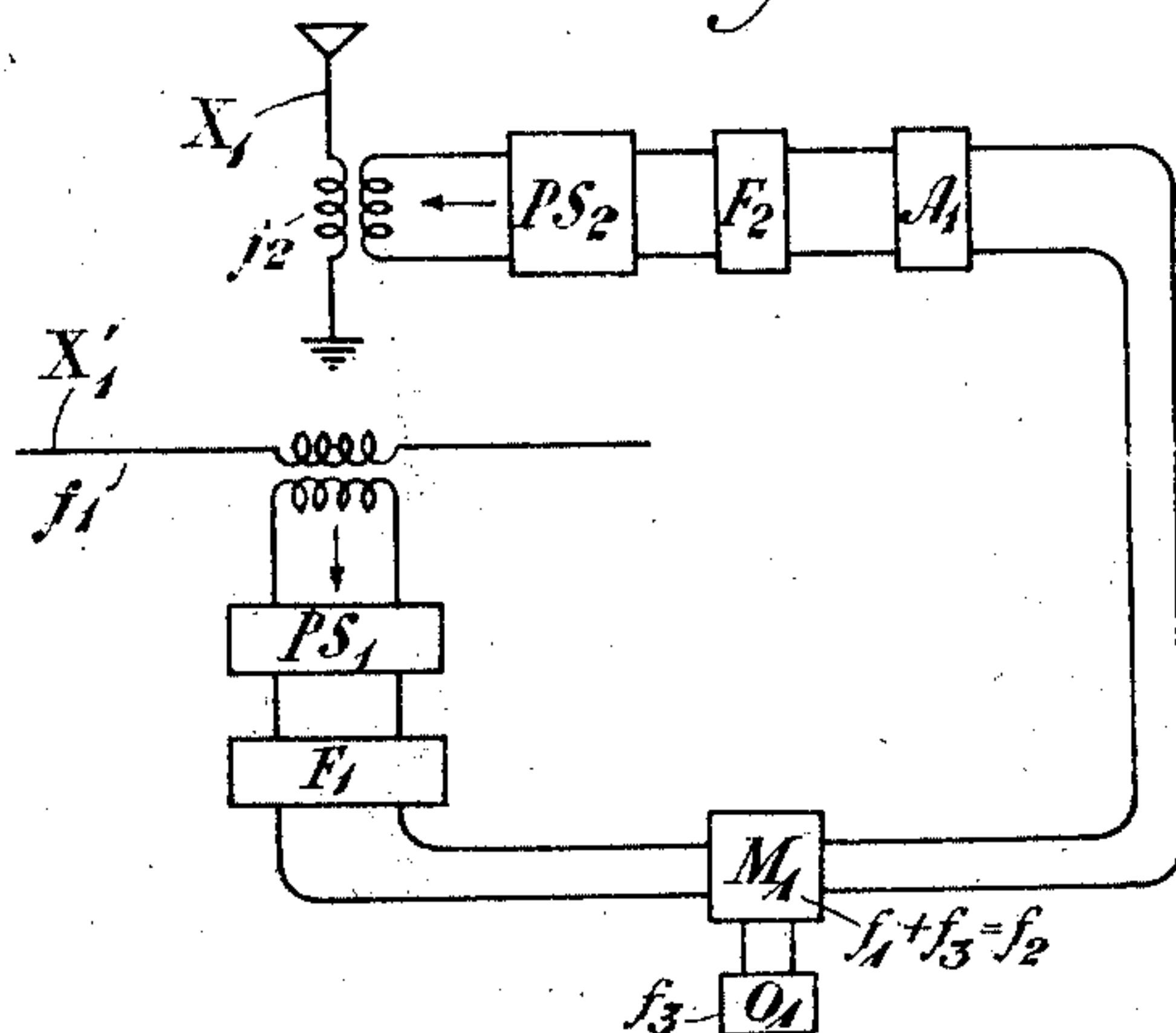


Fig. 3

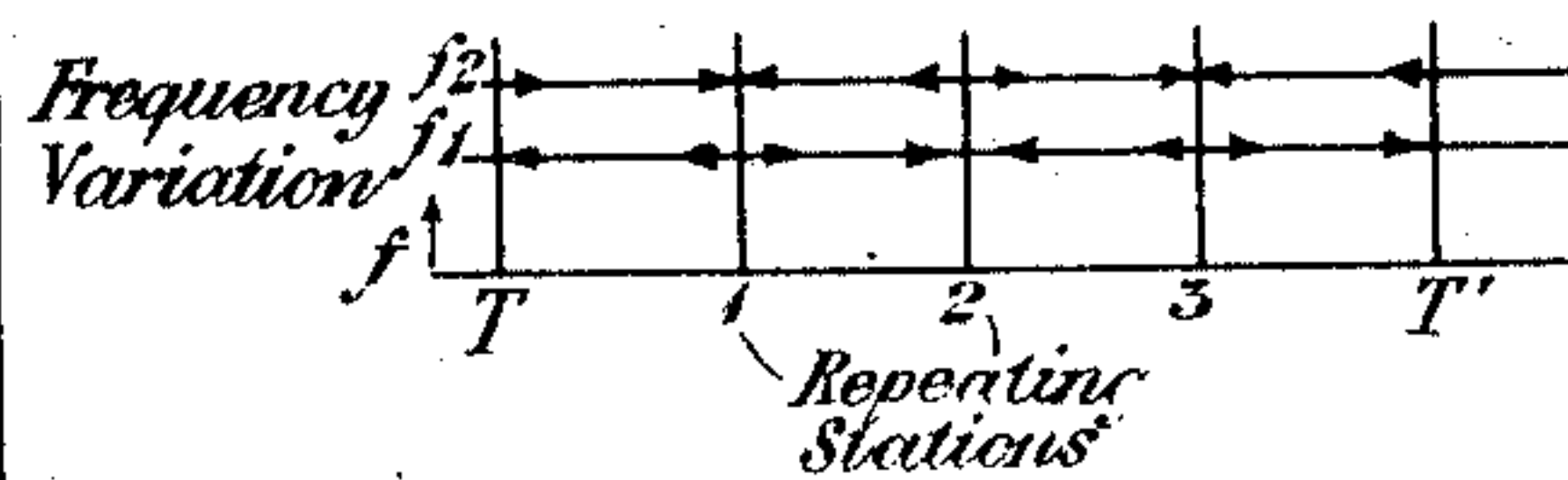


Fig. 3a

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4 Sheets-Sheet 2

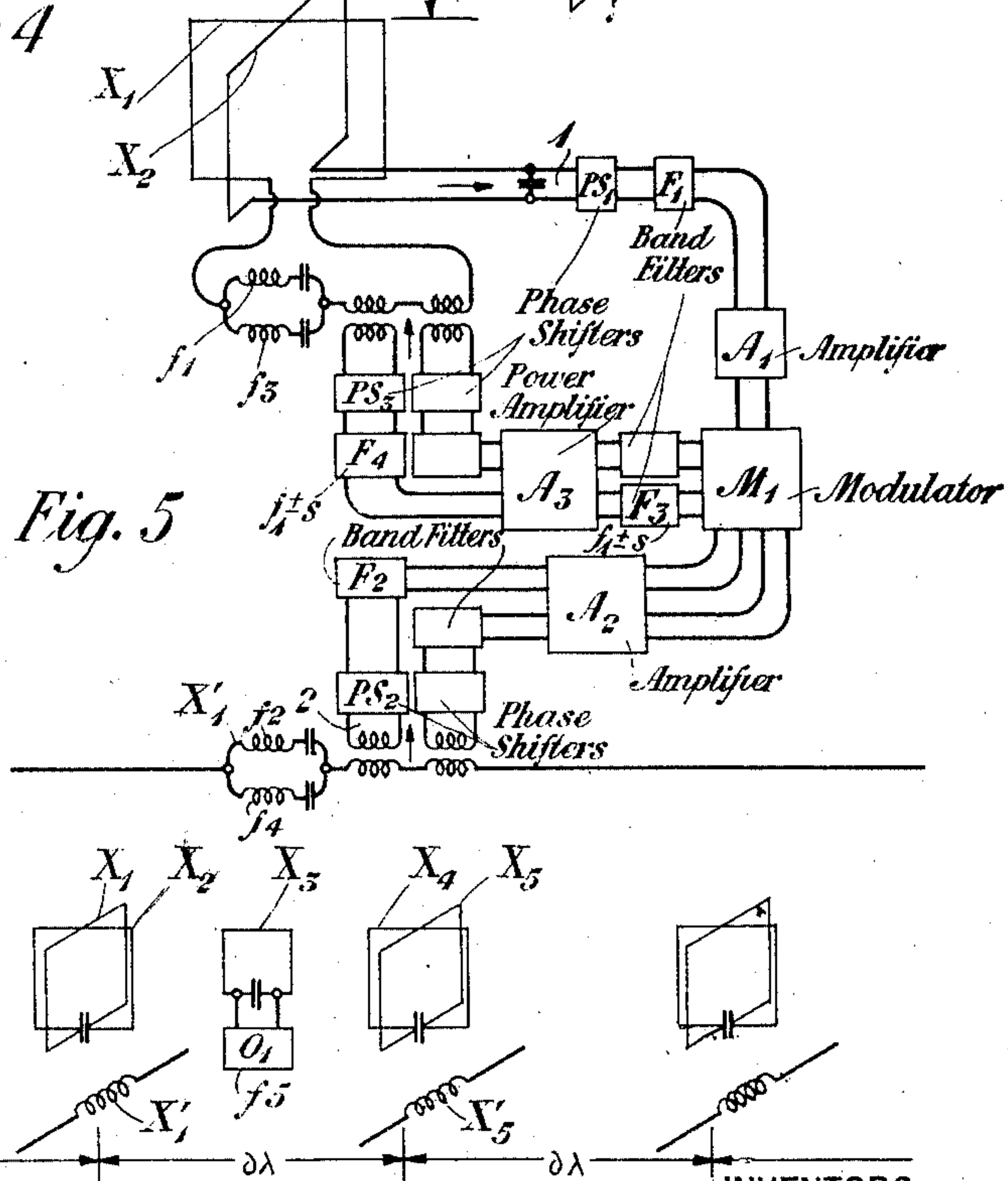
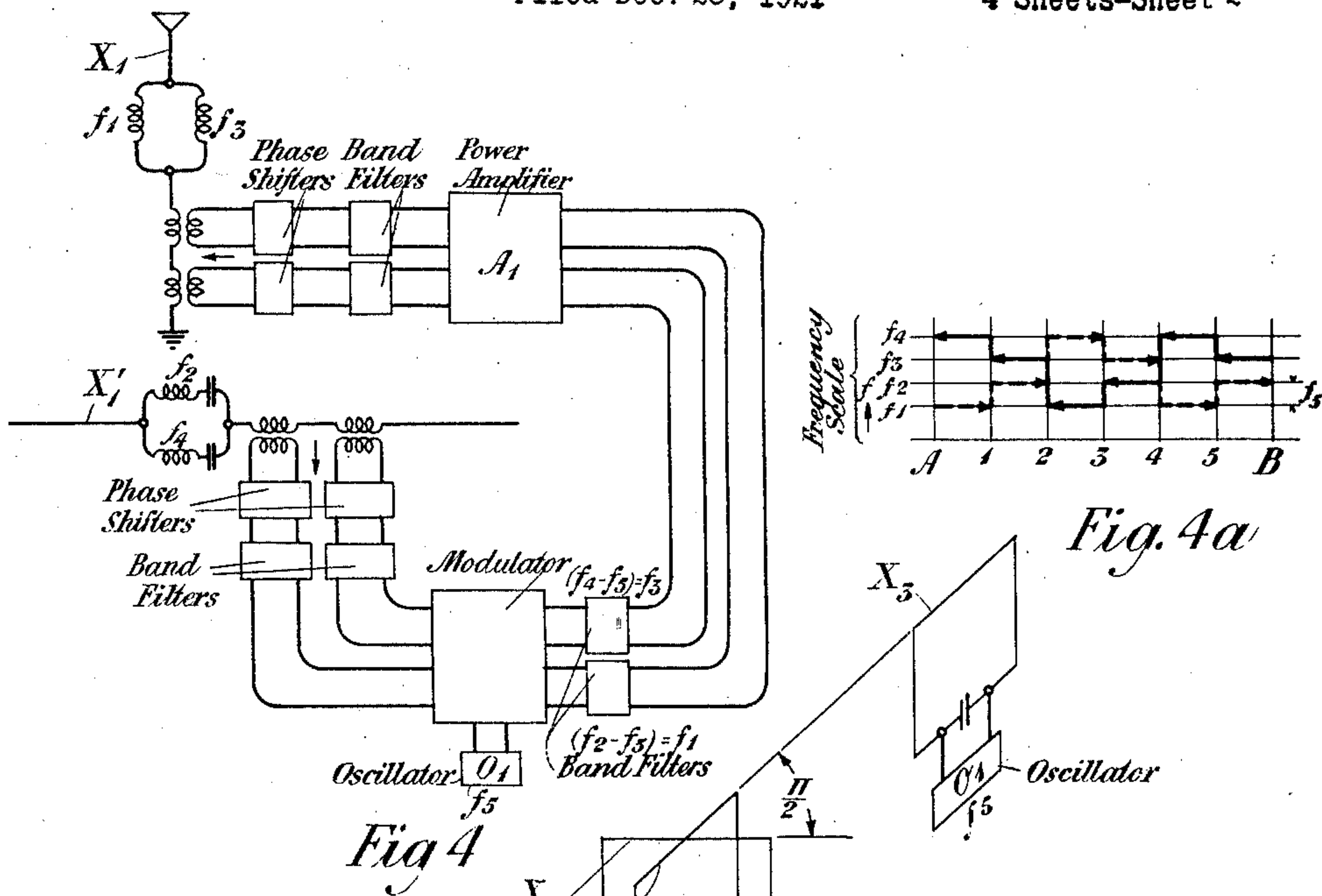


Fig. 5a L. Espenschied and D. K. Martin
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4 Sheets-Sheet 3

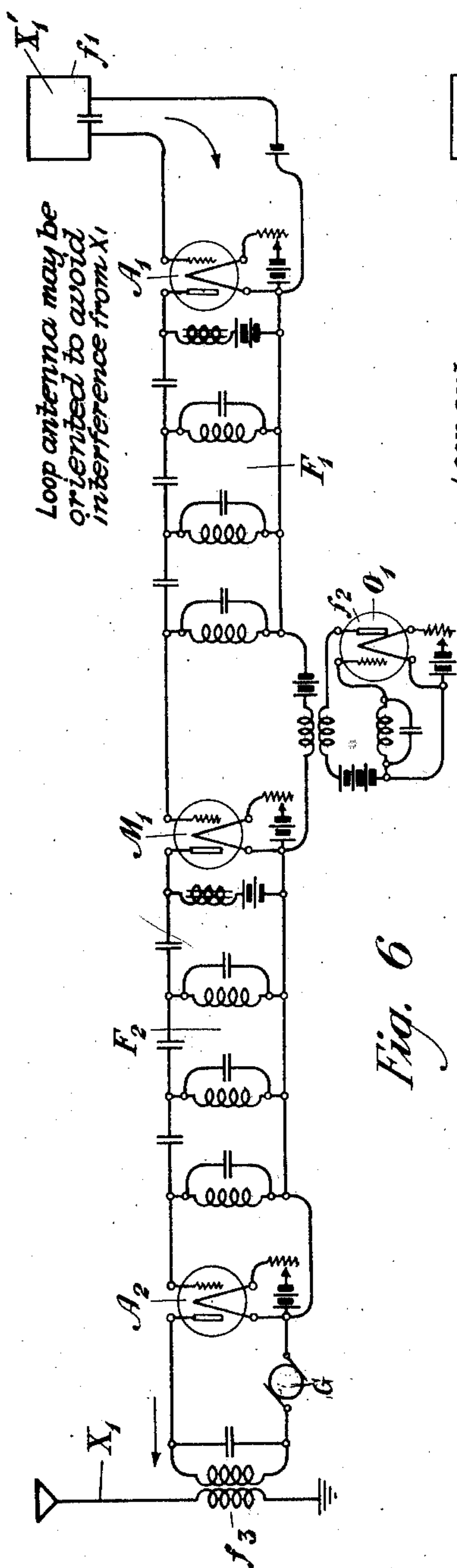


Fig. 6

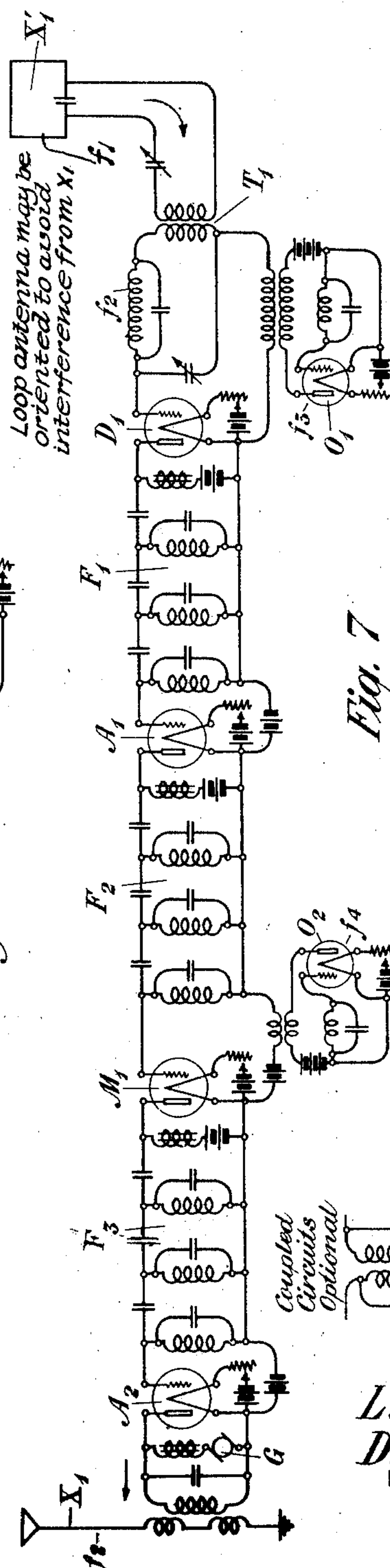


Fig. 7

Coupled
Circuits
Optional

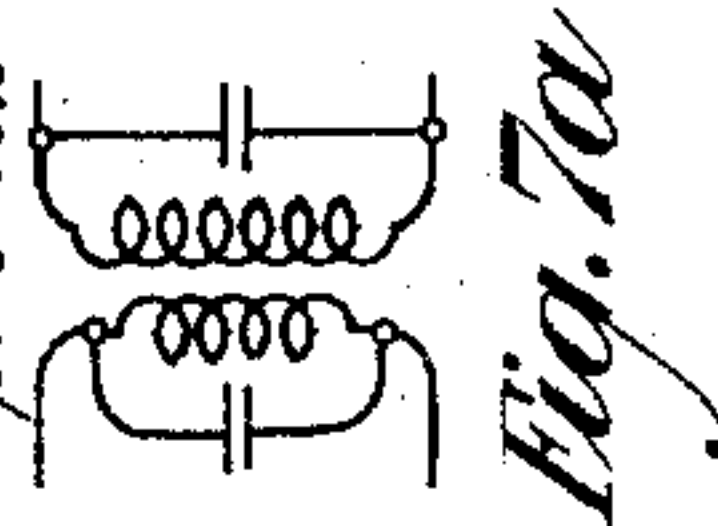


Fig. 7a

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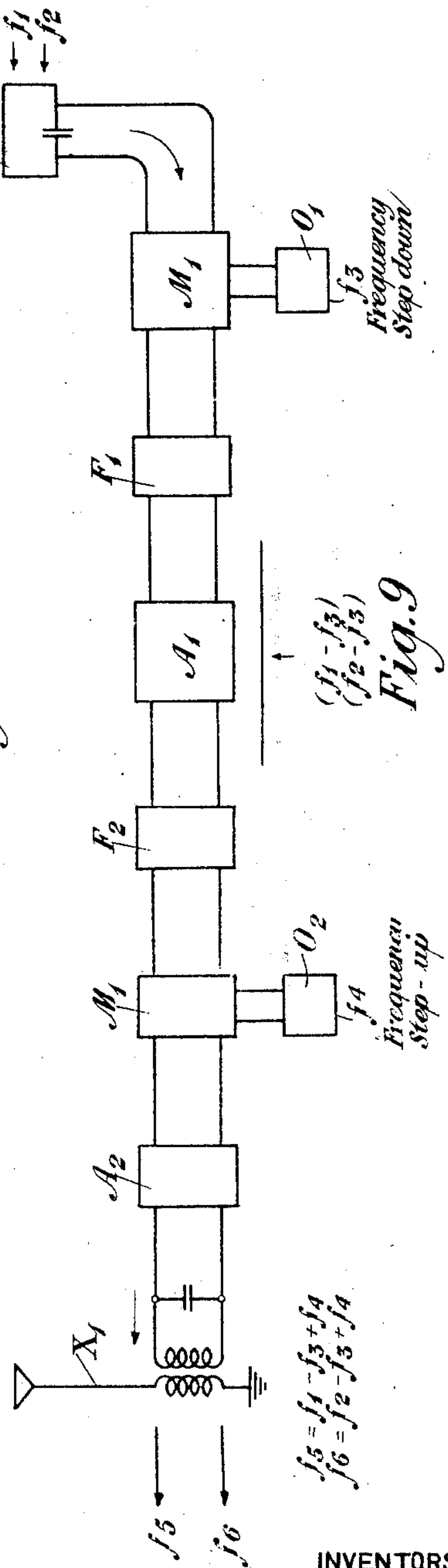
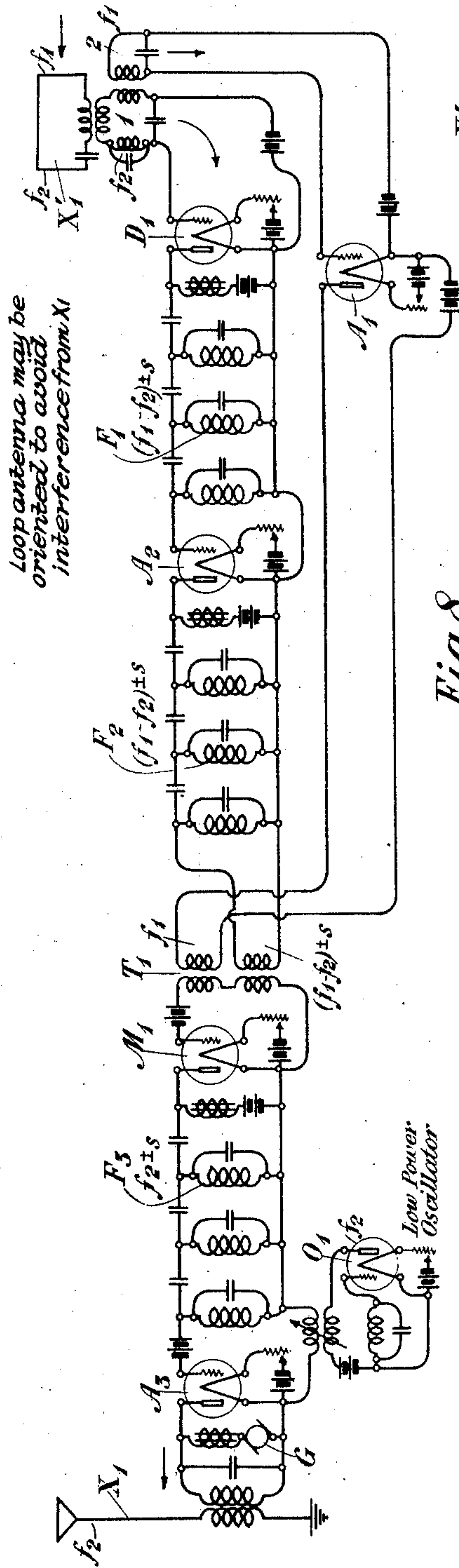
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DIRECTIVE RADIO REPEATING SYSTEM

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4 Sheets-Sheet 4



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1,668,638

UNITED STATES PATENT OFFICE.

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DIRECTIVE RADIO REPEATING SYSTEM.

Application filed December 28, 1921. Serial No. 525,442.

This invention relates to radio repeating systems characterized by directional control of the received and transmitted signals, and particularly to that type of system, adjusted to have a bilateral receiving and transmitting characteristic, in which transmission and reception are effected at different frequencies.

In our copending applications, Serial Nos. 525,440 and 525,441, both filed December 28, 1921, we have disclosed means for the directive relaying of radio signals in which transmission and reception are effected at the same frequency. It is the broad object of the present invention to provide means for repeating radio signals in which the transmitted signals are of different frequency from the received signals.

This invention also provides long distance radio transmission using waves of short length, by the proper spacing of repeater stations involving the principles of our invention whereby the effect of static is greatly reduced, and also the liability of the singing of adjacent repeater stations is minimized.

Furthermore, this invention also provides specific means for effecting long distance transmission without appreciable static interference by keeping up the energy level between terminals so that the ratio of signaling energy to static will always be high.

Further objects of this invention will be apparent from the following description when read in connection with the attached drawing, of which Figure 1 shows one unit of an antenna array, in which reception and transmission is effected by the same antenna which is responsive to two frequencies; Fig. 1^a represents the bilateral characteristic of such antenna array and Fig. 1^b represents graphically the change of frequency at the repeating stations; Fig. 2 shows a unit of an array in which each antenna is responsive to four frequencies used for multiplex operation, and Fig. 2^a shows graphically the change of frequencies at the various repeating stations; Fig. 3 shows a unit of an array having balanced vertical and ground antennae employing different frequencies, and Fig. 3^a is a frequency graph of such repeating system; Fig. 4 shows a unit having a balanced vertical and ground antenna in which four frequencies are employed, and Fig. 4^a shows graphically the

change of frequencies at the repeating points of such system; Fig. 5 shows a unit employing balanced loop and ground antennae in which four frequencies are used and also in which the modulating frequency is supplied through the ether from an antenna connected with a source of oscillations; Fig. 5^a shows the relative positions of the loop antennae of Fig. 5 with respect to the antenna constituting the source of beating oscillations; Figs. 6 and 7 show two combinations of balanced loop and vertical antennae employing different frequencies for reception and transmission; Fig. 7^a shows coupled tuned circuits which may be substituted in the circuit shown in Fig. 7; Fig. 8 shows another form of the balanced loop and vertical antennae in which local singing is prevented by a modulated balance, the transmitting frequency being used for modulation; and Fig. 9 shows a balanced arrangement using the vertical and the loop antennae designed for duplex operation.

In Fig. 1 X_1 represents one of the antennae of a directive array which is designed to have two degrees of freedom, being responsive, for example, to two bands of frequencies, one based upon the carrier frequency f_1 and the other upon the frequency f_2 . The antenna X_1 is connected with a local amplifying circuit by means of the transformer T_1 and is balanced by a balancing network N_1 . The local circuit comprises a phase shifting device PS_1 , a low power amplifier A_1 , a modulator M_1 , a source of oscillations O_1 having a frequency f_3 , a band filter F_1 , a high power amplifier A_2 , and a second phase shifting device PS_2 . When a signalling wave represented by a band of frequencies $f_1 \pm s$ strikes the antenna X_1 , current of that range of frequency will be impressed upon the local amplifying circuit by means of the transformer T_1 . This current will be given a certain phase adjustment by the phase shifting device PS_1 , and will be amplified by the amplifier A_1 which may be of a sufficient number of stages to ensure the efficient operation of the power amplifier A_2 . The current of the frequency $f_1 \pm s$, when amplified by A_1 , will be impressed upon the modulator M_1 and will beat with the unmodulated oscillations of the frequency f_3 from the source O_1 producing two other bands $(f_1 \pm s) + f_3$ and $(f_1 \pm s) - f_3$. The

value of f_3 is so chosen that one of the resultant bands, as $(f_1 \pm s) - f_3$, may be represented by the expression $f_2 \pm s$. The current of this band of frequencies will pass through the band filter F_1 , and when amplified by the power amplifier A_2 , will be given the proper phase angle by the phase shifting device PS_2 before being applied to the antenna X_1 which, as heretofore stated, is responsive to the frequencies $f_2 \pm s$.

By properly balancing the antenna X_1 by its network N_1 , and by adjusting the frequency range of the band filter F_1 to transmit only the band represented by $f_2 \pm s$, currents of other frequencies will not pass through and consequently the circulation of energy around the local circuit known as singing is prevented.

It will be seen from the radiation characteristic of the array, shown in Fig. 1^a, that equal transmission and reception efficiency is attainable in two directions diametrically opposite along the major axes of the loops. Singing is prevented at each repeating station by changing the frequency of the current as it passes through each local amplifying circuit. In Fig. 1^b, 1 and 4 represent two terminal stations of a system connected through two repeating stations, 2 and 3. A signal based upon the frequency f_1 , received at station 2, is changed therein to frequency f_2 , represented by the upper arrow. This frequency is transmitted to station 3, wherein by means of beating oscillations of suitable frequency the received frequency is changed to frequency f_1 and transmitted to the terminal station 4.

The arrangement shown in Fig. 2 represents a unit circuit of an array in which each antenna is responsive to four frequencies and designed for the simultaneous two-way relaying of signals. The antenna X_1 , for example, is responsive to four carrier frequencies, f_1, f_2, f_3 and f_4 , or to the bands of frequencies, as, for example, $f_1 \pm s, f_2 \pm s$, etc., based upon the carrier frequencies. The local circuit has connected therewith apparatus similar to that shown in the foregoing figure, such as phase shifting devices, filters, a power amplifier, a modulator and a source of beating oscillations O_1 of the frequency f_5 . Oscillations of the frequency f_1 received by the antenna X_1 will be impressed by the transformer T_1 upon the input circuit 1 and will in turn be transmitted through the phase shifting device PS_1 and the band filter F_1 , having a range of frequencies $f_1 \pm s$. This band will be beaten with the oscillations of the frequency f_5 in the modulator M_1 thereby producing bands having the range $(f_1 \pm s) + f_5$ and $(f_1 \pm s) - f_5$. The current at these frequencies will be amplified by the power amplifier A_1 and the filter F_2 , will select for

transmission $(f_1 \pm s) - f_5$ which will be designated $f_2 \pm s$. This current will be given the proper phase by the phase shifting device PS_2 and will then be impressed upon the antenna X_1 and radiated therefrom. In a similar manner another band of frequencies as, for example, $f_3 \pm s$, may be transmitted through the local circuit, being amplified therein and having its frequency range changed by modulation with oscillations of the frequency f_5 . By means of the network N_1 , which is designed to balance the antenna X_1 , and by using different frequencies for transmission and reception, the circulation of energy around the local circuit, known as singing, is prevented. The frequency distribution of a radio repeating system employing units, such as shown in Fig. 2, is graphically shown in Fig. 2^a. In this figure, 1 and 4 represent two terminal stations of the system, and 2 and 3 represent repeater stations. Thus signals based upon the frequency f_1 transmitted from terminal 1 are received at relay station 2 and transmitted to relay station 3 upon the frequency f_3 . Here they are stepped up again to frequency f_4 and transmitted to terminal station 4. Similarly a signaling channel based on a carrier frequency f_2 may be transmitted from station 4 to repeater station 3 where it will be changed by local beating to the frequency f_1 and transmitted to repeater station 2. Here it will be stepped up in frequency to f_2 and transmitted to the terminal station 1. By means of a system as shown in Fig. 2^a, two channels may be simultaneously transmitted and received at each of the terminal stations.

Fig. 3 shows a simple combination of balanced vertical and ground antennae constituting a unit of an array. Oscillations of the frequency f_1 , or a band represented by $f_1 \pm s$, impressed upon the ground antenna, are transmitted through a phase shifter PS_1 and a band filter F_1 to the modulator M_1 , where they are beaten together with oscillations of the frequency f_5 from the source O_1 . One of the resultant bands of frequency, $f_2 \pm s$, when amplified by the power amplifier A_1 and given the proper phase angle by the phase shifting device PS_2 , will be radiated from the transmitting antenna X_1 . Such arrangement affords means for two-way, nonsimultaneous relaying of signals. Singing is prevented by the balanced antenna arrangement and by changing the frequency. The distribution of frequencies in such repeater system is shown in Fig. 3^a.

Fig. 4 represents one unit of an antenna array, using a vertical antenna X_1 for transmission and a ground antenna X_1' for reception, and employing four frequencies, whereby simultaneous two-way operation

may be effected. Oscillations of the frequencies f_2 and f_4 and the side bands superimposed thereon are received by the ground antenna X_1' and transmitted through the local circuit, wherein they are beaten with local frequency f_5 , form the oscillator O_1 . By beating, we obtain a plurality of frequencies representing the sum and difference of each received frequency and the locally generated frequency, and we select, for example, the difference frequencies, that is $f_2 - f_5$ which equals f_1 and $f_4 - f_5$ which equals f_3 . These resultant frequencies f_1 and f_3 , properly amplified by the power amplifier A_1 , are impressed upon the transmitting antenna X_1 and radiated therefrom. The frequency scale, Fig. 4^a, represents two terminal stations A and B, and five repeating stations therebetween designated from 1 to 5 inclusive. Thus, oscillations of a frequency f_1 transmitted from station A to the repeating station 1 are changed therein to the frequency f_2 and transmitted to the repeating station 2. Here the oscillations are changed to a frequency f_4 and transmitted to the repeating station 3, where the frequency is stepped down to frequency f_3 . This frequency is transmitted to station 4, where it is again stepped down to the frequency f_1 and transmitted to station 5. Here the frequency is again stepped up to frequency f_2 and transmitted to the terminal station B.

	Terminal station A	Repeating stations					Terminal station B
		1	2	3	4	5	
Receiving freq. Trans.	f_4 f_1	$f_1 \& f_3$ $f_2 \& f_4$	$f_1 \& f_3$ $f_2 \& f_4$	$f_2 \& f_4$ $f_1 \& f_3$	$f_1 \& f_3$ $f_2 \& f_4$	$f_1 \& f_3$ $f_2 \& f_4$	f_1 f_2

The unit shown in Fig. 4 is one of the array constituting the third repeating station in which reception is effected on frequencies f_2 and f_4 , and transmission on f_1 and f_3 . By means of this arrangement it is possible to change the frequency of the carrier in either direction by using one beating frequency at each repeater point. The same frequency is used only at every other repeater station. The repeating stations intermediate the said first repeating stations use a beating frequency which is twice the beating frequency at the said first stations. By using this frequency scale, singing between adjacent repeating stations is eliminated.

Fig. 5 represents a unit of an array employing loop antennae for transmission and ground antennae for reception, and also having an additional loop antenna associated with each unit for the reception of the beating frequency from a master antenna which has the source of beating frequency connected therewith. X_1 represents the

transmitting antenna of the unit and X_1' , the ground antenna, the former being adapted for the transmission of the frequencies f_1 and f_3 and the latter for the reception of the frequencies f_2 and f_4 . Also associated with the antenna X_1 is a second loop antenna X_2 , by means of which the beating oscillations of frequency f_5 are received from the master antenna X_3 , connected with a source of oscillations O_1 having a frequency f_5 . The beating oscillations, received by the antenna X_2 , are impressed by the circuit 1 upon the phase shifting device PS_1 and are then transmitted through the filter F_1 or a circuit tuned to frequency f_5 . This current is then amplified by A_1 and impressed upon the modulator M_1 . Oscillations of the frequency f_2 set up in the ground antenna X_1' , or a band of frequencies as $f_2 \pm s$, are impressed upon the input circuit 2, and passing through the phase shifting device PS_2 and the band filter F_2 , are amplified by the low power amplifier A_2 . This frequency, or band of frequencies, is then modulated by the beating frequency f_5 in the modulator M_1 , producing a band $f_1 \pm s$, which is passed through the band filter F_3 which transmits frequencies $f_1 \pm s$. The resultant oscillations, when amplified by the power amplifier A_3 , are transmitted through the band filter F_4 having the range $f_1 \pm s$, and thence through phase shifting devices PS_3 . The oscillations of the proper phase will be impressed upon the transmitting antenna X_1 and radiated therefrom. In Fig. 5^a, the arrangement in an array of the various antenna units as shown in Fig. 5 is clearly set forth. The antenna X_3 connected with the oscillator O_1 represents the source of beating oscillations of the frequency f_5 . This frequency is transmitted to the antennae X_2 , X_4 , etc., of the array. The figure shows the relative arrangement of the transmitting antennae, represented by X_1 , X_3 , etc., to the ground antennae X_1' , X_3' , etc., so as to produce substantially no disturbance in the latter.

The arrangement shown in Fig. 6 illustrates a system employing at each repeater station a loop array for the reception of signals of the carrier frequency f_1 and a vertical antenna array for the transmission of signals of the carrier frequency f_3 . Signals of the frequency f_1 , or a band of frequencies, based upon this carrier frequency received by the loop X_1' , will be amplified by the amplifier A_1 and transmitted through the band filter F_1 having a range of frequency $f_1 \pm s$. This band of frequencies will be modulated with oscillations of a frequency f_2 from the source O_1 , modulation taking place in the modulator M_1 . The resultant oscillations having a frequency range $f_3 \pm s$ will be transmitted through the band filter F_2 and amplified by the power

amplifier A_2 . The amplified oscillations will then be transmitted from the antenna X_1 . In the arrangement shown in Fig. 6, which represents one unit of a repeater, singing is prevented by proper orientation of the loop X_1' with respect to the vertical antenna X_1 and also by suitable change of frequency.

The arrangement shown in Fig. 7 is characterized by the stepping down of the radio frequency to some intermediate frequency in order to obtain greater selectivity and amplification. Oscillations received by the antenna X_1' having the frequency $f_1 \pm s$ will be impressed by the transformer T_1 upon the input circuit of the detector D_1 , where they will be beaten with the frequency f_3 from the source of oscillations O_1 . The input circuit of the detector D_1 , which is connected between the filament and the grid, has included in series therewith an anti-resonant circuit which is tuned to the frequency transmitted by the transmitting antenna X_1 . The current from the output side of the detector D_1 , which may be, for example, of the magnitudes of 30,000 cycles, will be transmitted through the band filter F_1 , amplified by amplifier A_1 and then transmitted through the band filter F_2 . This current will then be beaten in the modulator M_1 with oscillations of the frequency f_1 from the source O_2 . The resultant band of oscillations represented by $f_2 \pm s$, which are radio frequencies, will be transmitted through the band filter F_3 and amplified by the power amplifier A_2 . These oscillations will then be radiated from the transmitting antenna X_1 . It will be seen that in the arrangement shown in Fig. 7 singing is prevented not only by the proper relative arrangement of the transmitting and receiving antennae, but also by the use of different frequencies for transmitting and receiving. The arrangement shown in this figure is also characterized by the use of a detector for stepping down the frequency in order to obtain greater selectivity and amplification and also by the use of an anti-resonant circuit for the purpose of stopping the transmitted frequency in the receiving circuit and preventing its effect upon subsequent parts of the circuit. Fig. 7^a shows the use of coupled tuned circuits for obtaining proper selectivity, which may be substituted in the circuit between the modulator and the power amplifier in place of the filter F_3 , shown in Fig. 7.

Fig. 8 shows another arrangement employing the use of balanced loop and vertical antennae in which a modulated balance is used to eliminate local singing of modulating current being supplied by the local transmitter. The loop antenna X_1' is adapted to receive, not only oscillations of the reception frequency f_1 , but also of the

transmitting frequency f_2 . These oscillations will be impressed upon the tuned input circuit of the detector D_1 , which has included therein an anti-resonant circuit tuned to the frequency f_2 , by means of which the amplitude of the current f_2 may be controlled. Oscillations of the frequency range represented by $f_1 \pm s$ will be impressed upon the detector D_1 together with the beating frequency f_2 of proper amplitude, and the resultant current will be transmitted through the band filter F_1 , which is designed to have a range $(f_1 - f_2) \pm s$. This current will be amplified by the amplifier A_2 , and the resultant current will be transmitted through a second band filter F_2 having the same range as F_1 . Coupled with the resonant input circuit 1 is another circuit 2 tuned to the frequency of f_1 . Current of this frequency will be transmitted through the amplifier A_1 and impressed by the transformer T_1 upon the input side of the modulator M_1 together with the frequencies represented by $(f_1 - f_2) \pm s$. The resultant current, having a frequency range $f_2 \pm s$, will be transmitted through the band filter F_3 and will be impressed upon the power amplifier A_3 simultaneously with the impression thereon of current of the same frequency, viz., f_2 , from the lower power oscillator O_1 . The resultant oscillations of the frequency $f_2 \pm s$ will be transmitted from the antenna X_1 . A repeater of this type has the advantage of added selectivity, due to the fact that the received carrier frequency must equal f_1 , or, as the result of modulation, the intermediate frequency will not pass through the band filters.

Fig. 9 shows an arrangement for the simultaneous two-way relaying of signals. This arrangement is also characterized by a two-fold modulation system in order to insure greater selectivity. Oscillations of the frequency f_1 , or of a band of frequencies, superimposed upon this carrier frequency will be impressed by the loop receiving antenna upon the modulator M_1 , wherein these oscillations will be beaten with oscillations of the frequency f_3 from the source O_1 . It is the object of the oscillator O_1 and the modulator M_1 to step down the frequency of the received oscillations to a value of, for example, 30,000 cycles. This frequency will be transmitted through the band filter F_1 and amplified by the amplifier A_1 . The resultant oscillations will then be transmitted through a second band filter F_2 and again modulated in the modulator M_1 by oscillations of a frequency f_1 from the source O_2 . The resultant oscillations of the frequency f_5 will be amplified by the power amplifier A_2 and radiated from the antenna X_1' . In like manner oscillations of the frequency f_2 received by the loop antenna X_1' will be transmitted through the repeating

circuit and radiated from the transmitting antenna X_1 as of the frequency f_6 . Local singing of this circuit is obtained by proper orientation of the receiving and transmitting antennæ and also by the use of selective circuits, which would prevent the transmission through the circuit of current of the transmitting frequency when beaten with the oscillations of the local frequencies.

10 The arrangements shown in Figs. 6 to 9 inclusive represent unit circuits of repeating stations in a radio repeater system. Each of the said stations would include a plurality of transmitting antenna and also of receiving antenna and a plurality of local circuits individual to pairs of receiving and transmitting antennæ. In such arrays of antennæ, directivity is dependent upon the proper amplitude and phasing of the received and transmitted currents in each of the local circuits as shown in the copending application of G. A. Campbell, Serial No. 327,553, filed September 30, 1919. It is understood, therefore, that suitable phase shifting devices of any well known type should be inserted in each of the circuit arrangements, shown in Figs. 6 to 9 inclusive, in the same manner in which they are shown in the preceding figures.

30 Although this invention has been described as embodied in certain forms and arrangements of parts it is to be understood that it is capable of embodiment in other and more widely varied forms without departing from the spirit and scope of the appended claims.

What is claimed is:

1. In a radio repeating system, the combination with an antenna array responsive to a definite frequency and adjusted to have a bilateral radiation characteristic of a plurality of amplifying circuits, and a second antenna array responsive to a different frequency and also adjusted to have a bilateral radiation characteristic, and a plurality of circuits individual to and connected with corresponding antennæ of each array.

2. In a radio repeating system characterized by directive control of the 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, a plurality of circuits individual to and connecting together each antenna of the receiving array and its corresponding antenna of the transmitting array, each of the said circuits being characterized by frequency selecting means, frequency changing means, energy amplifying means connected with the output side of the said frequency changing means, and means to control the phase of the amplified current radiated by each antenna of the transmitting array.

3. In a radio repeating system having directive, receiving and transmitting characteristics, the combination with a receiving array, of a transmitting array, the antennæ of the respective arrays being relatively positioned in space in such manner as to balance against mutual interference, and a plurality of amplifying circuits individual to the corresponding antennæ of the said arrays.

4. In a radio repeating system, the combination with a transmitting antenna array of a receiving antenna array, the said arrays each having a bilateral direction characteristic and being so positioned relative to each other as to substantially avoid singing, and a plurality of translating circuits each individual to a pair of antennæ, one belonging to the receiving array and the other to the transmitting array, each translating circuit having means to control the phase of the current applied thereto by its associated receiving antenna, means to change the frequency of the received current, and means to control the phase of the current of changed frequency as applied to the transmitting antenna associated with the said translating circuit.

5. In a radio repeating system, the combination with a transmitting antenna array of a receiving antenna array, the said arrays each having a bilateral direction characteristic and being so positioned relative to each other as to substantially avoid singing, and a plurality of translating circuits each individual to a pair of antennæ, one belonging to the receiving array and the other to the transmitting array, each translating circuit having means to control the phase of the current applied thereto by its associated receiving antenna, means to amplify the received current, means to change the frequency of the received current, and means to control the phase of the current of changed frequency as applied to the transmitting antenna associated with the said translating circuit.

6. In a radio repeating system, the combination with a transmitting antenna array of a receiving antenna array, the said arrays each having a bilateral direction characteristic and being so positioned relative to each other as to substantially avoid singing, and a plurality of translating circuits each individual to a pair of antennæ, one belonging to the receiving array and the other to the transmitting array, each translating circuit having means to control the phase of the current applied thereto by its associated receiving antenna, means to amplify the received current, means to change the frequency of the received current, means to amplify the current of changed frequency, and means to control the phase of the current of

changed frequency as applied to the transmitting antenna associated with the said translating circuit.

7. In a radio repeating system, the combination with a transmitting antenna array of a receiving antenna array, the said arrays each having a bilateral direction characteristic and being so positioned relative to each other as to substantially avoid singing, and a plurality of translating circuits each individual to a pair of antennæ, one belonging to the receiving array and the other to the transmitting array, each translating circuit having means to beat the received frequency to an intermediate frequency, means to select the desired intermediate frequency, means to amplify the selected frequency, means to change the selected frequency to another frequency different from the frequency as received by the receiving antenna.

8. In a radio repeating system the combination with a transmitting antenna array of a receiving antenna array, the said arrays

each having a bilateral direction characteristic and being so positioned relative to each other as to substantially avoid singing, and a plurality of translating circuits each individual to a pair of antennæ, one belonging to the receiving array and the other to the transmitting array, each translating circuit having means to control the phase of the received currents, means to change the frequency of the received currents, means to control the phase of the currents of said changed frequency as applied to the transmitting antenna, and a source of beating oscillations common to all of the said frequency changing means to supply oscillations thereto to change the frequency of the received currents.

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

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