

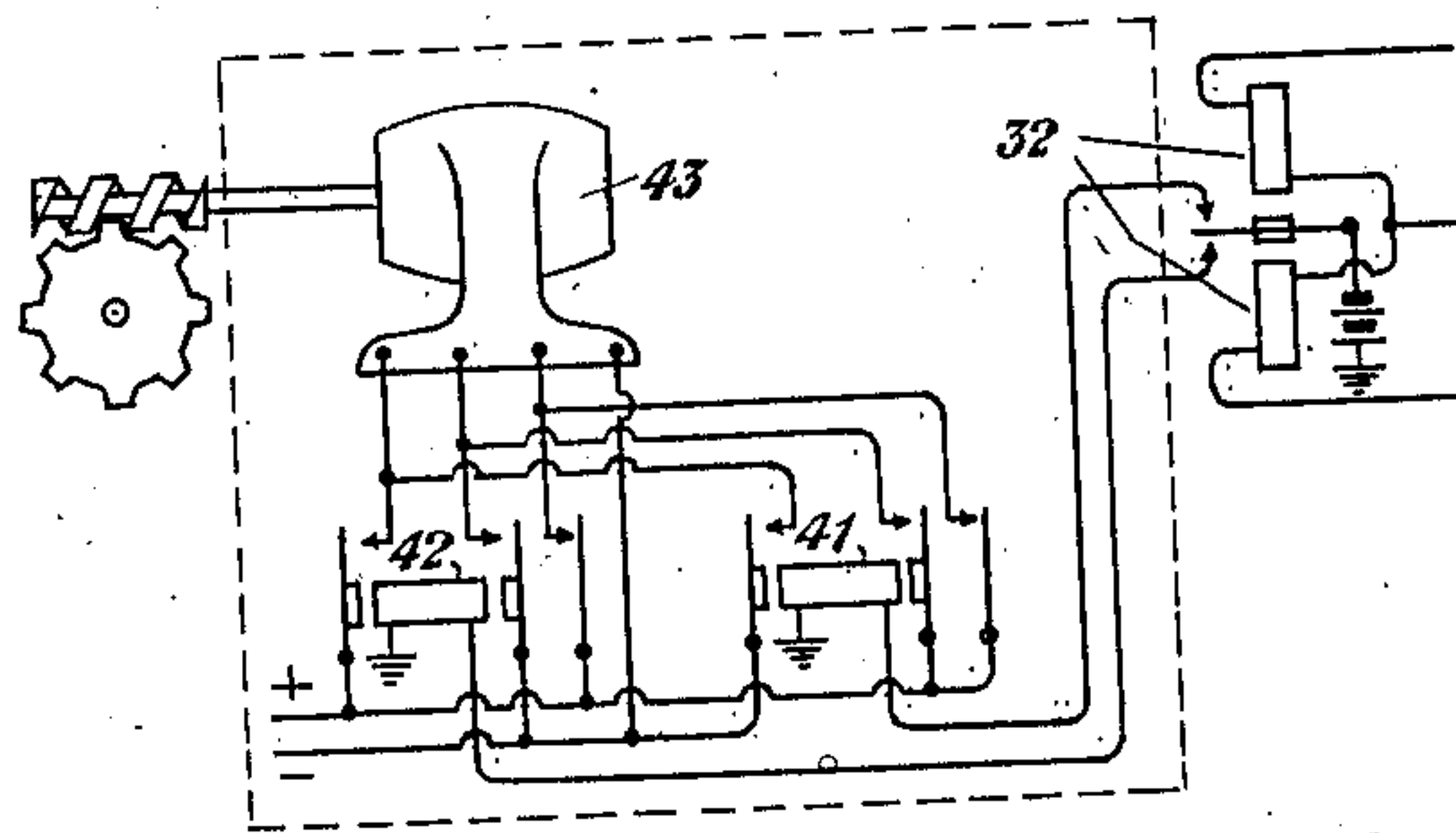
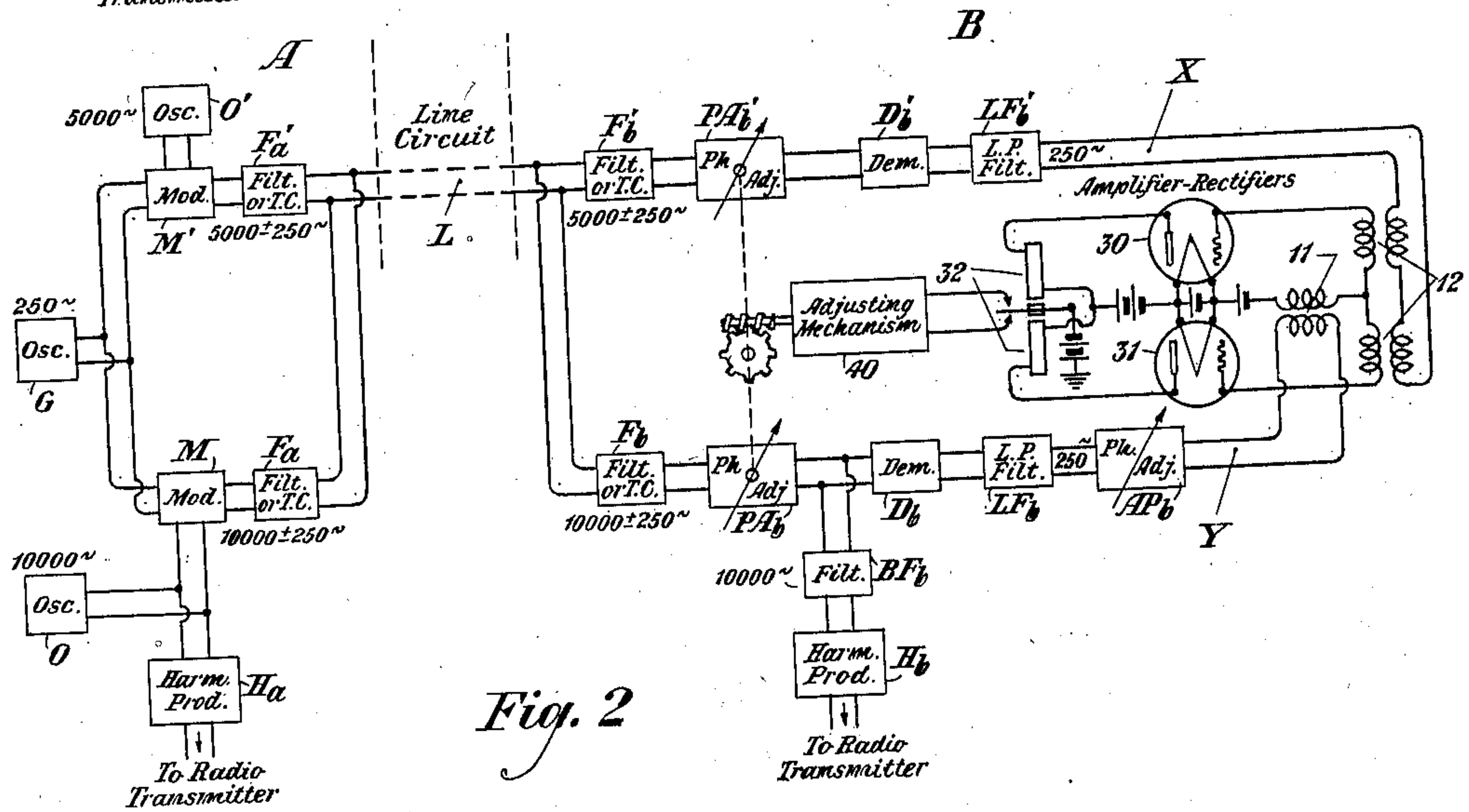
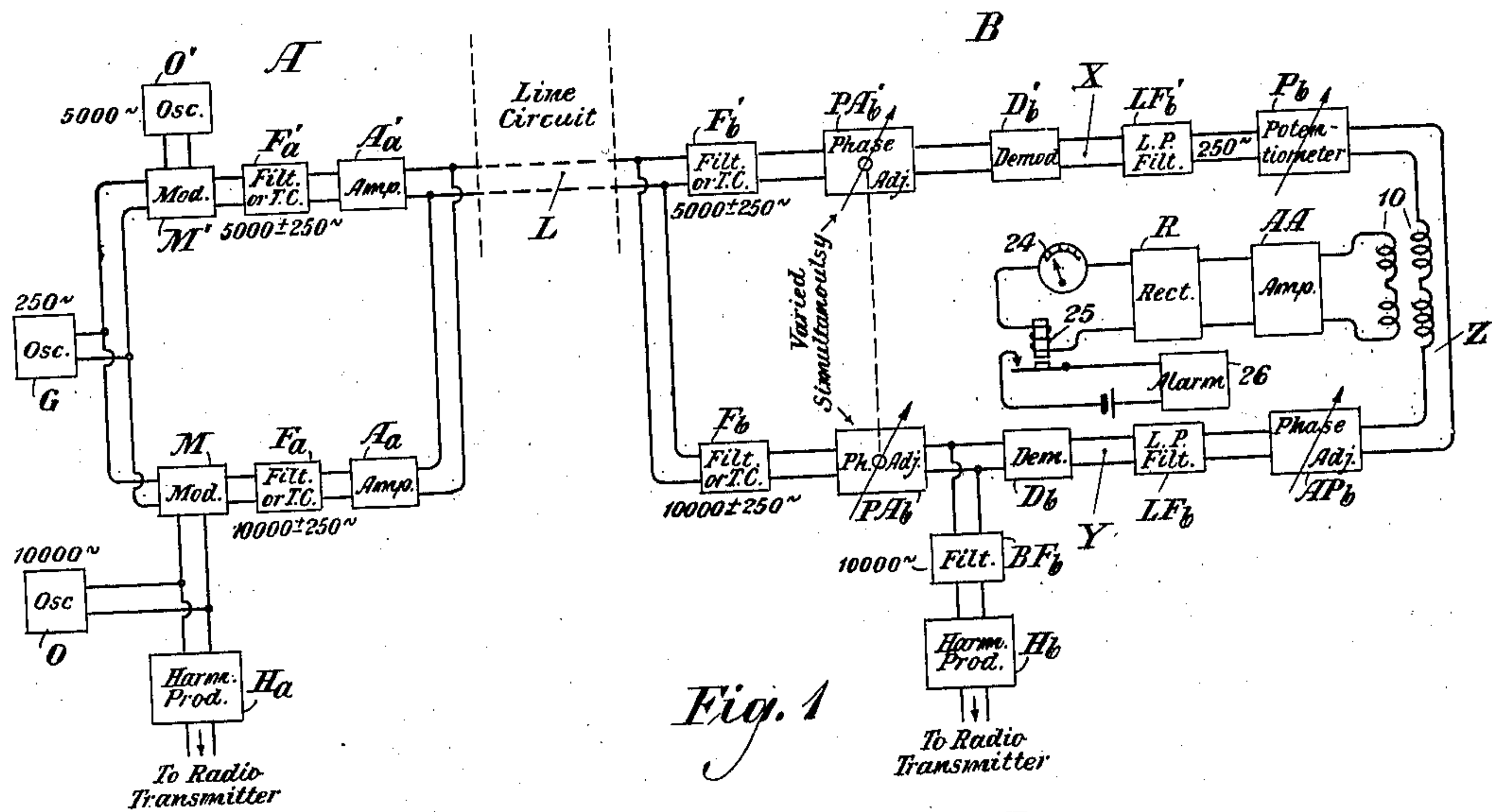
Feb. 26, 1929.

1,703,142

E. I. GREEN

COMPENSATION FOR PHASE VARIATIONS

Filed Sept. 23, 1927



INVENTOR.  
E. I. Green

BY

ATTORNEY



## UNITED STATES PATENT OFFICE.

ESTILL I. GREEN, OF EAST ORANGE, NEW JERSEY, ASSIGNOR TO AMERICAN  
TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK.

## COMPENSATION FOR PHASE VARIATIONS.

Application filed September 23, 1927. Serial No. 221,546.

This invention relates to arrangements and methods by which phase variations on line circuits, and more particularly on open-wire lines, may be counteracted or equalized.

5 While it may be important to counteract or equalize phase variations of line circuits under various circumstances, it is more particularly important where the line circuits are employed for transmitting a pilot or control frequency for a chain broadcasting system. It has been proposed, for example, that broadcasting be accomplished from a number of stations employing a common frequency and that the different stations be kept in synchronism by means of a control frequency transmitted over wires. With such an arrangement, relatively small variations in the phase of the low frequency currents transmitted over the line would, by virtue of the frequency multiplication employed at each broadcasting station, be greatly magnified in stepping up the control frequency to a radio frequency. For a listener so located as to receive approximately equal field strengths from two broadcasting stations operating on the same wave length, the variations in the phase of the radio frequency currents at the two stations would produce slow fading effects or other interference. For a common frequency broadcasting system, therefore, it is highly desirable to eliminate variations in the phase of the control frequency transmitted over the wire circuits.

In accordance with the present invention, it is proposed to accomplish this result by making phase adjustments at each broadcasting station in accordance with the observed change in phase of the control frequency as it arrives at the station. In doing this the difficulty at once arises that there is no direct method of comparing the phase of the current as it arrives at the broadcasting station with its phase at the distant transmitting end of the line. It is therefore proposed to determine the phase change of the desired control frequency by comparing the phase change at that frequency with the phase change of a current of a different frequency transmitted over the same circuit. This becomes possible due to the fact that while the phase changes

are different for different frequencies, the phase change at a particular frequency bears a predetermined relation to the phase change at some other frequency. In its more specific aspects the present invention involves a comparison of the relative phase shift of two different frequencies transmitted over a circuit, by producing a phase balance between two components of a relatively low modulating frequency superposed upon each of the frequencies to be compared. These two modulated components, upon arriving at the broadcasting station and being demodulated thereat, will be shifted in phase with respect to each other by an amount dependent upon the frequencies upon which each component was superposed. The method is then carried out by balancing these components against each other under normal conditions and then adjusting suitable phase controlling devices either automatically or manually whenever an unbalance occurs in order to restore the normal condition of balance.

The invention will now be more fully understood from the following description, when read in connection with the accompanying drawing, Figures 1 and 2 of which represent two different circuit arrangements for carrying out the invention; and Fig. 2<sup>a</sup> of which illustrates certain details of an automatic adjusting mechanism for controlling the phase adjustment used in the circuit of Fig. 2.

Before proceeding with the detailed description of the arrangement for carrying out the invention, it is desirable to set forth certain fundamental considerations bearing upon the phase shift occurring on open wire lines and the factors which bring it about. The major part of the variation in the phase shift produced by an open-wire circuit results from changes in the capacities of the insulators with changing weather conditions. In the following table the amount of this variation over a representative range of frequencies is given for pairs of 165 mil and 104 mil copper wires spaced approximately 12 inches between center and equipped with insulators of a type commonly employed for telephone purposes. In this table,  $\beta$  is the



phase shift, measured in radians, per mile of open-wire line.

TABLE

*Changes in phase constant due to weather changes*

| Frequency cycles per sec. | Dry weather $\beta$ per mi. | Wet weather $\beta$ per mi. | Change in phase shift in radians per mi. | Change in phase shift in degrees per mi. |
|---------------------------|-----------------------------|-----------------------------|------------------------------------------|------------------------------------------|
| 165 pair                  |                             |                             |                                          |                                          |
| 1,000                     | .03504                      | .03533                      | .00029                                   | .0166                                    |
| 5,000                     | .1737                       | .1753                       | .0016                                    | .092                                     |
| 10,000                    | .3458                       | .3490                       | .0032                                    | .184                                     |
| 30,000                    | 1.0295                      | 1.0389                      | .0094                                    | .539                                     |
| 104 pair                  |                             |                             |                                          |                                          |
| 1,000                     | .03555                      | .03582                      | .00027                                   | .0155                                    |
| 5,000                     | .1740                       | .1758                       | .0018                                    | .103                                     |
| 10,000                    | .3468                       | .3504                       | .0036                                    | .206                                     |
| 30,000                    | 1.0330                      | 1.0438                      | .011                                     | .620                                     |

In the above table the values of the phase constant  $\beta$  per loop mile under dry weather conditions are given in the second column, while the third column gives the corresponding values under wet weather conditions. The difference between the two values is given in the fourth column, while the fifth column gives the difference in degrees instead of radians.

There are, of course, other factors bringing about a shift in phase, but of these only one is of sufficient importance to receive consideration at this point. This is the phase shift produced by changes in the conductor resistance, due to temperature. In cable circuits this factor is of great importance as it is indeed the principal factor producing phase shift. On an open-wire circuit, however, the change in phase due to change in conductor resistance is principally of importance for frequencies below the carrier range. If, therefore, open-wire circuits are employed for transmitting controlling frequencies within the carrier range, changes in phase due to variations in conductor resistance with temperature may be disregarded, and compensation adjustments may be made on the assumption that the variation in phase is due largely to changes occurring at the insulators and bears a definite relation to the frequency.

It is of interest to note the effect of these phase variations on common frequency broadcasting systems which utilize a synchronizing channel transmitted over an open-wire circuit. Owing to the approximate proportionality which exists between the phase variation and the frequency in the carrier range, the amount of phase variation for the broadcasting system is determined almost entirely by the broadcasting frequency itself and not by the frequency of the control or synchronizing channel. For example, if the synchronizing frequency is 5 kilocycles and the phase variation at this frequency is B, this same variation will be

increased to 200B when the control frequency is stepped up to a broadcasting frequency of 1,000 kilocycles, since the broadcasting frequency is 200 times that of the control frequency. Now as has already been explained, the phase variation of open-wire lines is for all practical purposes directly proportional to the frequency transmitted over the line. Therefore, if the control frequency be 10 kilocycles, the phase variation will be approximately twice as great as in the case of 5 kilocycles, and will therefore be 2B. If the control frequency of 10 kilocycles be stepped up to a broadcasting frequency of 1,000 kilocycles, the phase variation will in turn be increased one hundred fold, that is, 2B times 100, or 200B. Now this is the same phase variation that we had in the previous case and it therefore is obvious that the ultimate phase variation with which we are concerned will be substantially the same for a given broadcasting frequency regardless of what may have been the particular control frequency from which the broadcasting frequency was derived.

The amount of the phase variation is, of course, directly proportional to the length of the line circuit. If, therefore, we have an open-wire circuit 100 miles long, with a synchronizing frequency of 10,000 cycles, the maximum phase variation produced in a broadcasting frequency at 1,000,000 cycles would be approximately 1840 electrical degrees. (The phase variation per mile as given in the fifth column of the above table is .184 at 10,000 cycles. When stepped up to 1,000,000 cycles, this becomes 100 times as great, or 18.4. As this is the value per mile, it must be multiplied by 100 to obtain the phase variation for a circuit 100 miles in length.)

Now, while such a phase variation, while it lasts, represents a change of frequency, it is not of importance from this standpoint. Let us assume that the maximum time required for a 100-mile line to change from conditions of dry weather to conditions of wet weather is about two hours. If the phase change of 1840 degrees, derived above, occurred uniformly over this period, the maximum frequency difference between the broadcasting stations at the two ends of the circuit would be only about .0007 cycle per second. Even for a circuit 1,000 miles in length, the frequency difference should not be more than ten times this amount or, in other words, not more than 2.5 degrees. Obviously, from the standpoint of producing a beat note between the broadcasting frequencies of two adjacent stations, this frequency difference would be of little importance. The factor that is of importance is the gradual change in phase which results in the received signal alternately fading and then increasing to a maximum. With a



phase change of 1840 degrees in two hours the signal would obviously die away, perhaps to complete inaudibility, a number of times during such a period.

5 It appears then that the frequency differences between common frequency broadcasting stations, which result from these variations occurring on open-wire lines, should ordinarily be unimportant. The difference  
10 in phase between two broadcasting stations will, however, produce changes in the interference experienced between the programs coming from the two stations by a listener who receives similar field strengths from  
15 both stations.

Coming now to the application of the foregoing to the correction of phase variation, Fig. 1 shows an arrangement for maintaining a constant phase relation at a given  
20 broadcasting station by producing a phase balance between components carried by two different frequencies. In this figure it is assumed that two broadcasting stations, located at A and B, are to transmit on the  
25 same wave length and that the radio frequency at each station will be derived by harmonic production or some equivalent method from a base or control frequency. In the circuit arrangement illustrated, the radio  
30 frequency at station A is derived directly from a fundamental frequency of 10,000 cycles, for example. At station B, the radio frequency is derived from this same base frequency of 10,000 cycles, this frequency being  
35 transmitted to the station over a line. The control frequency at station A is generated by an oscillator O of known type and is impressed upon the harmonic producer H<sub>a</sub> to produce the desired wave length for the radio  
40 transmitter at A. This harmonic producer may, of course, be of any known type, such, for example, as a distorting vacuum tube provided with a suitable selecting means on its output side to select the desired harmonic.  
45 The control frequency from the oscillator O may also be transmitted over the line circuit L to the station B.

In order that the phase of the current arriving at the station B may be controlled,  
50 a second carrier frequency of 5,000 cycles, for example, may be generated by an oscillator O' at station A. An auxiliary frequency which, in the case assumed, may be 250 cycles, is generated by a third oscillator G and is  
55 modulated upon the carrier frequency from the oscillator O and the carrier frequency from the oscillator O' by means of the modulators M and M', respectively. From the output of the modulator M the carrier frequency of 10,000 cycles, with the corresponding  
60 side frequencies, is passed through a filter or other selecting device F<sub>a</sub> to an amplifier A<sub>a</sub> and thence to the line L. Likewise, the carrier frequency of 5,000 cycles, with its  
65 two side frequencies, is transmitted from the

output of the modulator M' through a filter F<sub>a</sub>' to an amplifier A<sub>a</sub>', and thence to the line L.

At the station B the frequency of 5,000 cycles, together with its side frequencies, 70 is selected by means of a filter or other selective device F<sub>b</sub>' into one branch circuit X. Likewise the 10,000 cycle frequency, with its side frequencies, is selected by means of a filter or other selective device F<sub>b</sub> into branch 75 Y. The branch Y includes a phase adjuster PA<sub>b</sub> followed by a demodulating device D<sub>b</sub>. Likewise the branch X includes a phase adjuster PA<sub>b</sub>' followed by a demodulating device D<sub>b</sub>'. The two phase adjusters may be 80 connected together mechanically so as to be varied simultaneously and in accordance with some predetermined relation to each other.

The demodulator D<sub>b</sub> detects a 250 cycle component from the 10,000 cycle carrier and 85 its side frequencies, and this component is selected by a filter LF<sub>b</sub> and transmitted to the combining circuit Z which includes the primary of a transformer 10, the secondary of said transformer being connected in a circuit including an amplifier AA, a rectifier R, a meter 24, and a relay 25. In a similar manner, the demodulator D<sub>b</sub>' detects a component of 250 cycles which is selected by the filter or other selective device LF<sub>b</sub>' and impressed 95 upon the combining circuit Z. A potentiometer P<sub>b</sub> and a phase adjuster AP<sub>b</sub> are included in the low frequency combining circuit Z so that initially the two low frequency currents may be made equal and opposite, 100 thereby producing no effect upon the rectifier R and the meter 24. When a change in phase occurs on the line, due to some change in the weather conditions, the amount of this change will be different for the two carrier 105 frequencies, and hence the two demodulated components of 250 cycles, detected from the two carrier frequencies, will be accordingly shifted in phase. A departure from balance will therefore be indicated by the meter 24 110 and an effective current will be impressed upon the rectifier R. The relay 5 will accordingly be operated to close the circuit of the alarm 26. An attendant may then operate the phase adjusters PA<sub>b</sub> and PA<sub>b</sub>' to restore 115 the condition of balance.

It is obvious, of course, that whatever may be the relation between phase variations at different frequencies, the two phase adjusters PA<sub>b</sub> and PA<sub>b</sub>' may be so designed and so 120 geared together that when one of them is adjusted to compensate for the change in phase at one frequency, the other will be so adjusted as to compensate for the change in phase of the other frequency. Due to the 125 fact that the phase change bears a known relation to the frequency, the design of the phase adjusters and the mechanical connection between them becomes very simple. For example, each of the phase adjusters may be 130



a simple adjustable condenser with the movable parts connected upon a common shaft so as to move simultaneously. A given adjustment of the one condenser, which will compensate for the change in phase of the one frequency, will also exactly compensate for the change in phase at the other frequency.

Normally the change in phase which occurs on the line would be accompanied by a change in attenuation which would be different for the two carrier frequencies. Consequently, in order to restore the balance after a change, it will ordinarily be necessary to make an adjustment of the potentiometer  $P_b$ , included in the low frequency circuit  $Z$ , at the time the combined phase adjusters  $PA_b$  and  $PA_b'$  are operated in the high frequency circuits. The phase adjuster  $AP_b$ , however, which is included in the low frequency circuit  $Z$ , is only for the purpose of obtaining an initial balance and thereafter should be left unchanged.

The radio frequency for the broadcasting transmitter at station B is obtained by selecting through a filter  $BF_b$  on the output side of the phase adjuster  $PA_b$ , the 10,000-cycle carrier frequency, and then impressing the selected carrier frequency upon a harmonic producer  $H_b$  of some known type which will produce the harmonic corresponding to the desired radio frequency. It will, of course, be obvious that as the phase varies and the high frequency phase adjusters  $PA_b$  and  $PA_b'$  are adjusted to restore the balance, the radio frequency at the station B will automatically be brought back into a fixed phase relation with the radio frequency at the station A.

There are several points to be noted with respect to the method and apparatus above described. The low frequency modulated upon each of the carriers transmitted over the line  $L$  is necessary because it is impossible, by any balancing method, to compare the phases of currents of two different frequencies. While currents of two different frequencies might be related in phase, they cannot actually be in phase with each other because of the very fact of the difference in frequency. Therefore, the system as above outlined involves modulating at the controlling station the same low frequency upon each of the two carrier frequencies to be compared. By separately detecting the two low frequency components of a carrier at a distant station, the detected components will each be shifted in phase with respect to the other.

A second point to be noted is that it is desirable to keep the low frequency, which is modulated upon the carriers, low as compared with either carrier. This is desirable in order that the difference in phase shift of the two side frequencies associated with a given carrier during transmission will be approximately the same. In detecting, actually two

low frequency components are produced from each carrier, one corresponding to each side frequency. These components would be shifted in phase in accordance with the phase shift of the two side frequencies rather than the carrier itself. Since, however, one of the side frequencies is higher than the carrier and the other lower than the carrier, the component detected from the one side frequency will have a slightly greater phase shift, and the carrier detected from the other side frequency will have a slightly smaller phase shift, than the carrier. If, therefore, the two side frequencies are close to the carrier (as will be the case when the modulating frequency is relatively low) the phase differences in the two components, due to the difference between the two side frequencies, will approximately counteract each other and the resultant low frequency component detected from a particular carrier will be shifted in phase in proportion to the phase shift of the carrier itself.

By the use of the arrangement above described, and particularly where a low frequency current is modulated on each of two high frequency carriers, an extremely sensitive balance may be obtained and relatively small changes in phase may be accurately neutralized. The carrier frequencies for determining the phase change may, of course, be transmitted over an open-wire line which is used for the transmission of carrier channels, the two control frequencies being fitted in between the carrier frequencies employed for the various channels of the carrier system. Or, if desired, one of the two control frequencies might be the same frequency as that which is ordinarily employed in a carrier system as a pilot channel for regulating the transmission equivalent of the other carrier channels. Also, either or both of the control frequencies might be supplied by utilizing the carrier frequencies assigned to two of the channels of a carrier telegraph system. Again, the two control frequencies may, if desired, be obtained from a single generator by making use of the fundamental frequency and one of its harmonics. Obviously, of course, the two carrier frequencies employed in connection with the control channel of the system above described might, if desired, be transmitted over separate circuits on the same pole line.

The same general method, employing two control frequencies, is illustrated in the modified circuit arrangement of Fig. 2. In this case, however, the phase balance of the two low frequency components is obtained by means of a vacuum tube circuit of the type described in the U. S. patent to L. M. Ilgenfritz, No. 1,539,903, dated June 2, 1925. The arrangement at station A is identical with that described in connection with Fig. 1, except that for simplicity the amplifiers  $A_a$  and  $A_a'$  have been omitted. At station B the ele-



ments in the branches X and Y, up to and including the low frequency filters  $LF_b$  and  $LF_b'$ , are identical with those illustrated in Fig. 1. The branch Y, however, is connected by a transformer to the common path of a duplex vacuum tube circuit comprising amplifier-rectifier tubes 30 and 31, which are connected in push-pull formation. The branch X, on the other hand, is connected by means of the transformer 12 to the grid circuits of the tubes in such a manner as to produce opposite effects thereon. A polar relay 32 has its windings connected in the output circuits of the two tubes, as shown. A phase adjuster  $AP_b$  is connected in the branch Y on the low frequency side of the demodulator  $D_b$  for the purpose of obtaining an initial phase balance.

The circuits of the vacuum tubes 30 and 31, and their association with the branches X and Y, are such that when the 250-cycle components from the branches X and Y differ in phase by 90 degrees (plus or minus), the potentials appearing at the inputs of the two rectifying tubes 30 and 31 will be equal regardless of the relative amplitudes of the two components in the circuits X and Y. When the potentials at the inputs of the two tubes are equal, the currents flowing through the two windings of the relay 32 in the output circuit will balance each other and the armature of the relay will be held in neutral position. Initially the 90-degree relation will be obtained by adjustment of the phase adjuster  $AP_b$ , and no potentiometer adjustment is necessary. Thereafter, the same relation will be maintained by the simultaneous control of the two phase adjusters  $PA_b$  and  $PA_b'$  in the high frequency parts of the branches X and Y.

While the relay 32 may be used merely for the purpose of giving an indication so that an attendant may adjust the high frequency phase adjusters manually, the relay is illustrated as controlling an automatic adjusting mechanism conventionally indicated at 40. This adjusting mechanism may be any type of apparatus well known in the art and capable of causing an adjustment in one direction when the armature of the relay 32 is on one contact, and an adjustment in the opposite direction when the armature is on its opposite contact. One form of such mechanism is shown somewhat in detail in Figs. 2<sup>a</sup> in which the armature of the relay 32, when on one contact, energizes a relay 41, and when on the other contact, energizes a relay 42. When the relay 41 is energized, the circuits of a motor 43 are connected to a power source in such a manner as to rotate the motor in one direction. When the relay 42 is energized, the circuits of the motor are connected to the power source so as to rotate the motor in the opposite direction. The motor is conventionally geared

by means of a worm and pinion to drive a shaft which is common to the phase adjusters  $PA_b$  and  $PA_b'$ . With the circuit as shown, no adjustment of these phase adjusters will occur when the armature of the relay 32 is in neutral position. When, however, an unbalance occurs such that the armature is thrown upon either its front or its back contact, the adjusting mechanism will be operated to move the phase adjusters in such direction as to bring the phase back to normal.

It will be obvious that the general principles herein disclosed may be embodied in many other organizations widely different from those illustrated without departing from the spirit of the invention as defined in the following claims.

What is claimed is:

1. The method of compensating for variation in the phase shift resulting from transmission over a transmission line, which consists in subjecting two frequencies to the phase shift produced by the line, comparing the changes in the phase shift for the two frequencies, and adjusting a phase-varying element of the line in accordance with the observed comparison.

2. The method of compensating for variation in the phase shift resulting from transmission over a transmission line, which consists in subjecting two frequencies to the phase shift produced by the line, producing from each of said frequencies a component of a third frequency shifted in phase in proportion to the phase shift of the frequency from which it is derived, comparing the variations in phase shift in the two derived components, and adjusting a phase-varying element of the line in accordance with the observed comparison.

3. The method of compensating for variation in the phase shift resulting from transmission over a transmission line, which consists in subjecting two frequencies to the phase shift produced by the line, producing from each of said frequencies a component of a third frequency shifted in phase in proportion to the phase shift of the frequency from which it is derived, impressing the two components upon a responsive device in opposite phase relations so as to produce a balance when conditions are normal, and adjusting a phase-varying element of the line in accordance with the resulting unbalance when conditions vary from normal.

4. The method of compensating for variation in the phase shift resulting from transmission over a transmission line, which consists in modulating each of two carrier frequencies in accordance with the same low frequency, transmitting the modulated carrier frequencies over the transmission line, separately detecting from each carrier frequency the low frequency component in accordance with which it was modulated, comparing the



variations in phase shift of the two detected components, and adjusting a phase-varying element of the line in accordance with the observed comparison.

5 5. The method of compensating for variation in the phase shift resulting from transmission over a transmission line, which consists in modulating each of two carrier frequencies in accordance with the same low  
10 frequency, transmitting the modulated carrier frequencies over the transmission line, separately detecting from each carrier frequency the low frequency component in accordance with which it was modulated, im-  
15 pressing the two detected components upon a responsive device in opposing phase relation so as to produce a balance under normal conditions, and adjusting a phase-varying element of the line in accordance with the  
20 unbalance observed under abnormal conditions.

6. A system to compensate for variation in phase shift, comprising a transmission line, means to transmit two frequencies over  
25 said line thereby producing changes in the phases of the two frequencies, means responsive to variations of the difference of the phase shifts of the two frequencies, and phase adjusting means associated with the  
30 line and adapted to be adjusted in accordance with the variation of the difference in the phase shift of the two frequencies.

7. A system to compensate for variation in phase shift, comprising a transmission  
35 line, means to transmit two frequencies over said line thereby producing a change in the phase of each frequency, means to produce from each frequency a component of a third frequency shifted in phase in proportion to  
40 the phase shift of the frequency from which it is derived, means responsive to the phase difference in the two derived components, and phase-varying means associated with the line and adapted to be adjusted in accordance  
45 with variation in the phase difference between the two derived components.

8. A system to compensate for variation in phase shift, comprising a transmission  
50 line, means to transmit two frequencies over said line thereby producing a change in the phase of each frequency, means to produce from each of the said frequencies a component of a third frequency shifted in phase

in proportion to the phase shift of the frequency from which it is derived, a responsive  
55 device, means to impress the two components upon said responsive device in opposite phase relation thereby producing a balance when conditions are normal, and phase-varying  
60 means associated with the line and adapted to be adjusted in accordance with the resulting unbalance when conditions are abnormal.

9. A system to compensate for variation in phase shift, comprising a transmission line, means to generate two carrier frequencies,  
65 means to modulate each of said carrier frequencies in accordance with the same low frequency, means to transmit the resultant modulated carrier frequencies over the transmission line, means to select the transmitted  
70 carrier frequencies into different circuit branches, means in each circuit branch to detect from the selected carrier frequency the low frequency component in accordance with which it was modulated, means responsive to  
75 variations in the difference in phase of the two detected components, and phase-varying means associated with the line and adapted to be adjusted in accordance with variations in the difference in phase of the two detected  
80 components.

10. A system to compensate for variation in phase shift, comprising a transmission line, means to generate two carrier frequencies,  
85 means to modulate each of said carrier frequencies in accordance with the same low frequency, means to transmit the resultant modulated carrier frequencies over the transmission line, means to select the transmitted  
90 carrier frequencies into different circuit branches, means in each circuit branch to detect from the selected carrier frequency the low frequency component in accordance with which it was modulated, a responsive  
95 device, means for impressing the two detected components upon said responsive device in opposing phase relation so as to produce a balance under normal conditions, and phase-adjusting means associated with the line and adapted to be adjusted in accordance  
100 with the degree of unbalance under abnormal conditions.

In testimony whereof, I have signed my name to this specification this 22nd day of September, 1927.

ESTILL I. GREEN.