Dec. 15, 1925.

1,565,522

J. S. STONE

CARRIER CURRENT MULTIPLEX SIGNALING SYSTEM

Filed Nov. 23, 1923

3 Sheets-Sheet 1

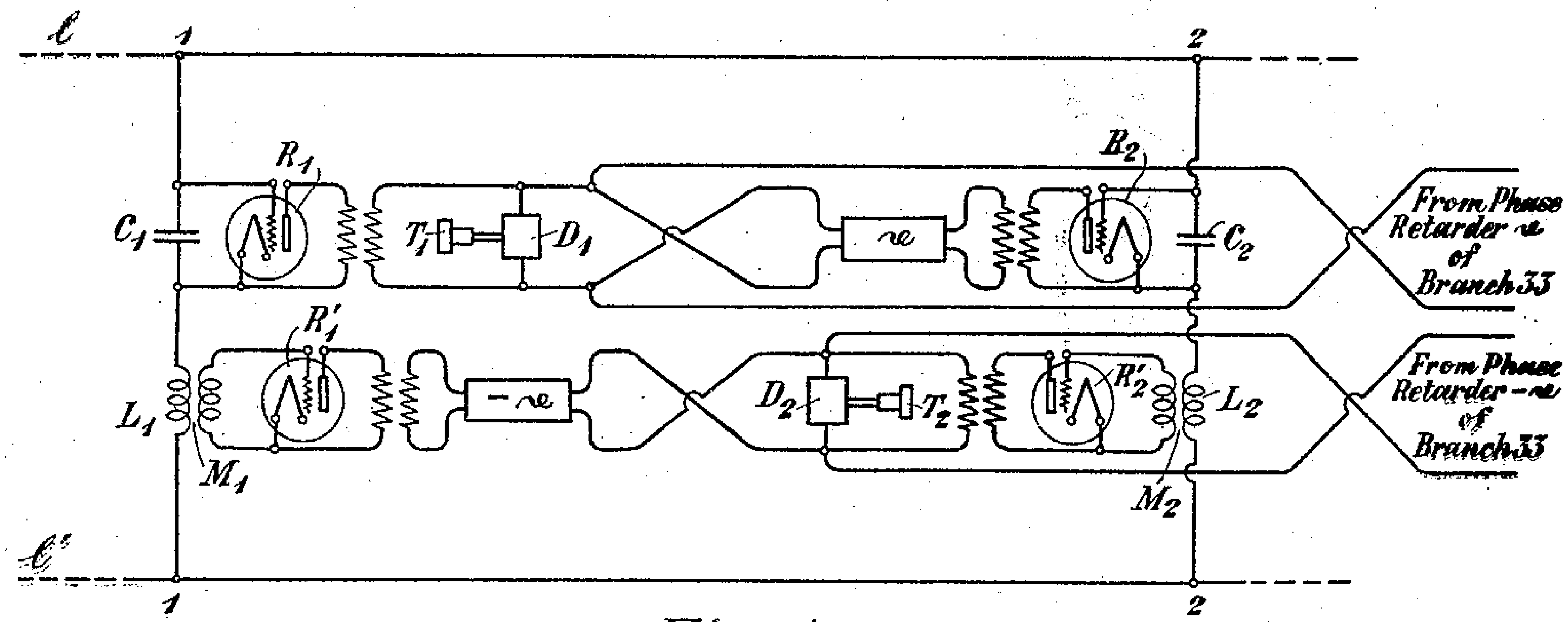

Fig. 1

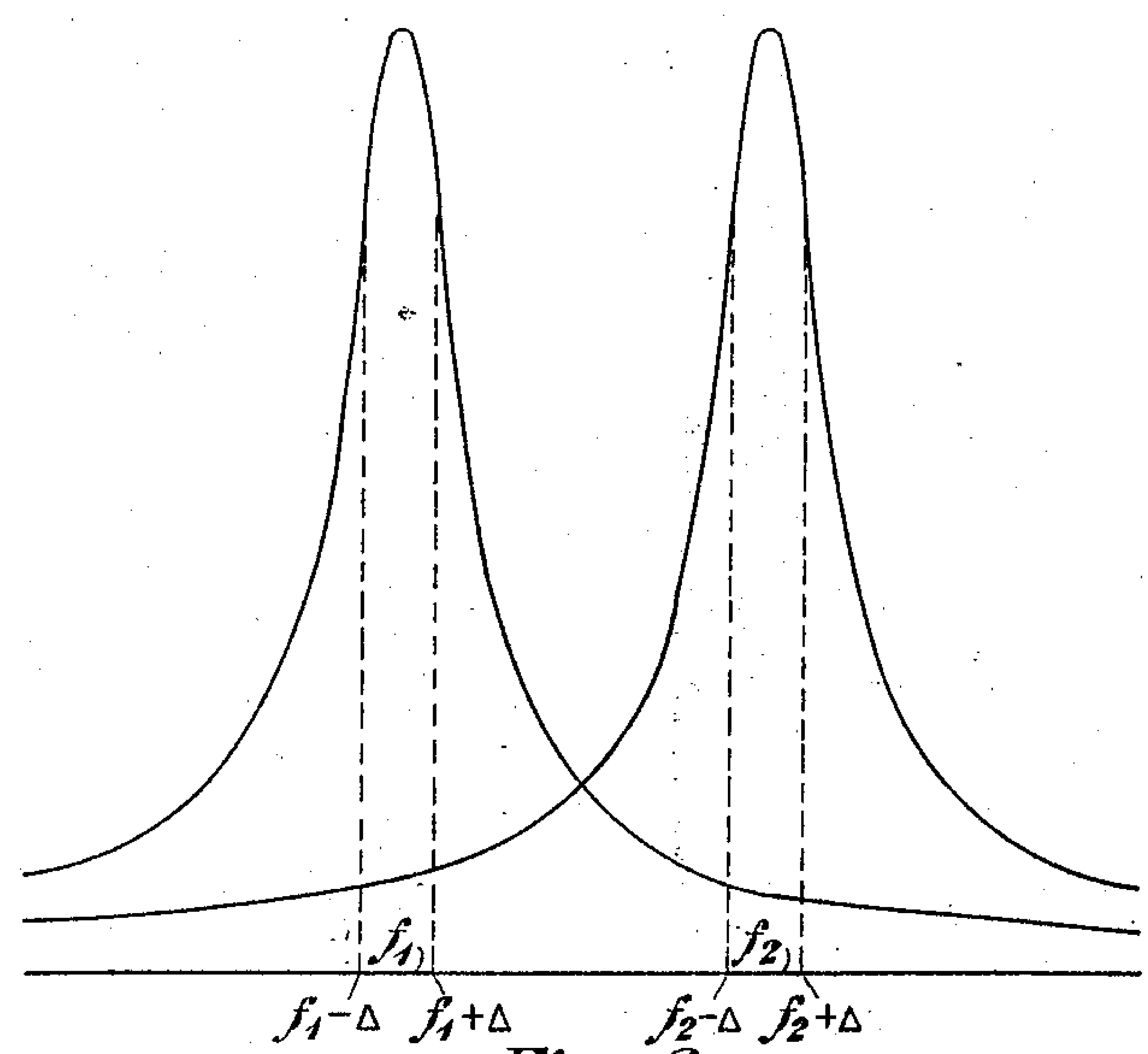

Fig. 2

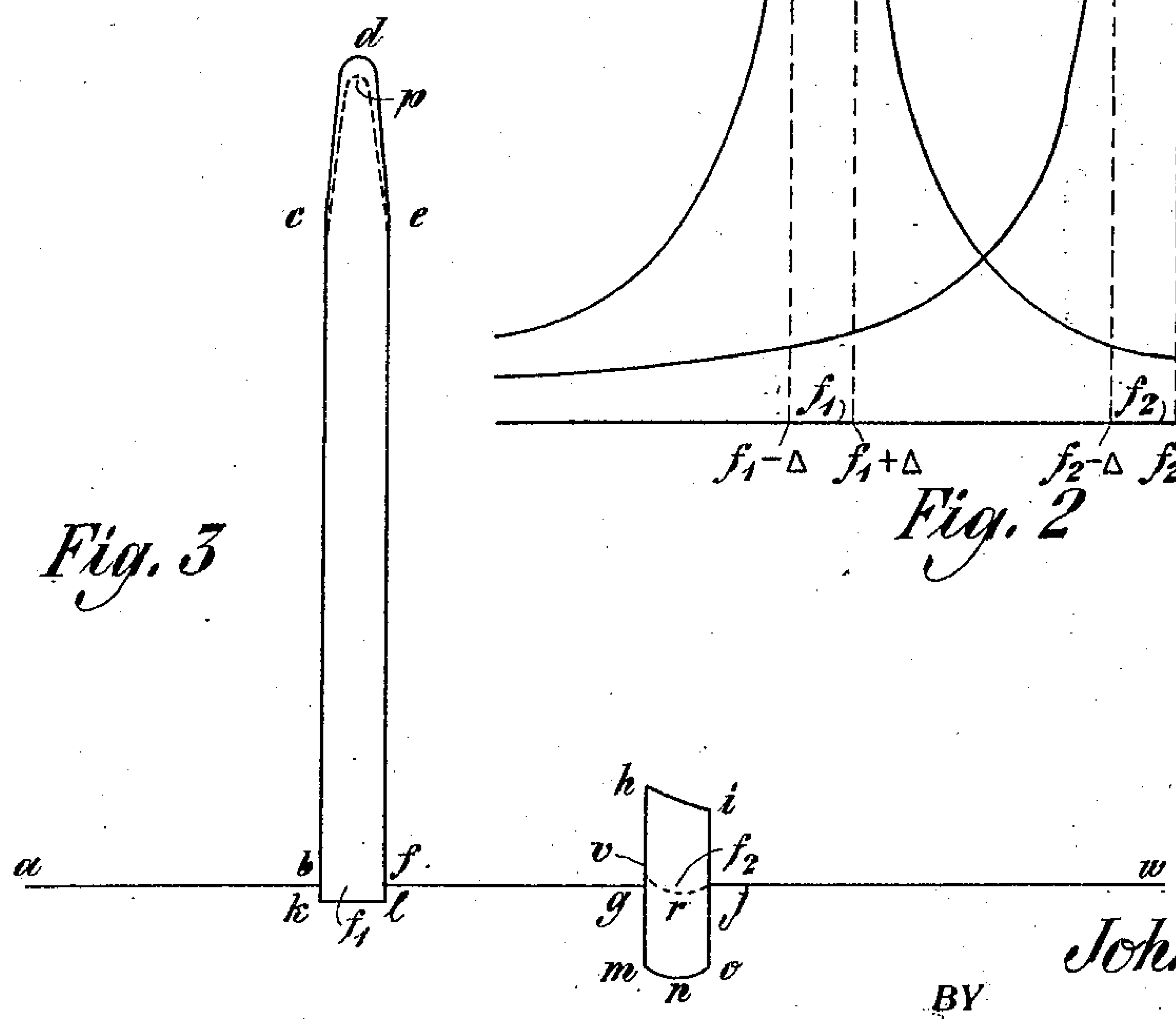

Fig. 3

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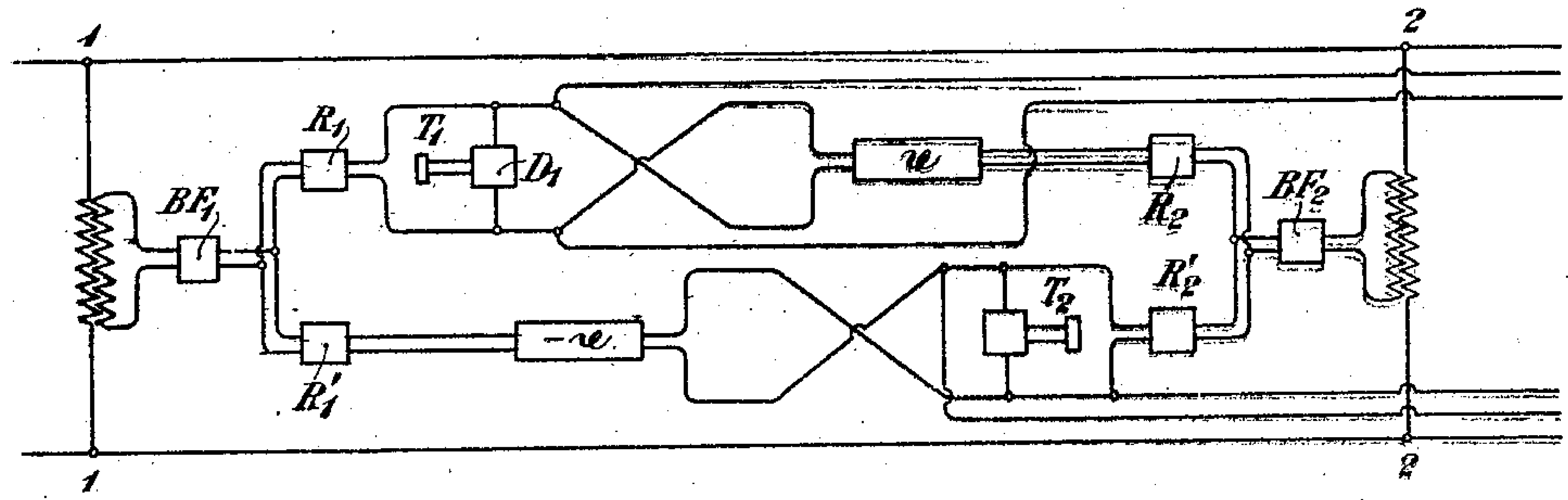

Fig. 4

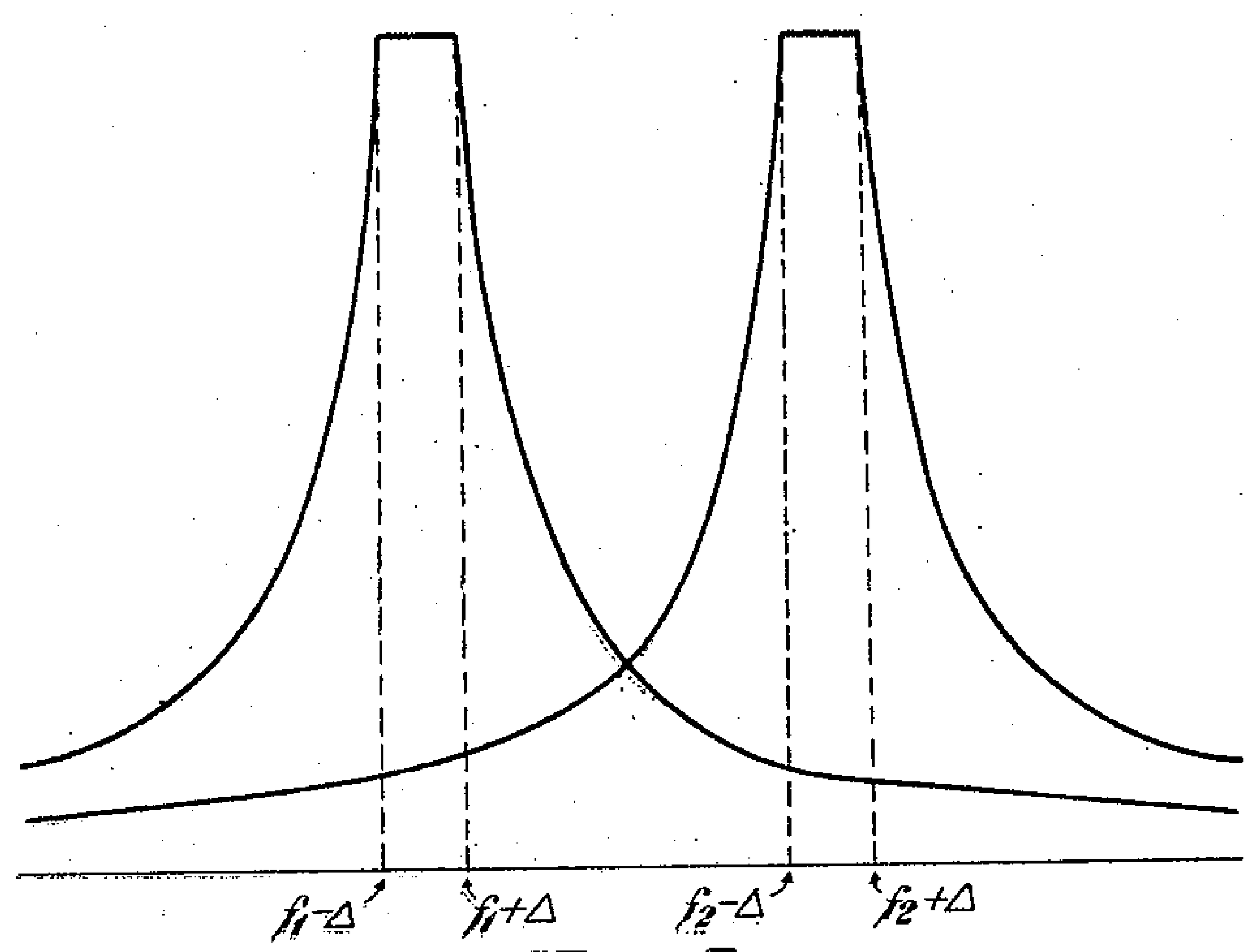

Fig. 5

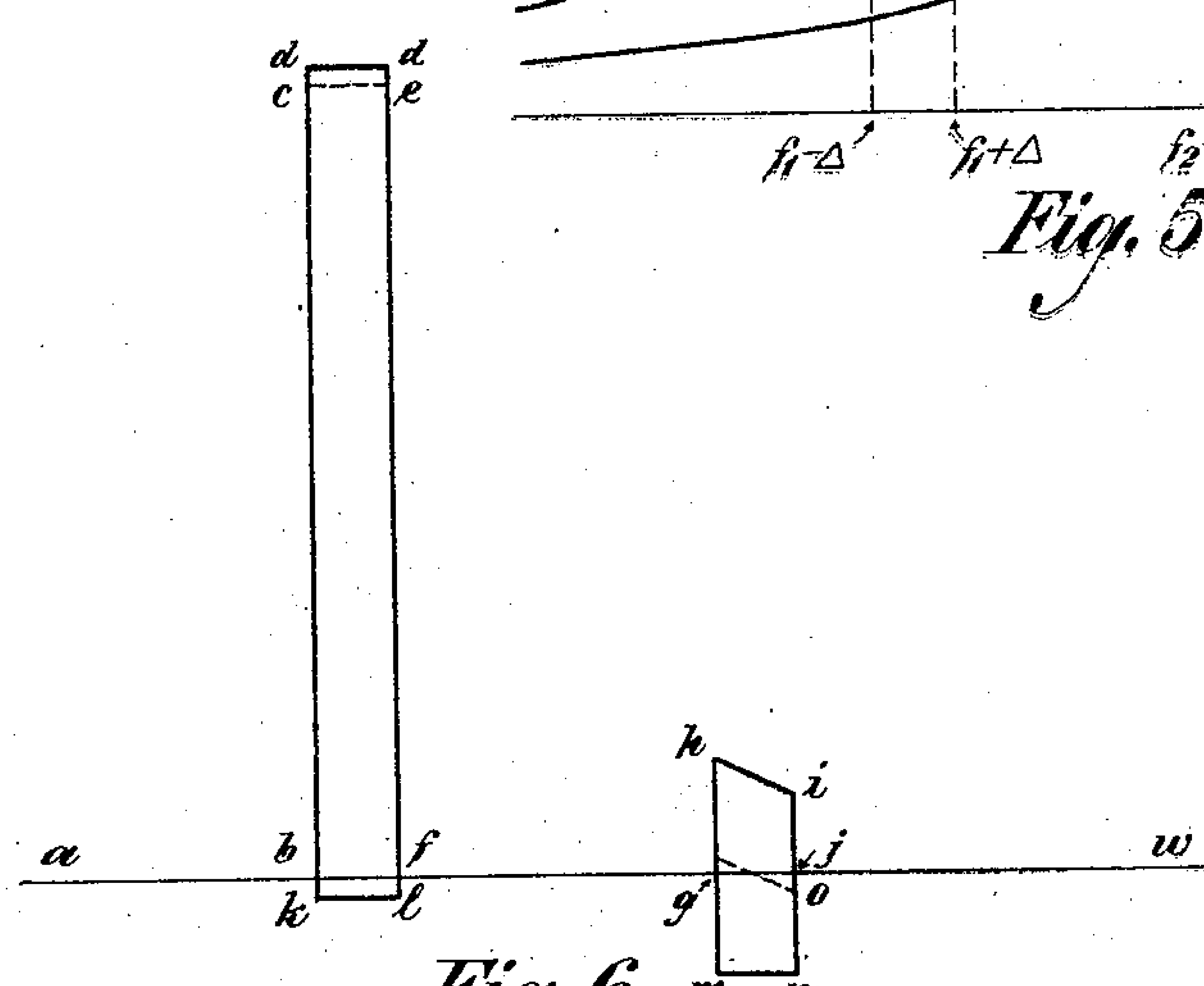

Fig. 6

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3 Sheets-Sheet 3

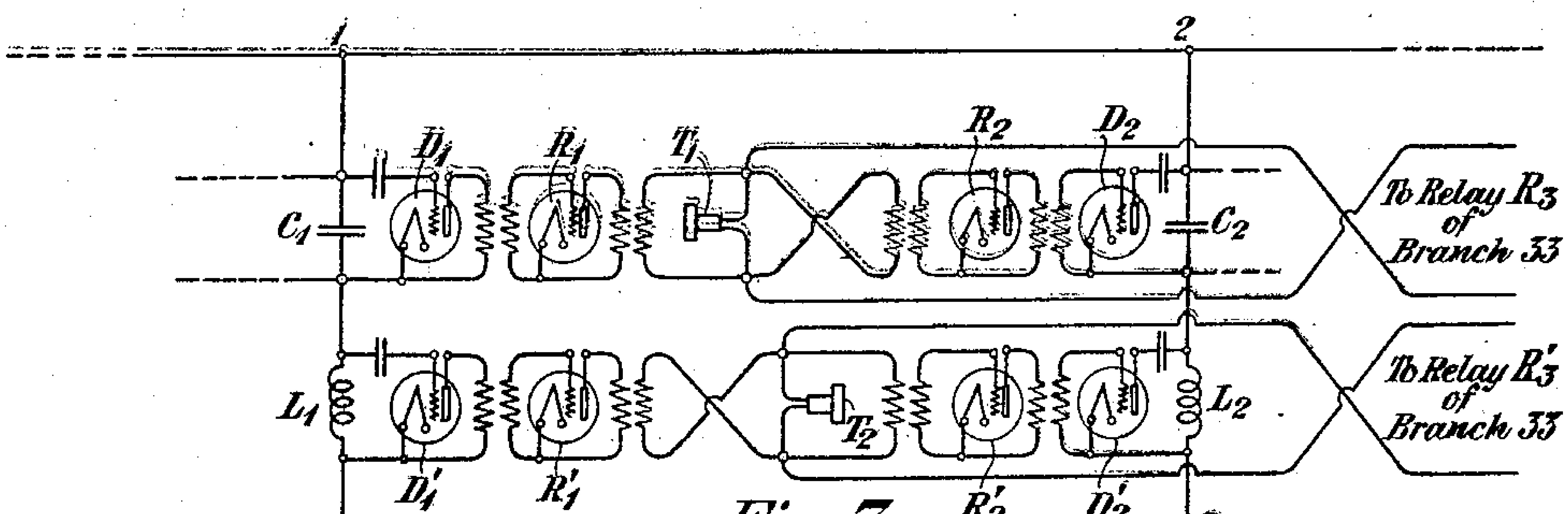

Fig. 7

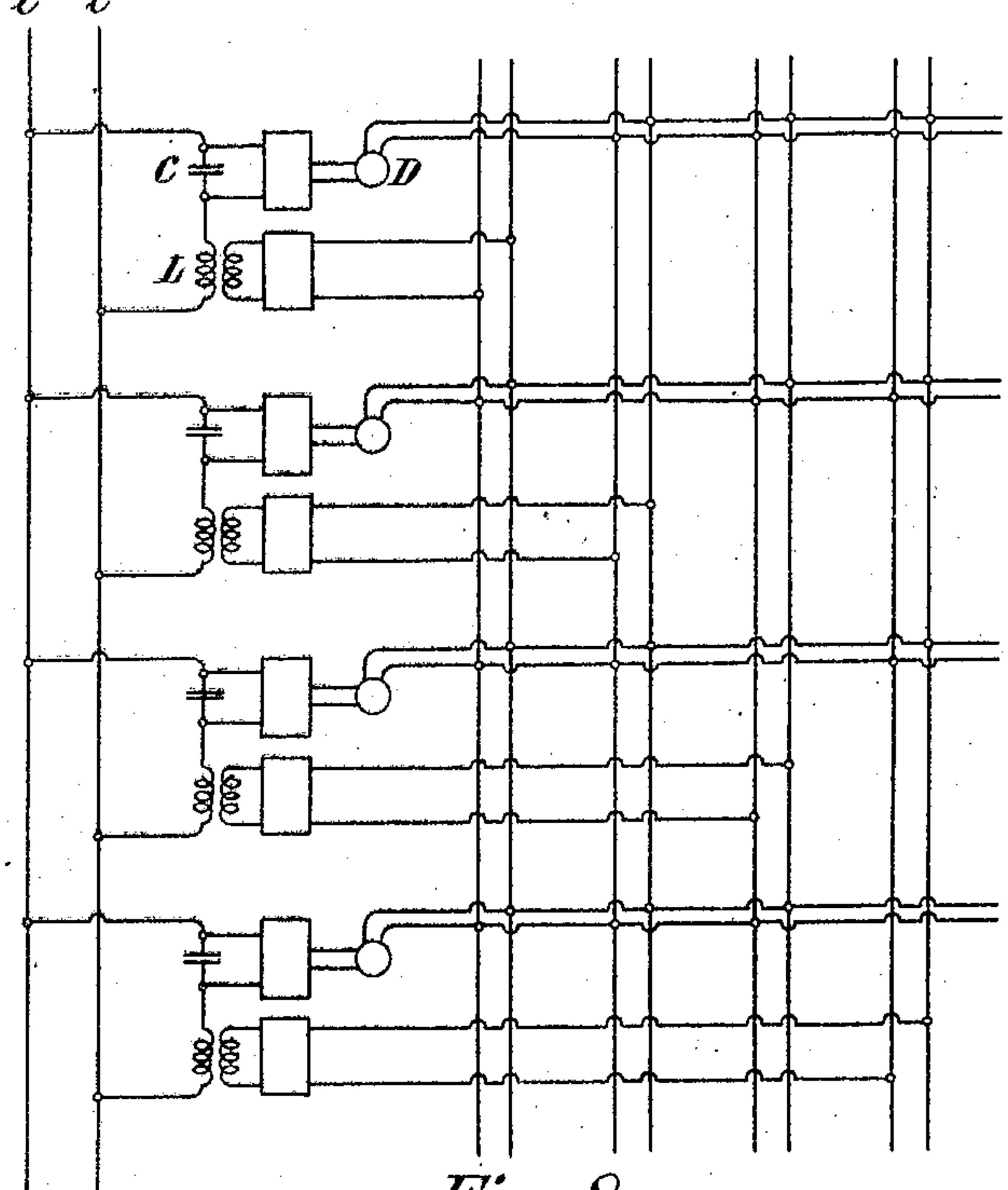

Fig. 8

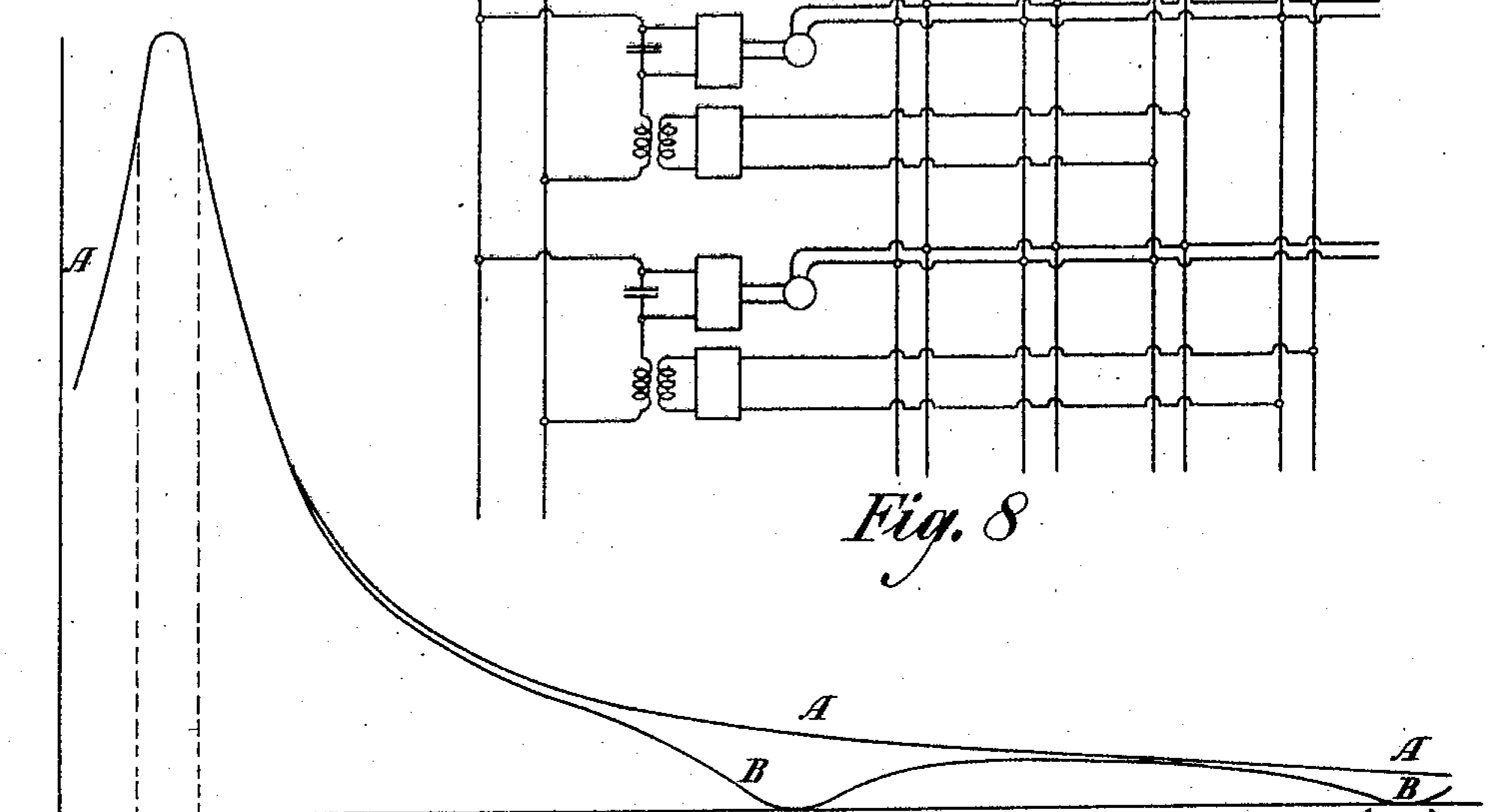

Fig. 9

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Patented Dec. 15, 1925. **1,565,522**

UNITED STATES PATENT OFFICE.

JOHN STONE STONE, OF SAN DIEGO, CALIFORNIA, ASSIGNOR TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK.

CARRIER-CURRENT MULTIPLEX SIGNALING SYSTEM.

Application filed November 23, 1923. Serial No. 676,624.

To all whom it may concern:

Be it known that I, JOHN STONE STONE, residing at San Diego, in the county of San Diego and State of California, have invented certain Improvements in Carrier-Current Multiplex Signaling Systems, of which the following is a specification.

An object of my invention is to provide an improved method and apparatus for selective reception of currents of various frequencies in a multiplex receiving system. Another object of my invention is specifically to guard each of several branch receiving circuits in a multiplex system from effects due to currents appropriate to the other branches. By the practice of my invention it is made possible to put the channels closer together along the frequency range in a multiplex carrier current system, so that more message channels can be provided within a given range of carrier frequencies without increasing the inherent selectivity of the individual receiving branches. These objects are attained by establishing certain associative relations between the branches of which examples will be shown in the following specification. In this specification certain embodiments of the invention are disclosed with the understanding that these are illustrative examples and that the invention is defined in the appended claims.

Referring to the drawings, Figure 1 is a diagram illustrating one embodiment of my invention. Figs. 2 and 3 are curve diagrams to which reference will be made in explaining the operation of the apparatus of Fig. 1. Fig. 4 is a diagram showing a modification as compared with Fig. 1. Figs. 5 and 6 are curved diagrams to which reference will be made in explaining the operation of the apparatus of Fig. 4. Fig. 7 shows still another modification as compared with Fig. 1. Fig. 8 is a simplified diagram showing the principle involved in extending the invention to a larger number of receiving branches; and Fig. 9 is a curve diagram to which reference will be made in discussing the principle of the invention.

Referring to Fig. 1, ll' is a transmission line over which are sent alternating currents of several different frequencies which are intended to be received in respective branches such as 1, 1 and 2, 2. The branch 1, 1 comprises in series a condenser C_1 and an inductance L_1. Across the condenser C_1 there is connected the input of an audion relay R_1 whose output goes to the demodulator D_1 with the associated telephone receiver T_1. Another audion relay R_2 is connected in a similar manner across the condenser C_2 and its output goes through a phase shifter θ and thence to the terminals of the demodulator D_1.

Associated with the inductance L_2 by means of a one-to-one transformer M_2 are an audion relay R_2', demodulator D_2 and telephone receiver T_2 corresponding respectively to R_1, D_1 and T_1. Associated with the inductance L_1 by means of a one-to-one transformer M_1 are the audion relay R_1' and phase shifter designated $-\theta$ corresponding respectively to R_2 and θ, and the output from the last mentioned phase shifter goes to the demodulator D_2.

The elements of apparatus mentioned in the foregoing explanation have predetermined values for their electromagnetic constants that will be mentioned in the following explanation of the mode of operation. It is assumed that the current coming in over the line ll' consists of two superposed alternating currents of respective frequencies f_1 and f_2 to which respectively the branches 1, 1 and 2, 2 are resonant. Each branch has a certain selectivity S defined by the equation

$$S=\sqrt{\frac{L}{CR^2}} \quad (1)$$

where the resistance R of the branch, and its inductance L and capacity C are so related that S is the same for both branches although f_1 and f_2 are different.

The impressed electromotive force on the terminals of each branch is given by the expression

$$E_1 \cos 2\pi f_1 t + E_2 \cos 2\pi f_2 t \quad (2)$$

and accordingly the potential difference across the condenser C_1 will be

$$eC_1 = E_1S \sin 2\pi f_1 t + \frac{E_2 f_1 S}{f_2\sqrt{1+S^2\left\{\frac{f^2_1-f^2_2}{f_1 f_2}\right\}^2}} \sin 2\pi f_2\left(t+\frac{1}{2\pi f_2}\tan^{-1} S\frac{f^2_1-f^2_2}{f_1 f_2}\right) \quad (3)$$

The potential difference across the other condenser C_2 is

$$eC_2 = E_2S \sin 2\pi f_2 t + \frac{E_1 f_2 S}{f_1\sqrt{1+S^2\left\{\frac{f^2_1-f^2_2}{f_1 f_2}\right\}^2}} \sin 2\pi f_1\left(t+\frac{1}{2\pi f_1}\tan^{-1} S\frac{f^2_2-f^2_1}{f_1 f_2}\right) \quad (4)$$

Now let the audion relay R_2 be adjusted so that the ratio of its amplification (α_2) to that of the relay R_1 (α_1) shall be given by the expression

$$\frac{\alpha_2}{\alpha_1}=\frac{f_1}{f_2\sqrt{1+S^2\left\{\frac{f^2_1-f^2_2}{f_1 f_2}\right\}^2}} \quad (5)$$

Also, let the phase shifter θ be adjusted so that its output will be retarded relatively to the output of amplifier R_1 by the time interval

$$\frac{1}{2\pi f_2}\tan^{-1} S\frac{f^2_2-f^2_1}{f_1 f_2} \quad (6)$$

Making these changes in relation to equation 4, the result is as follows:

$$e' = \alpha_1\frac{E_2 f_1 S}{f_2\sqrt{1+S^2\left\{\frac{f^2_1-f^2_2}{f_1 f_2}\right\}^2}} \sin 2\pi f_2\left(t+\frac{1}{2\pi f_2}\tan^{-1} S\frac{f^2_1-f^2_2}{f_1 f_2}\right)$$
$$+\frac{E_1 S}{1+S^2\left\{\frac{f^2_1+f^2_2}{f_1 f_2}\right\}^2} \sin\left\{2\pi f_1 t+\left(1-\frac{f_1}{f_2}\right)\tan^{-1} S\frac{f^2_2-f^2_1}{f_1 f_2}\right\} \quad (7)$$

This is the electromotive force derived from the branch 2, 2 and applied to the terminals of the demodulator D_1. To get the resultant electromotive force on the demodulator D_1, multiply the right hand side of equation 3 by α_1 and subtract equation 7, and the result is

$$eC_1 - e' = \alpha_1 E_1 S\left[\sin 2\pi f_1 t - \frac{1}{1+S^2\left\{\frac{f^2_1-f^2_2}{f_1 f_2}\right\}^2} \sin\left\{2\pi f_1 t+\left(1-\frac{f_1}{f_2}\right)\tan^{-1} S\frac{f^2_2-f^2_1}{f_1 f_2}\right\}\right] \quad (8)$$

In practical cases the ratio f_1/f_2 will not differ much from unity, so that without substantial error we can assume that this ratio is unity in equation 8, which then reduces to

$$eC_1 - e' = \alpha_1 E_1 S\left(1-\frac{1}{1+S^2\left\{\frac{f^2_1-f^2_2}{f_1 f_2}\right\}^2}\right)\sin 2\pi f_1 t \quad (9)$$

Thus by adjusting the relay R_2 to have its amplification related to that of R_1 by the ratio given in expression 5 and by adjusting the phase regulator θ to introduce a time lag of the output of relay R_2 compared to relay R_1 as given by the expression 6, the result is obtained that the potential difference across the terminals of the demodulator D_1 is given by equation 9. An examination of this equation shows that the amplitude of the potential difference at the terminals of the demodulator D_1 is determined solely by the amplitude of the incoming signal train of frequency f_1. The result has been secured that the demodulator D_1 responds in amplitude only to the current of frequency f_1 and is not affected by the other current of frequency f_2.

Without going into details, it can be shown in a similar manner that if the ratio of the amplification of relay R'_1 to that of relay R'_2 be given by the expression

$$\frac{f_2}{f_1\sqrt{1+S^2\left\{\frac{f^2_1-f^2_2}{f_1 f_2}\right\}^2}} \quad (10)$$

and if the phase shifter designated $-\theta$ introduces the time lag given by the expression

$$\frac{1}{2\pi f_1}\tan^{-1} S\frac{f^2_1-f^2_2}{f_1 f_2} \quad (11)$$

then the amplitude of the potential difference at the terminals of the demodulator D_2 will be affected solely by the amplitude of the incoming alternating current of frequency f_2.

Referring to Fig. 2 in which the abscissas are frequencies, the two curves show the overlapping resonance curves for the two frequencies f_1 and f_2. As shown in Fig. 2, the amplitude of the component of the interfering frequency in each branch is about 10% of the amplitude of the component proper to that branch. The vertical dotted lines in Fig. 2 indicate two bands of frequencies of the same width and having respective mean frequencies f_1 and f_2. We may properly assume that the impressed electromotive force across each branch circuit 1, 1 or 2, 2 presents a continuous frequency spectrum of uniform intensity throughout the respective band of the width shown in Fig. 2. The frequency spectrum of the potential difference developed by the relay R_1 at the terminals of the demodulator D_1 is illustrated by the line *a-b-c-d-e-f-g-h-i-j-w* of Fig. 3. The frequency spectrum of the potential difference developed by the relay R_2 at the terminals of the same demodulator D_1 is illustrated by the line *a-b-k-l-f-g-m-n-o-j-w* of Fig. 3, and accordingly the frequency spectrum of the resultant potential difference at the terminals of the demodulator D_1 is given by the line *a-b-c-p-e-f-g-q-r-j-w* of Fig. 3. Thus it will be seen that the response due to frequency f_2 is substantially annulled.

Fig. 4 corresponds with Fig. 1 except that respective band filters BF_1 and BF_2 are employed in connection with the demodulators. With this explanation, Fig. 4 will readily be understood by comparison with Fig. 1. Corresponding respectively to the diagrams in Figs. 2 and 3 for the apparatus of Fig. 1, we have the diagrams of Figs. 5 and 6 for the apparatus of Fig. 4.

Fig. 7 illustrates another form of the invention in which the potential differences across the condensers and coils are first impressed upon the demodulators D_1, D_2, D_1' and D_2' and then upon the relays R_1, R_2, R_1' and R_2'. In this form of the invention it is no longer necessary to use the phase regulators designated θ and $-\theta$ in Fig. 1, and moreover the potential amplifying functions of the relays R_1, R_1', R_2 and R_2' may be performed by transformers or even by the demodulators D_1, D_1', D_2 and D_2'.

When there are more than two receiving branches, the application of the principle of the invention is suggested by the pairs of branch conductors coming in from the right as shown in Figs. 1, 4 and 7. Referring particularly to Fig. 1, the upper pair of conductors coming in from the right bring the proper corrective electromotive force to the terminals of the demodulator D_1 to annul the direct effect of the frequency in the line *ll'* appropriate to the branch 33.

Not only must such conductors come in from the branch 33, but they must go from the branches 1, 1 and 2, 2 to the branch 3, 3. A complete system showing these interconnections in highly diagrammatic form is illustrated in Fig. 8.

Referring to Fig. 9, the curve A represents the resonance curve of the branch circuit to which the frequency f_1 is appropriate. But this is not the curve for the terminals of the associated receiver T_1, because it receives certain annulling electromotive forces from all the other branches, and the resultant curve at the terminals of the receiver T_1 is given by the curve B. This has its peak at the frequency f_1, but it has dimples at all the other frequencies of which only two are shown in the diagram, so that at all the other frequencies the resultant is null, and at these other frequencies the telephone T_1 gives no response.

It will be seen that with a certain degree of selectivity in each of a plurality of receiving branches appropriate to respective frequencies, by my invention the direct effect of the frequencies in one branch is counteracted by cross-connections to the remaining branches. Each receiving branch is made peculiarly and specially non-responsive to the other frequencies of the system. In this way, without resorting to any measures to increase the selectivity of each branch, the frequency channels can be crowded closer together and more message channels can be provided within the available frequency range for the system under consideration. It is this one-way association feature which prevents reactions of the various circuits upon one another that makes the object of this invention attainable. Circuits so related I call "associated circuits" in counter-distinction to coupled circuits. The object of this invention can not be accomplished by coupling the various circuits but only by the one-way associations described or their equivalents.

I claim:

1. A conductor carrying currents of several different frequencies to be separated in their effects, respective branch conductors

appropriate to the respective frequencies, respective apparatus to be actuated by electromotive forces in said branches and cross-connecting means to each apparatus from the other branches to neutralize the effect through the corresponding branch due to currents to which the other branches are appropriate.

2. The method of discriminating among the different frequencies in a multiplex carrier current receiving system which consists in annulling in each branch the frequencies received therein appropriate to the other branches by means of currents in proper amplitude and phase relation derived from those other branches.

3. A conductor carrying currents of several different frequencies to be separated in their effects, respective branch conductors appropriate to the respective frequencies, respective apparatus to be actuated by electromotive forces in said branches and unilateral conducting means connecting each apparatus with the other branches to neutralize the effect through the corresponding branch due to currents to which the other branches are appropriate.

4. A conductor carrying currents of several different frequencies to be separated in their effects, respective branch conductors appropriate to the respective frequencies, respective apparatus to be actuated by electromotive forces in said branches and cross-connecting means to each apparatus from the other branches to neutralize the effect through the corresponding branch due to currents to which the other branches are appropriate, each such cross connection comprising an adjustable amplifier and an adjustable phase shifter.

5. A conductor carrying currents of several different frequencies to be separated in their effects, respective branch conductors appropriate to the respective frequencies, respective apparatus to be actuated by electromotive forces in said branches and associated circuit connections to each apparatus from the other branches to neutralize the effect through the corresponding branch due to currents to which the other branches are appropriate.

6. The method of discriminating among the different frequencies in a multiplex carrier current receiving system which consists in annulling in each branch the frequencies received therein appropriate to the other branches by means of currents in proper amplitude and phase relation derived through associated circuit connections.

In testimony whereof, I have signed my name to this specification this 14th day of November, 1923.

JOHN STONE STONE.