

March 11, 1947.

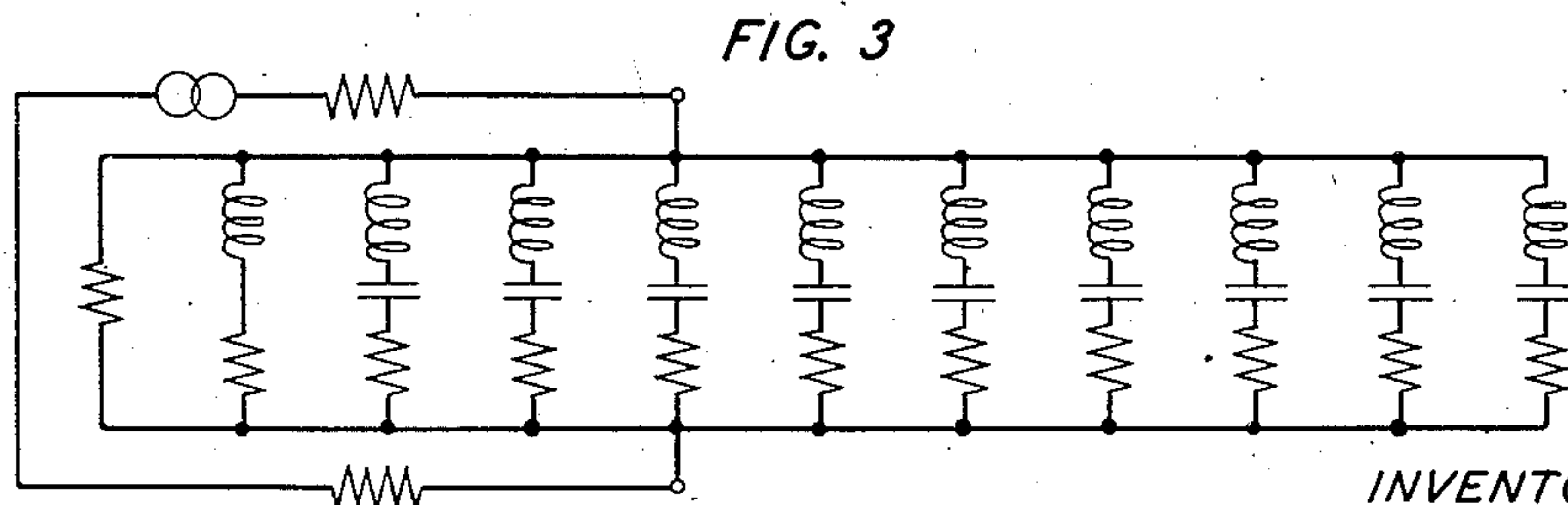
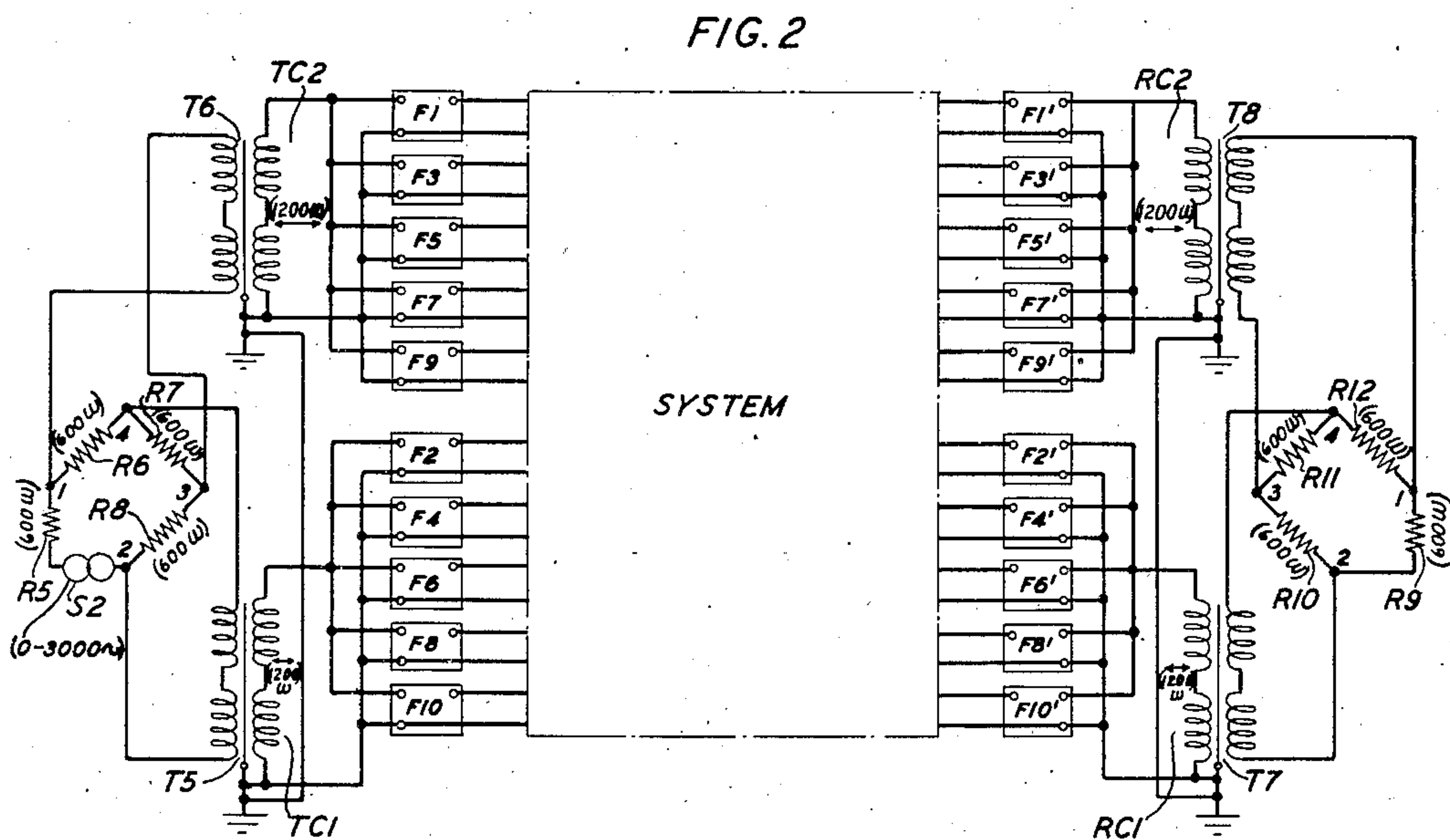
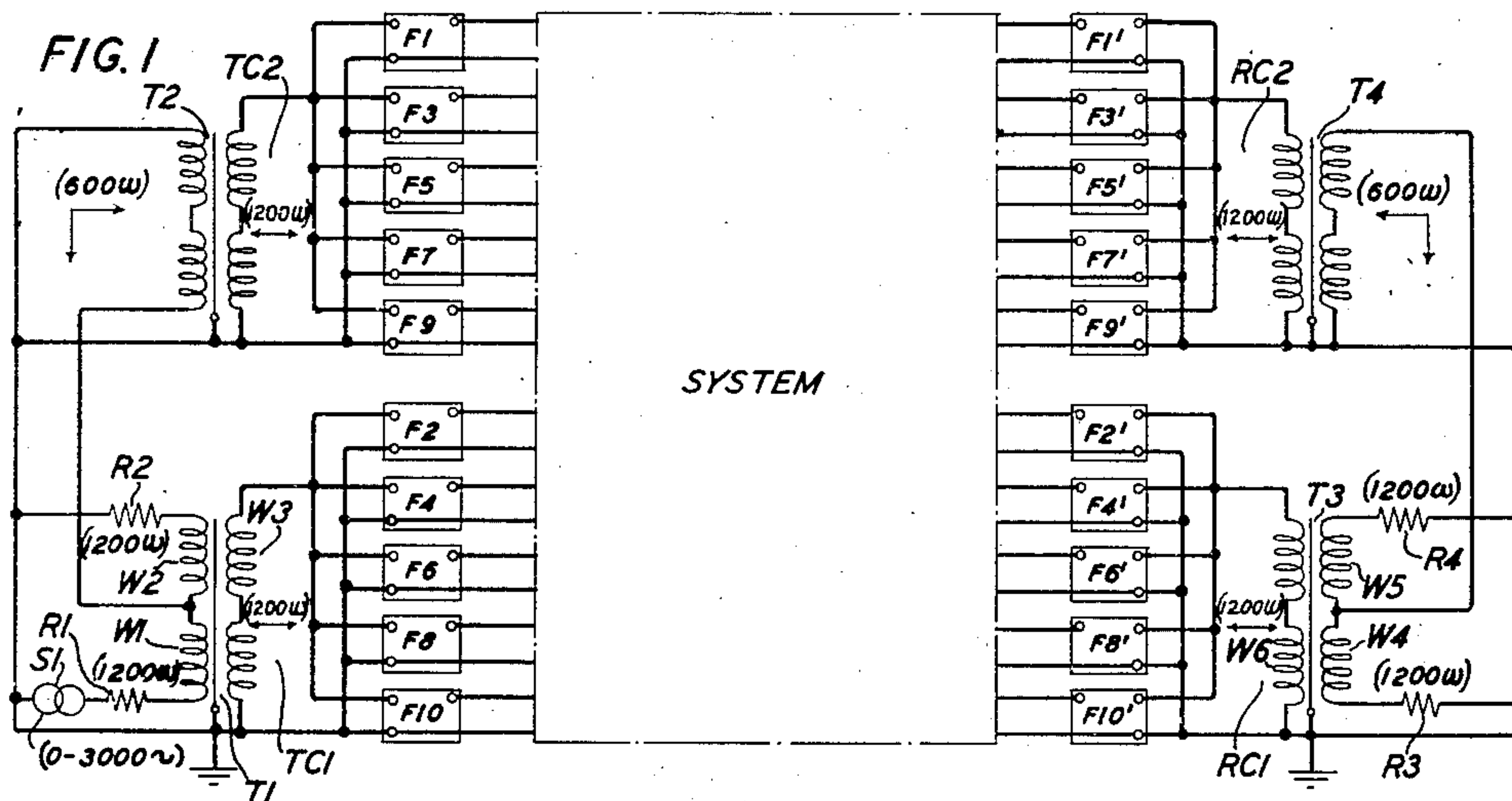
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2,417,069

WAVE TRANSMISSION SYSTEM

Filed Dec. 20, 1943

3 Sheets-Sheet 1



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FIG. 4

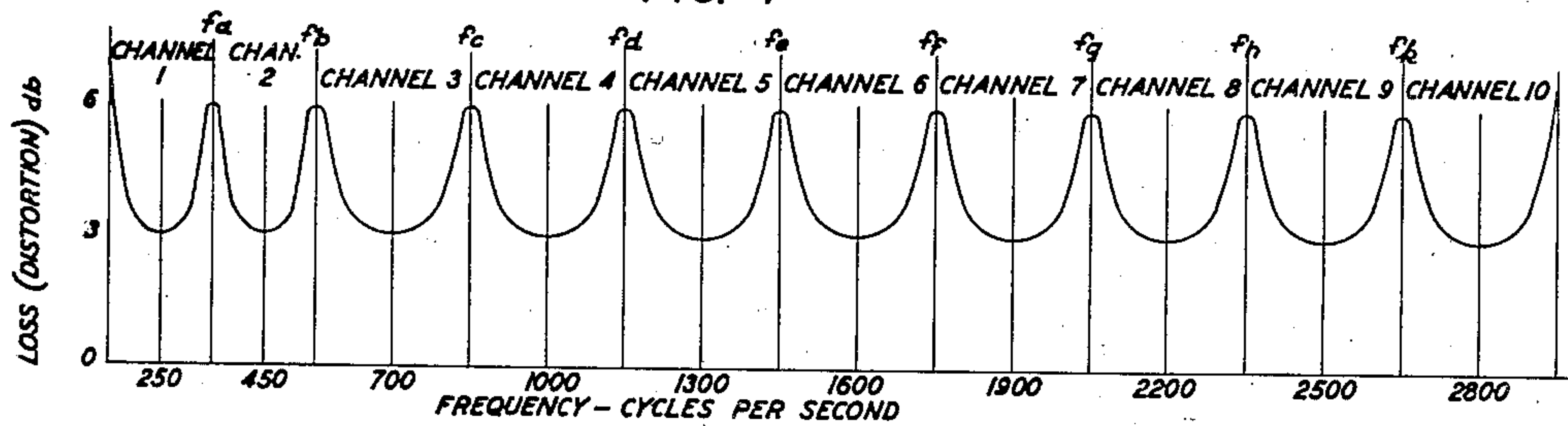


FIG. 6

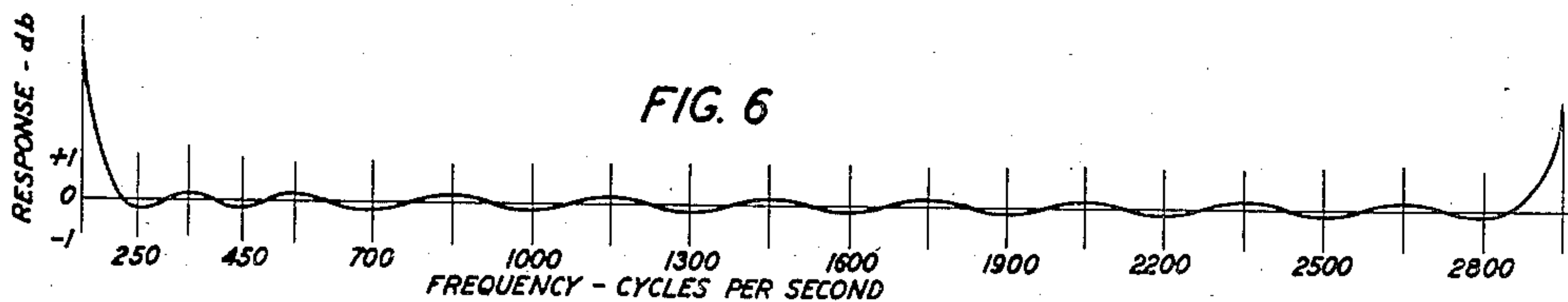


FIG. 7

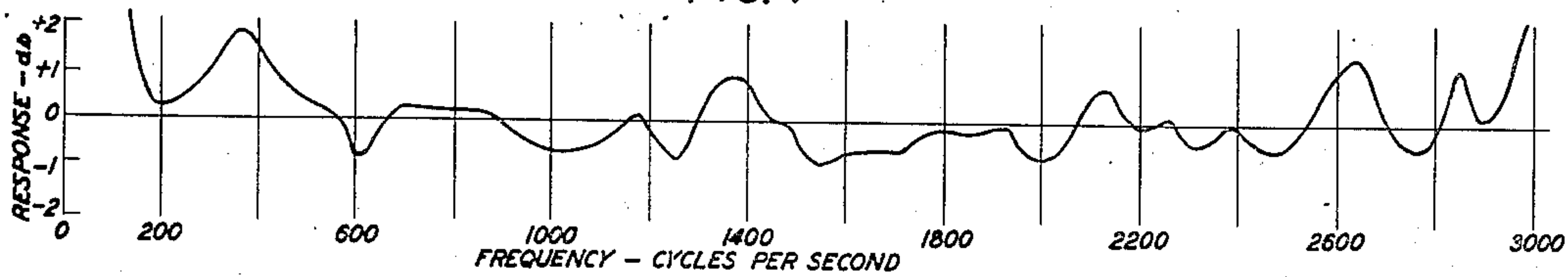
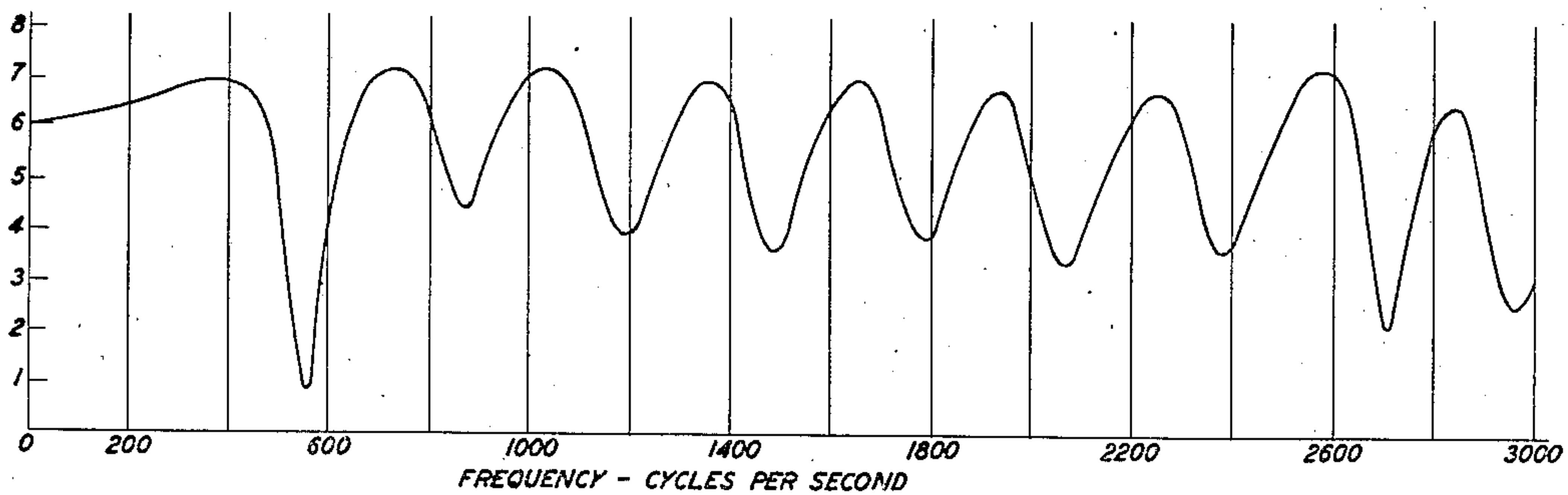


FIG. 8



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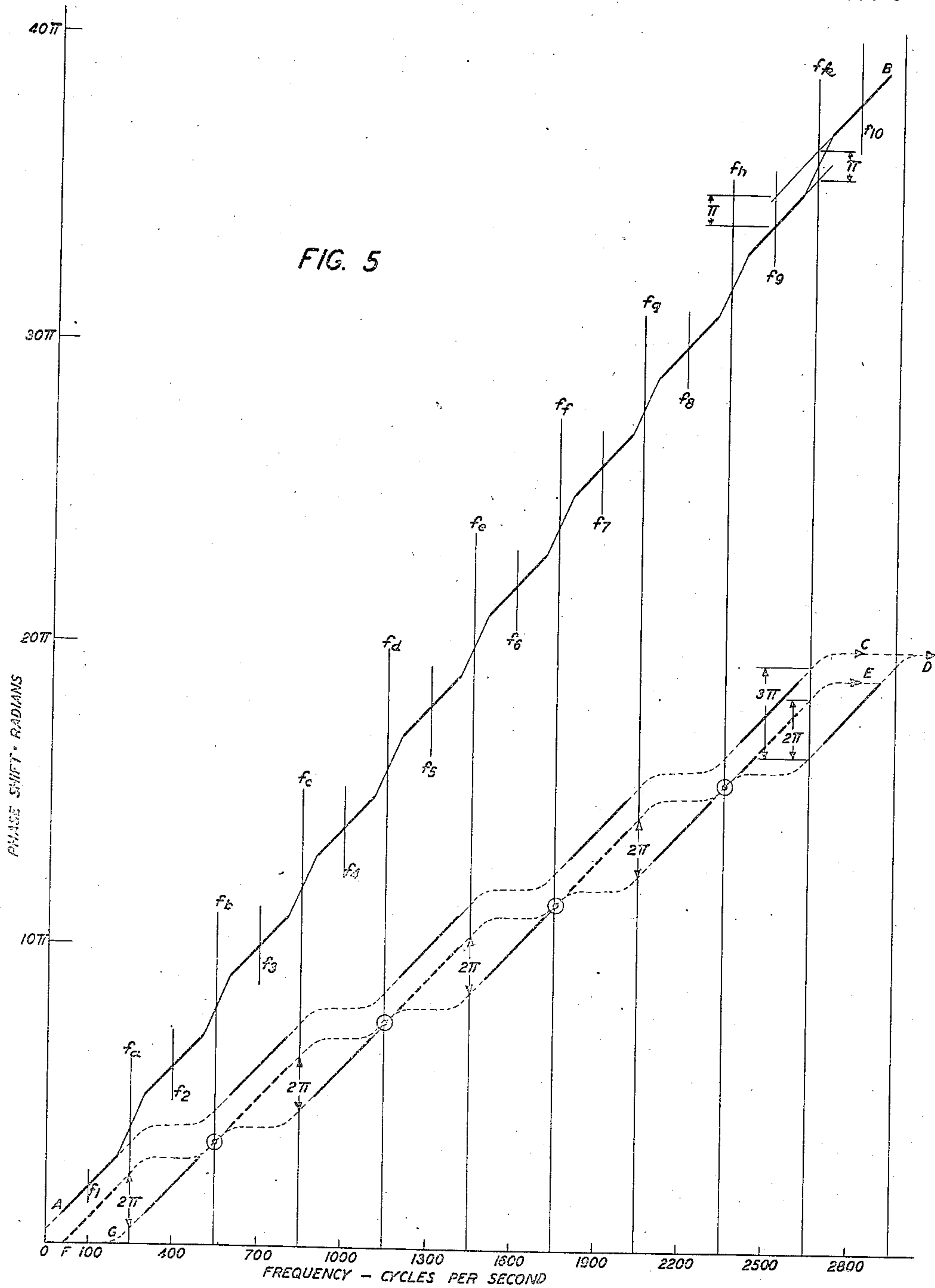
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WAVE TRANSMISSION SYSTEM

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3 Sheets-Sheet 3



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WAVE TRANSMISSION SYSTEM

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6 Claims. (Cl. 178—44)

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This invention relates to wave transmission systems utilizing a plurality of narrow frequency ranges for transmission of speech-representing or other alternating signals of a wide range of frequencies, and particularly to the signal band selecting or filtering arrangements used in such systems.

In carrier wave communication systems or other systems in which a plurality of signal frequency bands or channels are transmitted over a common circuit, it is desirable from the standpoint of efficient utilization of the available frequency range that the frequency intervals between the several signaling channels be made as small as possible consistent with the maintenance of the desired quality of transmission. The lack of sufficient selectivity in commercial filters used to obtain the separation between the frequency channels in such systems limits the reduction in interband waste space which may be obtained without signal distortion. If the frequency interval between adjacent frequency channels is made very small, each channel filter may pass, in addition to the signal frequency band it was designed to transmit, undesired waves of frequencies above and below that band within the frequency ranges of the filters in the adjacent channels, which results in interference between the transmitted channels. Also, if the channels are placed very close together in the frequency spectrum, and a number of filters at a transmitting station are connected in parallel to a common circuit, the impedance presented by the filter in one channel may be quite low and irregular within the pass frequency band of the latter. Since each filter is designed to work into a particular impedance, such impedance irregularities may result in deleterious reflections, and distortion will be produced particularly at frequencies near the edges of the transmitted signal bands. Such distortion may seriously affect the quality of signal transmission over the system.

Such detrimental effects have been reduced to a certain extent in prior art systems by a division of the channel filters into two groups of parallel-connected filters such that the frequency bands passed by the filters in one group are intermediate those passed by the filters in the other group, and the interconnection of the two groups of filters by a balanced bridge circuit or hybrid coil in conjugate relation with each other and in energy-transmitting relation with the common transmission line or circuit for all the frequency bands, so as to effectively prevent interaction between the two groups of channels. It has been

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found by tests of this general type of system, however, that when the frequency channels are closely spaced in the frequency spectrum to save frequency range, the peaking-up of losses in the transition frequency ranges of the paralleled channel filters substantially above that at the mid-frequency of the channels, causes the intelligibility of the speech or other signals at a receiving point in the system to be impaired to such an extent as to be objectionable in a high quality system.

An object of this invention is to effectively eliminate such distortion effects.

Another object is to increase the effectiveness of the frequency selective devices or filtering arrangements in such a system.

Another object is to increase the number of signal wave transmission channels that may be superposed in a given frequency range, that is, to effectively reduce the frequency range required for efficient transmission of signals of a wide band of frequencies.

A more specific object is to decrease the frequency intervals between adjacent signal frequency channels of a wide frequency band signal wave transmission system without detrimentally affecting the quality of transmission.

These objects are attained in accordance with the invention by simple and effective arrangements for minimizing the loss in the transition frequency ranges of the parallel-connected filters in a signal wave transmission system such as described above, so that over the whole transmission frequency range of the filter system the deviation from flat loss is so small as to produce negligible distortion in the transmitted signals.

In one embodiment of the invention applied to a multi-channel speech signal transmission system, a plurality of filters adapted for transmitting contiguous frequency subbands or channels of a continuous band of speech frequencies to be transmitted, at each terminal of the system are connected in parallel in two groups, such that the channel filters in one group transmit frequency subbands which are intermediate those transmitted by the channel filters of the other group. The two groups of parallel-connected filters at the transmitting and receiving ends of the system are connected to the common source of continuous frequency speech waves to be transmitted and to the common output circuit for all the frequency subbands, respectively, through like coupling circuits, except for a reversed poling at one end, such as to provide conjugacy between the two groups of transmitted signaling channels

and a phase reversal in the transition frequency ranges between adjacent signaling channels to reduce the attenuation distortion in those ranges. In one embodiment each coupling circuit comprises a three-winding hybrid transformer, a properly poled two-winding repeating coil and a resistor connected in an unbalanced bridge arrangement. In another embodiment each coupling circuit comprises a resistance hybrid and two properly poled repeating coils connected in a balanced bridge arrangement.

The various features and objects of the invention will be better understood from the following detailed description when read in conjunction with the accompanying drawings in which:

Fig. 1 shows schematically one embodiment of the invention applied to a signal transmission system of the above-described general type;

Fig. 2 shows schematically another embodiment of the invention applied to a similar system;

Fig. 3 shows schematically the type of equalizer arrangement which would be required in combination with a filter arrangement such as shown in the systems of Fig. 1 or 2, to provide a tolerable reduction in distortion over the whole frequency range of the combined filters; and

Figs. 4 to 8 show characteristic curves used in connection with an explanation of the invention.

Figs. 1 and 2 show block schematics of a system such as disclosed in Dudley Patent No. 2,151,091, issued March 21, 1939, for transmitting signals of a wide frequency range over circuits inherently capable of transmitting efficiently a narrower frequency range, modified in accordance with the present invention.

For the purpose of simplification of the drawings and brevity of the corresponding description only those parts of the systems of Figs. 1 and 2 to which reference is necessary in explaining the present invention are indicated separately in those figures and will be described. The remaining portions of the systems, which may be identical with those of the similar systems disclosed in the aforementioned Dudley patent, are represented by the box labeled "System" in each figure, and reference may be made to the specification of that patent for a description of the circuit details within that box and a detailed operation of the system.

The frequency pass ranges of the ten filters designated F1 to F10, inclusive, and the ten corresponding filters designated F1' to F10', inclusive, at the transmitting and receiving stations, respectively, of the systems shown in Figs. 1 and 2, are made such as to divide up a given continuous band of speech frequencies generated by a source, which may be a telephone transmitter, illustrated by the generator S1 and the associated 1200-ohm series resistor R1 representing its impedance, at the transmitting station of the system into a corresponding number of contiguous signaling subbands or channels.

The ten band-pass filters at the transmitting station of the system of Fig. 1 are divided into two groups of five filters each, one group comprising the filters F1, F3, F5, F7 and F9, transmitting the odd channel frequency subbands having respective mid-band frequencies of 250, 700, 1300, 1900 and 2500 cycles per second, and the other group the filters F2, F4, F6, F8 and F10 transmitting the intermediate even channel subbands having respective mid-band frequencies of 450, 1000, 1600, 2200 and 2800 cycles per second. The inputs of the five filters in each group are connected in parallel with each other, and the two groups of

parallel-connected filters are coupled to the common source S1 of voice frequency signals to be transmitted, by a coupling circuit including the three-winding hybrid transformer T1 and the two-winding repeating coil T2 connected in an unbalanced Wheatstone bridge circuit with that source and the 1200-ohm resistor R2. In the coupling circuit at the transmitting station of Fig. 1, the source S1 and the associated 1200-ohm series resistor R1 representing the impedance of that source, form one arm of the bridge circuit, the 1200-ohm resistor R2 the adjacent arm, and the windings W1 and W2 of the three-winding hybrid transformer T1, respectively form the other two adjacent bridge arms. The third winding W3 of hybrid transformer T1 symmetrically inductively coupled to the windings W1 and W2 effectively connects the input of the 1200-ohm circuit TC1 feeding into the group of parallel-connected even numbered channel filters F2 . . . F10, across one diagonal of the bridge, and the inductively coupled windings of repeating coil T2 effectively connect the input of the 1200-ohm circuit TC2 feeding into the other group of parallel-connected odd numbered channel filters F1 . . . F9 across the other diagonal of the bridge. The upper terminal of the primary winding and the lower terminal of the secondary winding of the repeating coil T2, and the lower terminal of the third winding W3 of the hybrid transformer T1 are respectively connected to the grounded shields between the windings of that repeating coil and transformer. This bridge arrangement couples the two filter groups in conjugate relation with each other and in energy transmission relation with the source S1, and the repeating coil T2 is poled so as to provide a phase reversal of the transmitted frequency subbands or channels in the transition frequency ranges between the adjacent conjugately connected channels to reduce the attenuation distortion in those ranges.

At the receiving station of Fig. 1, the unbalanced bridge coupling circuit comprises the common output circuit for all the channels represented by the 1200-ohm resistor R3 as one arm, the 1200-ohm resistor R4 as a second adjacent arm, and the windings W4 and W5 of hybrid transformer T3, respectively, as the other two adjacent arms. The third winding W6 of transformer T3 symmetrically inductively coupled to the windings W4 and W5 effectively connects the output of the 1200-ohm receiving circuit RC1 fed from the group of parallel-connected even numbered channel subband filters F2' . . . F10' across one diagonal of the bridge circuit, and the inductively coupled windings of the repeating coil T4 effectively connect the output of the 1200-ohm receiving circuit RC2 fed from the group of parallel-connected odd numbered channel filters F1' . . . F9', across the other diagonal of the bridge circuit. The corresponding lower terminals of the third winding W6 of hybrid transformer T3 and the lower terminals of the windings of repeating coil T4 are connected together and to the grounded shield between the windings of that transformer and coil, respectively. This bridge arrangement with the connections shown, besides providing the desired conjugacy between the two groups of receiving channels and coupling between each group and the common load circuit R3 also carries through the desired phase reversal of the signals transmitted into the latter circuit in the transition frequency ranges be-

tween adjacent signaling channels to reduce the attenuation distortion in those ranges.

In the particular system in accordance with Fig. 1 embodying the invention, which has been built and tested, the ten filters at each terminal station were single section, unbalanced narrow band-pass filters, "X" terminated for parallel operation between 1200-ohm circuits. Each filter was made up of a number of resistors and low Q retardation coils and condenser elements, providing an almost linear phase shift over its respective transmitted frequency subband. Each filter consists of one confluent section. The total phase shift of a confluent section between cut-off frequencies is 2π radians, and for two ideal sections corresponding to ideal transmitting and receiving filters, it will be 4π radians. However, the filters are dissipative in nature, and as a result of the low Q of the component elements and the parallel effect of associated circuits, and to give a linear phase shift between their cut-off frequencies only about $3/2\pi$ of the original 2π radians phase shift in a filter is realized.

Fig. 4 shows the insertion loss-frequency characteristic which will be obtained for ten such parallel-connected filters transmitting contiguous frequency subbands extending over the voice frequency range (0-3000 cycles) at the transmitting or receiving station of a system such as shown in Fig. 1, if an auxiliary phase reversing repeating coil is not employed in combination with the hybrid coil coupling the two groups of parallel-connected filters to the common voice frequency wave source S1 or the common load circuit R3, respectively. In such a system the cut-off frequencies between adjacent filters are arranged to give a 3-decibel discrimination loss in the transition frequency ranges of the filters without the hybrid coil coupling arrangement. Consequently, the currents in the transition ranges between filters corresponding to frequencies $f_a, f_b, f_c, f_d \dots f_k$ will be out of phase by π radians resulting in considerable delay and loss distortion. It will be noted that in the loss-frequency characteristics of Fig. 4 there is a loss peak at each of the transition frequency points $f_a, f_b \dots f_h, f_k$ between adjacent frequency channels, which is of the order of 6 decibels or more above the loss at the mid-band frequency of the adjacent channels for the transmitting and receiving filters.

Fig. 5 shows a number of phase shift frequency curves for the filter circuits in the system of Fig. 1 which may be used to explain the invention. Curve A-B shows the total phase shift through the parallel transmitting and receiving filters over the whole frequency range if no correction is made. Curves A-C and G-D correspond to the phase shift of the odd channels 1-3-5-7-9 grouped together and of the even channels 2-4-6-8-10 grouped together, respectively, by the hybrid arrangements of Fig. 1, but uncorrected for phase reversal. The phase shifts then in each group arrangement, corresponding to curves A-C and G-D will produce curve A-B described above. Inspection of curves A-C and G-D show that at each transition frequency corresponding to frequencies $f_a, f_b, f_c \dots f_k$, there is a difference of approximately 3π radians, and that if a π radian phase reversal is introduced into the group of channels 1-3-5-7-9 giving curve A-C (uncorrected), a phase shift in accordance with F-E would result. Inspection shows that at the transition frequencies $f_a, f_b, f_c, f_d \dots f_k$, the phase shift differences corre-

spond to $2\pi, 0, 2\pi, 0 \dots 2\pi$ radians, respectively, which makes the currents in phase at the transition points, so that the loss at frequency points $f_a, f_b, f_c \dots f_k$, which correspond to the 3 decibel discrimination points on the transmitting and receiving filters without the hybrid coil coupling arrangement of grouping odd and even numbered channels, is not changed appreciably from the loss throughout the channel filters between these transition points. By grouping the odd channels and even channels and reversing the phase of one of the groups with respect to the other by means of a properly poled auxiliary repeating coil connected in an unbalanced bridge arrangement with the hybrid coil and a resistor coupling the two groups of channel filters to the common source or common load circuit at the terminals of a system, as illustrated in Fig. 1 and described above, a 2π radian difference is obtained at each of the transition frequency points $f_a, f_b \dots f_k$, as indicated in Fig. 5. Since these differences are multiples of 2π , a typical smooth response-loss characteristic over the total frequency range of the combined filters, as shown in Fig. 6, is obtained by the use of the particular coupling arrangements illustrated in Fig. 1. The phase characteristic for channel No. 1 to channel No. 10 then has an almost positive linear slope throughout which results in a constant delay and a flat loss characteristic.

Fig. 2 shows a modified Wheatstone bridge coupling arrangement in accordance with the invention applied to a system such as shown in Fig. 1. The coupling arrangement at each terminal employs a resistance hybrid in combination with two repeating coils providing a balanced bridge arrangement for performing the functions of the hybrid coil, repeating coil and resistor unbalanced bridge arrangement used in the system of Fig. 1.

At the transmitting station of Fig. 2, the signal source S2 and associated 600-ohm series resistor R5 representing its impedance forms one arm of the bridge and the 600-ohm resistors R6, R7 and R8, respectively, the other three arms of the bridge. The two-winding repeating coil T5 has its primary winding connected across one diagonal of the bridge (the upper terminal of the primary winding of coil T5 being connected to bridge terminal 4 and the lower terminal of that winding being connected to the opposite bridge terminal 2), and its secondary winding connected in series with the 1200-ohm transmitting circuit TC1 feeding the group of five parallel-connected filters F2 $\dots$ F10 respectively transmitting the even number frequency subbands. The two-winding repeating coil T6 has its primary winding connected across the other diagonal of the bridge (the upper terminal of the primary winding of coil T6 being connected to bridge terminal 3 and the lower terminal of that winding being connected to the opposite bridge terminal 1), and its secondary winding connected in series with the 1200-ohm transmitting circuit TC2 feeding the five parallel-connected filters F1 $\dots$ F9 respectively transmitting the odd number frequency subbands or channels. The corresponding lower terminals of the secondary winding of repeating coil T5 and the secondary winding of repeating coil T6 are connected to each other and to the grounded shields between the windings of the two repeating coils. This balanced bridge arrangement with the connections described couples the two filter groups at the west terminal of the system in conjugate relation with each other and in energy

transmission relation with the source S2; and provides like poling of the repeating coils T5 and T6 with respect to the source S2 so that the π radians out-of-phase relation of the transmitted currents in the transition frequency ranges of the filters in the two groups and thus the loss peaks at the transition frequency points of the loss-frequency characteristic (Fig. 4) will be maintained.

Similarly, at the receiving station of Fig. 2, the 600-ohm resistor R9 representing the common output circuit for all the transmitted frequency subbands, forms one arm of the coupling bridge circuit and the 600-ohm resistors R10, R11 and R12 respectively the other three arms. The secondary winding of the repeating coil T7 is connected across one diagonal of the bridge circuit (the upper terminal of the secondary winding of coil T7 being connected to bridge terminal 4 and the lower terminal of that winding to the opposite bridge terminal 2), and its primary winding in series with the receiving circuit RC1 fed from the output of the five parallel-connected channel filters F2' . . . F10', respectively transmitting the even numbered frequency subbands. The secondary winding of the repeating coil T3 is connected across the other diagonal of the bridge circuit (the upper terminal of the secondary winding of coil T3 being connected to bridge terminal 1 and the lower terminal of that winding being connected to the opposite bridge terminal 3), and the primary winding of repeating coil T3 is connected in series with the receiving circuit RC2 fed from the parallel-connected channel filters F1' . . . F9' transmitting the odd numbered frequency signal subbands. The corresponding lower terminals of the primary windings of the two repeating coils T7 and T3 are connected to each other and to the grounded shields between the windings of the two coils as shown. These connections provide opposite poling of the two coils T7 and T3 with respect to the currents supplied thereto from the respective filter groups at the east terminal of the system.

The coupling arrangement of Fig. 2 operate in a manner similar to those of Fig. 1 as described above, to provide the required conjugacy between the groups of odd and even numbered frequency channels, as well as a phase reversal of the transmitted waves in the transition frequency range between adjacent channels to reduce the insertion loss in those ranges to an unobjectionable amount. The arrangement of Fig. 1 gives 6 decibels less loss in circuit than that of Fig. 2, but tests show that both give the identical transmission loss quality over the frequency range of the 10-channel arrangement, as shown by the curve of Fig. 6.

The curve of Fig. 8 shows the amount of loss correction which would be required in series with each parallel group of band filters in a system such as shown in Fig. 1 or 2 to provide proper equalization of the loss at one terminal of the system, if the coupling arrangements of the invention are not used.

Fig. 3 shows the circuit of an equalizer which was used in series with the filter groups to correct for the loss distortion of two terminals of a bank of ten filters each. The curve of Fig. 7 shows the deviation from flat loss over the frequency range of the ten filters which was obtained by the use of such an equalizer. Such equalizers are difficult to build as the loss must be shaped to fit the desired characteristic (Fig. 8) corresponding to the holes or sinks at the frequencies 560, 850, 1180, 1480, 1790, 2050, 2380, 2700 and

2950 cycles. The arrangements of the invention as described above are relatively simple and inexpensive, and tests which have been made indicate that they are effective to reduce distortion in high quality systems, such as described above, to an unobjectionable amount.

Various modifications of the circuits illustrated and described, which are within the spirit and scope of the invention, will occur to persons skilled in the art. For example, although the coupling arrangements of the invention as shown in Fig. 1 provide an unbalanced circuit connection between the energy source and load, with slight changes they may be made to provide a balanced circuit connection. This may be accomplished by disconnecting the low potential or ground circuit lead from the primary windings of T1, T2, T3 and T4. The input and output circuits away from the hybrid coils then will be balanced circuits as in the case of the resistance bridge arrangement illustrated in Fig. 2.

What is claimed is:

1. In a system for transmitting waves of a wide band of frequencies in a plurality of subbands closely spaced in the frequency spectrum, comprising a common transmission circuit for all the subbands, a plurality of filters each adapted to transmit a different one of said frequency subbands, connected in parallel in two groups, the filters in one group transmitting alternate ones of said subbands in the frequency spectrum and the filters in the other group the intermediate frequency subbands, means to couple the two filter groups in conjugate relation with respect to each other and in energy transmission relation with respect to said common circuit, and means to minimize attenuation distortion in the over-all transmission characteristic of said system due to the peaking up of the losses in the transition frequency ranges between adjacent frequency bands transmitted by the paralleled filters comprising means to produce a phase reversal of the transmitted waves in said transition frequency ranges.

2. In combination in a wave transmission system, a source of waves of a wide band of frequencies, a plurality of band-pass filters respectively adapted for transmitting different frequency subbands within said wide band closely spaced in the frequency spectrum, said filters being connected in parallel at their inputs in two groups, the filters in one group transmitting alternate ones of said frequency subbands and the filters in the other group the intermediate frequency subbands, means for coupling the inputs of the two groups of parallel-connected filters in conjugate relation with respect to each other and in energy transmission relation with said source of waves, and means to effectively produce a phase reversal of the transmitted waves in the transition frequency transmission ranges of said filters so as to reduce attenuation distortion in the transmitted waves in said frequency ranges.

3. The system of claim 2, in which said coupling means comprises a Wheatstone bridge circuit having said wave source in series with one of its arms and an element of impedance value equivalent to that of said source in series with each of its other three arms, the common input of one group of parallel-connected filters being effectively coupled to one diagonal of said bridge circuit and the common input of the other group of parallel-connected filters being effectively coupled to the other diagonal of said bridge circuit, and said means to produce a phase re-

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versal of the transmitted waves in said transition frequency ranges comprises means for causing the waves from said source impressed on said one group of filters to be substantially 180 degrees out of phase with respect to the waves therefrom impressed on said other group of filters.

4. The system of claim 2 in which said coupling means comprises a hybrid coil unbalanced bridge circuit including said source in one of its arms and an element of impedance value equivalent to that of said source in each of its other three arms, the input of one of said filter groups being connected effectively across one diagonal of said bridge circuit and the input of said other filter group being connected effectively across the other diagonal of said bridge circuit, and said wave phase reversing means comprising means for effectively reversing the connections of one of the bridge diagonals to one filter group with respect to those of the other bridge diagonal to the other filter group.

5. The system of claim 1 in which the coupling means between said two filter groups and said common circuit comprises a hybrid coil, a repeating coil and a resistor connected in an unbalanced Wheatstone bridge arrangement with said common circuit, and said means to pro-

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duce a phase reversal of the transmitted waves in said transition frequency ranges comprising means for causing the waves transmitted between said common circuit and said one filter group through said coupling means to be 180 degrees out of phase with respect to the waves transmitted therethrough between said common circuit and said other filter group.

6. The system of claim 2, in which the coupling means between said source and the inputs of the two filter groups comprises a balanced bridge circuit including said source in series with one of its arms and a resistor of the same impedance as the characteristic impedance of said source in each of the other three arms, a repeating coil coupling the input of one of said filter groups across one of the bridge diagonals and a second repeating coil coupling the input of the other filter group across the other diagonal of said bridge circuit, and said means for producing a phase reversal of the transmitted waves in said transition frequency ranges comprises means for poling the two repeating coils oppositely with respect to the waves supplied thereto from said source.

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