Aug. 21, 1934. C. L. FREDERICK 1,970,933

WAVE TRANSMISSION NETWORK

Filed Oct. 21, 1932

FIG. 1

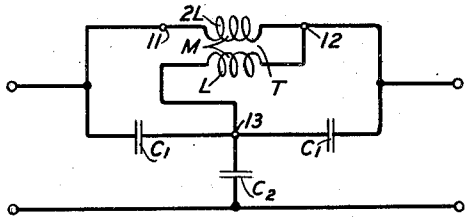


FIG. 2

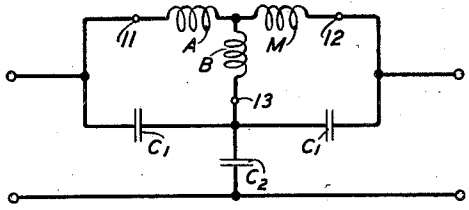


FIG. 3

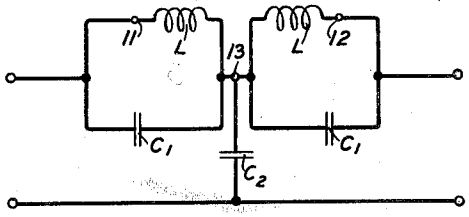


FIG. 4

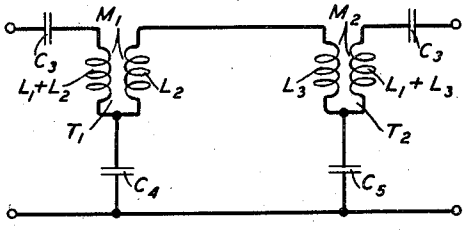
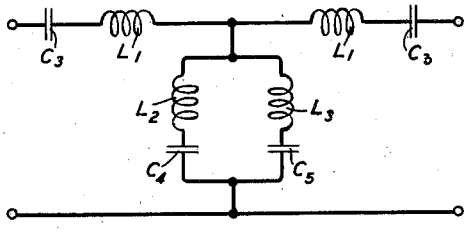


FIG. 5



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WAVE TRANSMISSION NETWORK

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Application October 21, 1932, Serial No. 638,951

10 Claims. (Cl. 178—44)

This invention relates to wave transmission networks, and more particularly to the use of mutually coupled inductances in such networks.

The principal object is to reduce the number of coils required in a transmission network.

Another object is to reduce the weight and size of transmission networks.

A further object is to reduce the manufacturing cost of transmission networks.

In effecting these objects, use is made of the mutual induction existing between two coil windings wound on the same core. It has been shown in the article "Mutual Inductance in Wave Filters with an Introduction on Filter Design" by K. S. Johnson and T. E. Shea in the Bell System Technical Journal, January 1925 that a coupled two-winding coil or transformer is electrically equivalent to a star or T-network of three inductances. If the two coil windings are connected series opposing the equivalent T-network will have three branches which are equal, respectively, to the value of the mutual inductance; the difference between the self inductance of one of the windings and the mutual inductance; and the difference between the self-inductance of the other coil winding and the mutual. If, therefore, the mutual inductance is made equal in value to the self-inductance of one of the windings, one of the arms of the T will become zero and thus disappear. The remaining two arms may be designed to have any desired values of inductance. In this way there is provided a coil consisting of two windings which may be placed on a common core and potted in the same case but which will supply the equivalent of two electrically separate inductances. When coils of this type are used in transmission networks such, for example, as wave filters, there is effected a saving of at least half of the separate coils required by the usual method of design, since one coil is made to take the place of two or more.

The nature of the invention and the manner of its application will be more fully understood from the following detailed description taken in connection with the accompanying drawing, of which:

Figs. 1 and 4 show two embodiments of the invention in wave filters;

Fig. 2 is a schematic diagram to which reference is made in explaining the invention; and

Figs. 3 and 5 represent circuits which are electrically equivalent to those shown, respectively, in Figs. 1 and 4.

One means of carrying out the inventive idea in practice is illustrated in connection with the wave filter shown in Fig. 1. The figure illustrates schematically a filter section having a pair of input terminals and a pair of output terminals, adapted to be connected between two sections of a circuit. A pair of equal condensers C_1 are connected in series between an input terminal and a corresponding output terminal. A third condenser C_2 forms the shunt impedance and is connected between the common terminal of the condensers C_1 and the other side of the filter. The inductance unit T comprises two windings having self inductances equal in value, respectively, to L and 2L, coupled by a mutual inductance M equal in value to L. The two windings have a common terminal 12 and are connected in series opposing relation with respect to their other two terminals 11 and 13; that is, they are so connected that flux produced by the current in one winding is opposed or decreased by the current flowing in the other winding. The winding of value 2L is connected in parallel with the two condensers C_1 between their outer terminals, and the other winding L is connected in parallel with one only of the condensers C_1.

The presence of the mutual inductance between the two windings of the inductance unit is equivalent to the insertion of an additional self inductance of value M in a branch common to the two coil windings. Fig. 2 shows a circuit which is electrically equivalent to the one shown in Fig. 1. By equivalence of networks, as the term is here used, is meant that one network may be substituted for the other in any system without affecting the current and voltage relations in any other part of the system. In Fig. 2 the two-winding inductance unit has been replaced by its equivalent T-network of three separate inductances, A, B and M, the values of which are given by the equations

$$A=2L-M=L \quad (1)$$
$$B=L-M=O \quad (2)$$
$$M=L \quad (3)$$

The coil terminals 11, 12 and 13 represent the same points in the network of Fig. 2 as they do in that of Fig. 1. As shown by Equations (1), (2) and (3), with the values assigned to the two coil windings and the mutual inductance in Fig. 1, the B arm of the equivalent T-network of Fig. 2 is equal to zero, and the two series arms A and M are each equal to L. It is readily apparent, then, that the circuit of Fig. 2 may be redrawn as shown in Fig. 3, in which the arm B is shown as a strap having zero impedance. The filter

section of Fig. 1 is thus shown to be the electrical equivalent of the one illustrated in Fig. 3, which will be recognized as one of the type described in U. S. Patent 1,493,600, issued May 13, 1924, to G. A. Campbell.

The two windings of the inductance unit of Fig. 1 may be wound on the same core and may be potted in the same coil case. If proper values of self and mutual inductance are assigned, the coil will provide the equivalent of the two separate inductances L shown in Fig. 3. In this way, one double-winding coil is made to take the place of two individual inductance coils.

Another filter section embodying the invention is shown schematically in Fig. 4, in which there are two inductance units T_1 and T_2. The unit T_1 has two windings with self inductances equal, respectively, to L_2 and to L_1 plus L_2, coupled by mutual inductance M_1 equal in value to L_2. The self inductances of the two windings of T_2 are equal, respectively, to L_3 and to L_1 plus L_3, with a mutual M_2 equal to L_3 effective between the windings. T_1 and T_2 have their windings connected in the series opposing relation. A pair of equal capacitances C_3 are connected in series with the inductance units, and two more capacitances C_4 and C_5, form a part of the shunt impedance of the filter. By replacing the inductance units T_1 and T_2 by their equivalent T-networks, as was explained above in connection with Figs. 2 and 3, it is seen that the circuit of Fig. 4 is electrically equivalent to that shown by Fig. 5, which will be recognized as a band-pass filter section of the type described in U. S. Patent 1,644,004, issued October 4, 1927, to O. J. Zobel. Each of the inductance units T_1 and T_2 may consist of two windings placed upon a single core and potted in a single coil case. Thus, two coils serve to provide the equivalent of four separate inductances L_1, L_1, L_2 and L_3, as shown in Fig. 5.

This invention is not limited to the particular filter sections shown but may be greatly modified and applied to other varieties of wave transmission networks without departing from the spirit of the invention, as defined in the appended claims. For example, other circuits such as series or parallel resonant circuits may be substituted for the condensers or may be connected in shunt to the inductances to give other transmission characteristics.

What is claimed is:

1. A wave transmission network comprising an inductance in series with respect to the direction of wave propagation and a second inductance in shunt thereto, said two inductances being so related as to have mutual inductance, said two inductances being connected in series opposing relation, said mutual inductance being equal in magnitude to said shunt inductance, and said inductances effectively adding a third inductance in series with said series inductance while reducing the effective impedance of said shunt inductance substantially to zero.

2. An electrical network adapted to be connected between two sections of a circuit, said network comprising a series inductance and a shunt inductance, said two inductances being so related as to have mutual inductance and being connected in series opposing relation, the value of said mutual inductance being equal to the self inductance of one of said inductances, said inductances effectively adding another inductance in series with said series inductance, and said added inductance cooperating with the other elements of said network to produce a transmission band in the attenuation characteristic of said network.

3. A wave filter section comprising a plurality of circuit branches disposed in series and shunt relationship with respect to the direction of wave propagation, reactive impedances associated in said branches, an inductance included in one of said series branches and a second inductance included in an adjacent shunt branch, said two inductances being so related as to have mutual inductance therebetween and being connected in series opposing relation, the value of said mutual inductance being equal to the self inductance of one of said inductances, said inductances effectively adding an inductance element to one of said series branches, the impedance of said element cooperating to permit the filter to pass freely a band of frequencies while attenuating other frequencies.

4. A wave transmission network having a pair of input terminals and a pair of output terminals, said network comprising electrical paths between each input terminal and a respectively associated output terminal, two impedances included in series in one of said paths, an inductance connected in parallel with said two impedances between the outer terminals thereof, a second inductance connected in parallel with one of said two impedances, and a third impedance connected between the junction point of said two impedances and a point in the other of said paths, said two inductances being so related as to have mutual inductance therebetween, and the valve of said mutual inductance being equal to one of said two inductances.

5. A wave transmission network adapted to be connected between two sections of a circuit, said network comprising a pair of capacitances connected in series between the two sections, a third capacitance included in a shunt path having one terminal connected to the junction point of said pair of capacitances, an inductance connected in parallel with said pair of capacitances between the outer terminals thereof, and a second inductance connected in parallel with one of said pair of capacitances, said two inductances being so related as to have mutual inductance and being connected in series opposing relation, the value of said mutual inductance being equal to the self inductance of said second inductance, said inductances effectively adding an inductance element in series between the two sections of circuit and nullifying the effect of said second inductance.

6. An electric wave filter having a pair of input terminals and a pair of output terminals, said network comprising electrical paths between each input terminal and a respectively associated output terminal, two capacitances included in series in one of said paths, an inductance connected in parallel with said two capacitances between the outer terminals thereof, a second inductance connected in parallel with one of said two capacitances, and a third capacitance connected between the junction point of said two capacitances and a point in the other of said paths, said two inductances being so related as to have mutual inductance and being connected in series opposing relation, the value of said mutual inductance being equal to the self inductance of one of said inductances.

7. A wave filter section comprising a plurality of circuit branches disposed in series and shunt relationship with respect to the direction of wave propagation, reactive impedances associated in

said branches, said impedances incuding a pair of coupled inductances included in two of said series branches which are separated by a shunt branch, said inductances effectively adding an inductance element to said shunt branch while at the same time annulling the effect of one of said pair of inductances, the impedance of said added inductance element cooperating to permit the filter to pass freely a band of frequencies while attenuating other frequencies.

8. A wave transmission network comprising a plurality of circuit branches arranged in series and shunt relationship to the direction of wave propagation, a reactive impedance in a shunt branch and two inductances included in two of said series branches which are separated by said shunt branch, said two inductances being so related as to have mutual inductance and being connected in series opposing relation, the value of said mutual inductance being equal to the self inductance of one of said two inductances, said inductances effectively adding an inductance element in said shunt branch while at the same time annulling the effect of one of said two inductances.

9. A wave transmission network comprising a reactive impedance, means for connecting said reactive impedance between two sections of a circuit and an inductance connected in series between said impedance and each of the two sections, said inductances being so related as to have mutual inductance and being connected in series opposing relation, the value of said mutual inductance being equal to the self inductance of one of said inductances, whereby an inductance element is effectively added to said reactive impedance and the effect of one of said series inductances is annulled.

10. A wave filter adapted to be connected between two sections of a circuit, said filter comprising a shunt impedance and an inductance at each side of said impedance, said inductances being so related as to have mutual inductance and being connected in series opposing relation, the value of said mutual inductance being equal to the self inductance of one of said two inductances, said inductances effectively adding an inductance element in said shunt impedance while at the same time annulling the effect of one of said two inductances, the impedance of said added inductance element cooperating to permit the filter to pass freely a band of frequencies while attenuating other frequencies.

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