April 12, 1927.

1,624,682

T. E. SHEA

ELECTRICAL NETWORK

Filed Jan. 31, 1925

Fig. 1

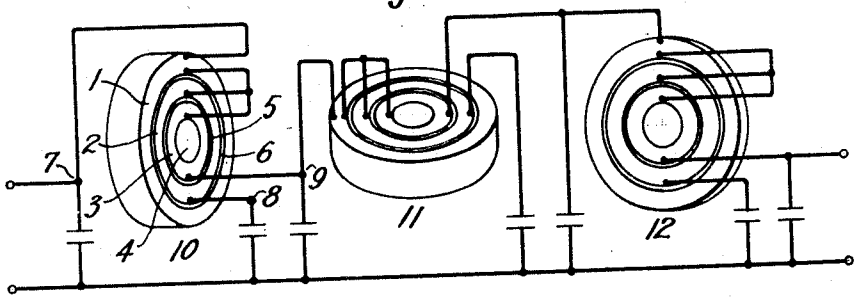
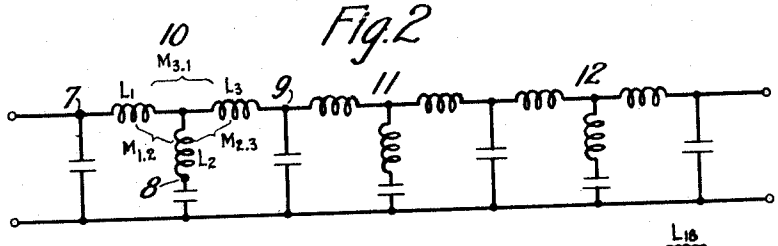


Fig. 2



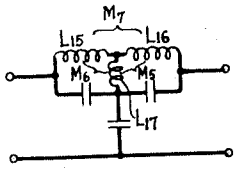


Fig. 3

Fig. 4

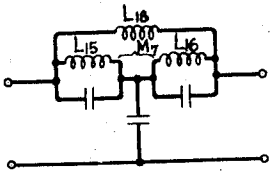


Fig. 5

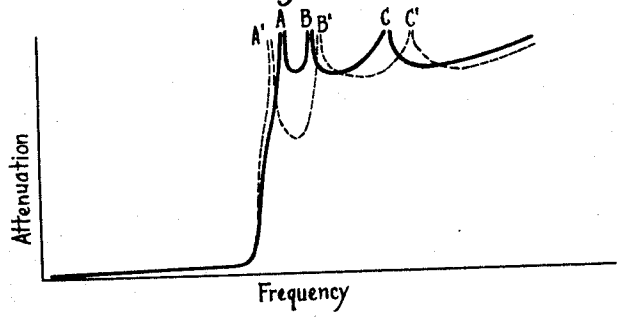


Fig. 6

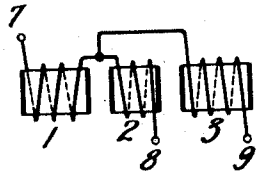
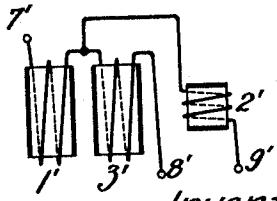


Fig. 7



Inventor:
Timothy E. Shea,
by Edwards Atty

Patented Apr. 12, 1927. 1,624,682

UNITED STATES PATENT OFFICE.

TIMOTHY E. SHEA, OF RUTHERFORD, NEW JERSEY, ASSIGNOR, BY MESNE ASSIGNMENTS, TO WESTERN ELECTRIC COMPANY, INCORPORATED, A CORPORATION OF NEW YORK.

ELECTRICAL NETWORK.

Application filed January 31, 1925. Serial No. 5,968.

This invention relates to wave transmission networks, and more particularly to inductance coils for use in such networks.

An object of the invention is to compensate the effects upon the transmission characteristics of networks having undesired mutual inductances between inductance elements.

The use of toroidal coils with evenly distributed windings has heretofore afforded the most certain means for preventing electromagnetic coupling between separate inductances of a network. The magnetic field of these coils being wholly confined within the toroidal winding, the mechanical assembly of a network in which they are employed is completely freed from any restrictions that the presence of a stray magnetic field might impose.

Under certain conditions, it has been found that a substantial economy of copper may be secured by the use of short solenoidal coils instead of toroidal coils, but, on account of their external fields, it has been impracticable to use coils of this type in complicated networks such as wave filters, in which it is frequently necessary to include a considerable number of coils within a comparatively small space.

The most important effect of the external fields is to produce electromagnetic coupling between the various coils as the result of which the transmission characteristics of a network may be harmfully modified.

By compensating the effects of electromagnetic coupling, the present invention makes possible the use of solenoidal coils in the mechanical assembly of wave filters and other networks and permits the copper economy resulting therefrom to be substantially realized.

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

Fig. 1 shows in partially schematic form a wave filter embodying the invention;

Fig. 2 is a fully schematic representation of the wave filter of Fig 1;

Figs. 3 and 4 illustrate the application of the invention in connection with a different type of network;

Fig. 5 illustrates the effect of electromagnetic coupling upon the attenuation characteristic of the filter of Fig. 1;

Fig. 6 is a detailed diagram of the windings of the inductance coils of Fig. 1; and

Fig. 7 is a winding diagram of a modified arrangement of the invention.

One means of carrying out the inventive idea in practice is illustrated in connection with the wave filter shown in Fig. 1. In this figure, the inductance unit 10 comprises a star connected group of three inductive windings 1, 2 and 3, which are wound concentrically upon a core 4 and separated by rings of insulating material 5 and 6. The various inductances of the unit are indicated in Fig. 2, the self-inductances of the windings, 1, 2 and 3 being denoted by L_1, L_2, and L_3 respectively and the mutual inductances between the windings being denoted in a corresponding manner by $M_{1.2}$, $M_{2.3}$, and $M_{3.1}$.

In a group of connected inductances, which, as in the present instance, are also coupled inductively, the effect of each mutual inductance is equivalent to a modification of each of the self inductances by an increase or a decrease of its value according to the sign of the mutual inductance. The sense of the coupling determines the sign of the mutual inductance, and the positive sign is arbitrarily applied to a mutual inductance which has the effect of increasing the total inductance of two coils connected in series.

The windings of the group inductance 10 may be arranged in accordance with Fig. 6, in which the windings and terminals are numbered to correspond to the designations of Fig. 1. With this arrangement, the mutual inductances are all negative.

It may be shown that the group of coupled inductances may be replaced, without changing the characteristics of the network, by three independent star connected inductances having the values

$$\left.\begin{aligned} L_1' &= L_1 - M_{1.2} + M_{2.3} - M_{3.1} \\ L_2' &= L_2 - M_{1.2} - M_{2.3} + M_{3.1} \\ L_3' &= L_3 + M_{1.2} - M_{2.3} - M_{3.1} \end{aligned}\right\} \quad (1)$$

in which L_1', L_2', L_3' are the independent inductances which would replace the coupled inductances L_1, L_2 and L_3 respectively.

In designing the three winding unit, the self inductances and the mutual inductances

may be adjusted until the effective inductances determined by equations (1) have the values required to produce the desired transmission characteristic. The self inductances may be adjusted by changing the number of turns of wire and the mutual inductances by varying the thicknesses of the separating rings 5 and 6.

In Fig. 1, additional units 11 and 12 of similar construction to the unit 10 are used to extend the number of sections in the wave filter. The three units are arranged with their centers in line and their planes mutually perpendicular, whereby the mutual inductances between the coils of the different units are reduced to zero. It is possible to dispose only three coils in this way but by grouping three windings in each coil unit in accordance with the foregoing method, a total of nine inductances may be included in a single filter.

A possible attenuation characteristic of the filter of Figs. 1 and 2 is shown in Fig. 5 by the continuous line curve. The abscissæ of this curve are proportional to frequency and the ordinates to the attenuation of the waves passing through the filter. The points of discontinuity A, B and C represent the large attenuations which occur at the resonance frequencies of each of the three series resonant circuits forming shunt branches of the network.

It is found that maintenance of a high degree of attenuation at frequencies between these resonance points requires careful choice of the resonance frequencies with respect to each other and careful construction of the circuit elements to insure that resonance will actually take place at the chosen frequencies. The kind of effect produced by small departures of the inductances from the correct values is indicated by the dotted curve. The resonance peaks may occur at different frequencies, indicated by A′, B′ and C′, with the result that the attenuation at frequencies between the resonance frequencies is greatly reduced.

This effect is particularly noticeable in wave filters which, for the purpose of securing the sharpest possible discrimination, are designed to have several resonance peaks very close to the cut-off frequency. The effect of mutual inductances in such cases may seriously affect the sharpness of discrimination by causing a shift of the resonance frequencies.

The stray field coupling between elements of a transmission network may be regarded as constituting an alternative channel by way of which a portion of the electrical wave energy may traverse the system. In general, the presence of a channel of this sort operates to prevent the proper functioning of the network. In the case of wave filters, for example, it limits the degree of attenuation possible, since there will appear in the output of the filter a wave component which has not been subject to the designed attenuation.

In the example already described, the effect of the mutual inductances is taken into account by modifying the inductances in a compensating manner. Other ways of employing the inventive idea are possible in which a unique degree of compensation is secured. Examples of these will also be described.

If instead of giving a sharp discrimination close to the cut-off frequency, the filter of Figs. 1 and 2 were required to effect the maximum possible attenuation at very high frequencies, it would preferably be designed as a simple filter comprising series inductances and shunt capacities as disclosed in U. S. patent to Campbell, No. 1,227,113, issued May 22, 1917. To secure this result without recourse to toroidal windings, it is necessary that the resultant inductances effective in the shunt branches due to the coupling between successive coils be neutralized.

This may be done with the type of inductance unit hereinbefore described by making the shunt arm self-inductance L_2 just great enough to neutralize the resultant of the mutual inductances $-M_{1.2}$, $-M_{2.3}$ and $+M_{3.1}$.

It may happen with the particular winding arrangement shown in Fig. 6 that the negative inductances $-M_{1.2}$ and $-M_{2.3}$ are too small to compensate the positive inductances L_2 and $M_{3.1}$ unless the compensating inductance L_2 is made of considerable size. Recourse may be had, however, to other systems of winding whereby this difficulty is obviated.

For example, if the inductance 1 of Fig. 6 be wound in the reverse direction to that shown in the figure the mutual inductances $M_{1.2}$ and $M_{3.1}$ will have positive sign, the mutual inductance $M_{2.3}$ remaining unchanged.

The values of the equivalent inductances in the three arms would then be

$$\left.\begin{aligned} L_1'' &= L_1 + M_{1.2} + M_{2.3} + M_{3.1} \\ L_2'' &= L_2 + M_{1.2} - M_{2.3} - M_{3.1} \\ L_3'' &= L_3 - M_{1.2} - M_{2.3} + M_{3.1} \end{aligned}\right\} \quad (2)$$

the inductances L_1'', L_2'', and L_3'' corresponding respectively to the inductances L_1', L_2' and L_3 of equations (1).

The value of the compensating inductance L_2 required to just neutralize the resultant effect of the various mutual inductances is given by the equation

$$L_2 = M_{3.1} + M_{2.3} - M_{1.2} \quad (3)$$

Since $M_{2.3}$ and $M_{1.2}$ will generally be small, it is evident that L_2 is approximately equal to the mutual inductance $M_{3.1}$ between the two principal inductances L_1 and L_3.

In Fig. 3 a star connected system of inductances L_{15}, L_{16} and L_{17} is combined with three condensers to form a four-terminal network. If solenoid coils are used, there will be present in addition to the self inductances three mutual inductances which are indicated in the figure by M_5, M_6 and M_7.

That this network may be constructed to be equivalent to a simple star type network, having in two of its branches anti-resonant circuits comprising an inductance and a capacity in parallel, and having in the third branch a capacity, follows from the relationships stated in equations (1). It is necessary only that the effective value of inductance L_{17} as modified by the mutual inductances be equal to zero, or, in other words, that the self-inductance of L_{17} be just sufficient to balance the effective negative inductances due to the coupling.

When one of the three inductances is introduced for the purpose of neutralizing in one branch of a network the effect of mutual inductance between the other two coils, its value will, in general, be relatively small and the effect of its own field upon other branches of the circuit will be negligible. It is not necessary in such cases that the compensating coil be incorporated in the same unit as the other two coils and it may be made as a small separate unit disposed in non-inductive relationship to both of the others. Under these conditions, two of the mutual inductances become zero and the small coil need only have an inductance equal to the mutual inductance between the principal coils. Fig. 7 shows a group of inductances arranged in this way, the windings and terminals being designated by the same numerals as are used in Fig. 6 to indicate corresponding parts. Prime marks are used to distinguish between the two figures.

An alternative manner of connecting a third coil to neutralize a mutual inductance is shown in Fig. 4, which illustrates the same network as Fig. 3 except that the compensating inductance L_{17} is replaced by a bridging inductance L_{18} not coupled to the other coils, the three coils forming a "delta" network instead of a star network. If the mutual inductance M_7 is negative, as hereinbefore defined, it may be shown that it produces the effect of a bridging inductance in parallel with L_{18} having the value

$$-\frac{L_{15}L_{16}-M_7^2}{M_7}$$

The admittance due to the effective negative inductance will be neutralized if L_{18} has an equal positive magnitude, and the network will have the properties of the simple star connection.

Networks of the type shown in Figs. 3 and 4 and also the filter of Figs. 1 and 2 belong to an important class of wave filter which is described by O. J. Zobel, "Theory and design of uniform and composite electric wave filters," Bell System Technical Journal, Vol. II, No. 1, January 1923, to which article reference may be made for detailed information regarding the properties of these filters.

Other arrangements are possible whereby the effect of undesired mutual inductances may be compensated in accordance with the principles of the present invention, the scope of which is defined by the appended claims.

In the claims the term "mesh" is used to describe the elementary portions, or closed circuits, into which an electrical network is divided by its various branches. As is customary in dealing with electrical networks, the meshes are identified with the circuit branches by which the various loops of the network are bounded, rather than with the spaces enclosed by these branches.

What is claimed is:

1. In a wave transmission network, a plurality of meshes coupled by impedances, additional coupling impedance between at least one pair of meshes due to the configuration of impedance elements included in said pair of meshes, and means for neutralizing said additional coupling impedance comprising an impedance having opposite sign and equal magnitude thereto at all frequencies.

2. In a wave transmission network, a plurality of meshes coupled by impedances, additional coupling impedance between at least one pair of meshes due to the mutual inductance of inductance elements included in said pair of meshes, and means for neutralizing said additional coupling impedance comprising an inductance having opposite sign and equal magnitude thereto.

3. In a wave transmission network, a plurality of meshes coupled in tandem by coupling impedances, additional coupling between at least one pair of adjacent meshes, said additional coupling being due to mutual inductances between elements included in separate branches of said pair of meshes whereby an effective negative inductance is introduced into a third branch of said pair of meshes, and means for neutralizing said additional coupling comprising an inductance included in said third branch having equal magnitude to said effective inductance.

4. In a wave transmission network, a plurality of meshes coupled in tandem by coupling impedances, additional coupling between at least one pair of adjacent meshes, said additional coupling being due to mutual inductances between elements included in separate branches of said pair of meshes whereby an effective negative inductance is introduced into a third branch of said pair of meshes, and means for neutralizing said additional coupling to a desired degree, said

means comprising an inductance included in said third branch.

5. In a wave transmission network, a plurality of meshes connected in tandem, constituted by series impedances and shunt coupling impedances, additional coupling impedance between at least one pair of consecutive series impedances, said additional coupling being due to the mutual inductance of inductive elements included therein whereby an effective negative inductance is introduced into a shunt coupling impedance, and means, comprising an inductance included in said shunt impedance, for neutralizing to a desired degree the effective inductance due to said additional coupling.

6. In a wave transmission network, a plurality of meshes coupled by impedances, at least one pair of said meshes comprising a star-connected group of three inductances which are mutually inductive by virtue of their physical configurations, and the component inductances of said group being so proportioned that a desired effctive inductance in one branch of the star-connection is secured as the resultant of the self inductance of said branch and the several component mutual inductances of said group.

7. In a wave transmission network, a plurality of meshes coupled by impedances, at least one pair of said meshes comprising a star-connected group of three inductances which are mutually inductive by virtue of their physical configurations, and the component self and mutual inductances of said group being so proportioned that the effective inductance of one branch of the group is reduced to zero.

8. In a wave filter, a plurality of meshes connected in tandem and constituted by series impedances and shunt coupling impedances, at least two pairs of said meshes having included therein inductances forming three branch star-connected systems, each of said systems being physically constructed in the form of a concentrically wound, multiple winding solenoid, the effective inductances in each branch being determined to desired values by the component self and mutual inductances of the windings comprising said solenoid, and said solenoids being disposed in mutually non-inductive relationships.

9. A wave filter comprising a plurality of circuit meshes in which are included capacity elements and solenoidal inductance elements, and means for neutralizing the coupling between two of said meshes due to the external fields of said solenoidal inductances, said means comprising an inductance coil connected to constitute an opposing coupling between said two meshes.

10. In a wave filter the combination comprising a plurality of groups of concentric co-axial solenoids, said groups being disposed in mutually non-inductive relationship, the individual solenoids of each of said groups being included in separate branches of the wave filter, and the mutual inductances of said individual solenoids being proportioned to cooperate with their self inductances in producing a predetermined wave attenuation characteristic.

11. In a wave filter the combination comprising three groups of concentric co-axial solenoids having their centres in line and their axes mutually perpendicular, each group comprising three individual solenoids, said individual solenoids being included in separate adjacent branches of the wave filter and the inductance of one of said individual solenoids being arranged to neutralize the effect of the mutual inductance between the other solenoids of the group with respect to wave transmission through the filter.

In witness whereof, I hereunto subscribe my name this 23 day of January, A. D., 1925.

TIMOTHY E. SHEA.