Dec. 27, 1927.

1,654,071

R. W. DE MONTE ET AL

ELECTRICAL WAVE FILTER

Filed Oct. 7, 1924

Fig. 1

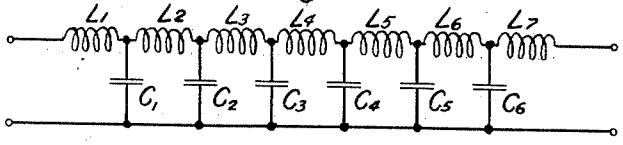


Fig. 2

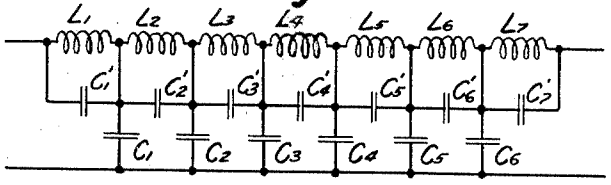


Fig. 3

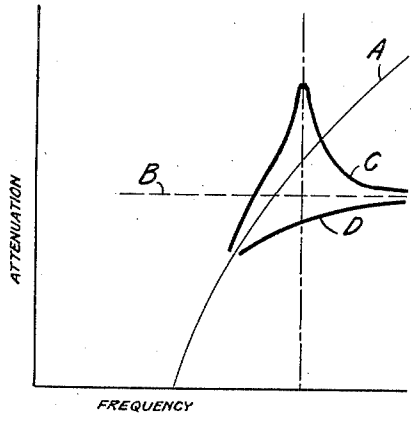


Fig. 4

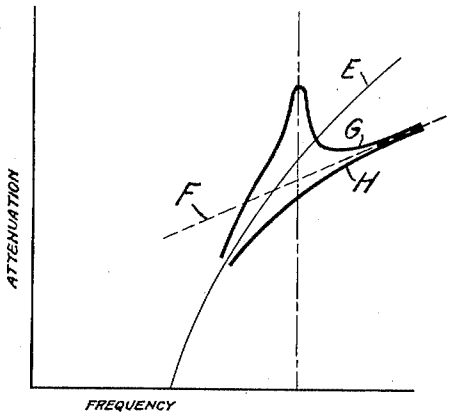


Fig. 5

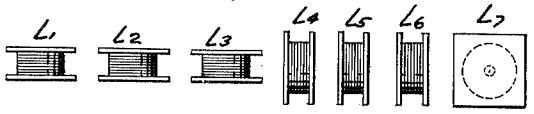
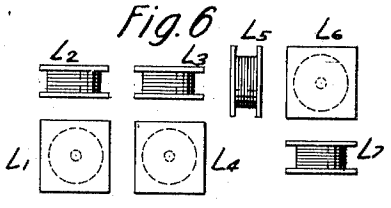


Fig. 6



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UNITED STATES PATENT OFFICE.

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ELECTRICAL WAVE FILTER.

Application filed October 7, 1924. Serial No. 742,125.

This invention relates to electrical wave filters, and more particularly to means by which the effects of undesirable reaction between the sections of the filter may be avoided or reduced.

The type of electrical wave filter to which this invention applies is that comprising a series of sections, each of which includes impedance elements so arranged as to attenuate certain frequencies and to transmit others without substantial attenuation. As each section is designed to transmit frequencies within a selected range of frequencies and more or less attenuate frequencies outside of this range, the accumulated effect of the successive sections of the filter is to prevent certain frequencies from reaching the output terminals of the filter, while permitting the passage of others thereto. In order to accomplish this result most effectively, it is desirable that the transmission of electrical energy be entirely between immediately adjacent points in the filter, that is, that energy, at least of the frequency desired to be suppressed, should not pass from one section of the filter to other sections without undergoing the attenuating effect of the impedance elements of every section between the two points. However, since in general each section of an electrical filter contains an inductance element, there is an opportunity for injurious reaction between sections of the filter through the external electromagnetic fields of these inductance elements.

This reaction or mutual inductance may be suppressed to some extent by the use of closed core coils for the inductance elements, but in general the interaction will still exist to some extent, and therefore to interfere with the efficient operation of the filter. Toroidal inductance coils having practically no external magnetic fields have also been used, but coils of this type are expensive to wind, and have a high effective resistance in relation to their inductance, as compared with straight core coils of proper design. It is therefore often desirable to use straight core inductances which can be cheaply constructed and which result in a small amount of power dissipation. Such inductances, however, have an inherently large stray magnetic field. In order to somewhat reduce the effect of this stray magnetic field, the inductance coils of successive sections have been arranged in groups of three, with the axes of the coils of the group in the same plane and perpendicular to each other. This, however, has not been found fully effective, and particularly fails when one of two corresponding coils of successive groups, whose axes are necessarily either parallel or on the same line, is part of an arrangement designed to resonate at or near the cut-off frequency of the filter.

It is an object of this invention to improve wave filters of the above described type, particularly those employing straight core inductances, by reducing the effects of mutual inductance between elements of different sections. This is accomplished by an arrangement of the inductances by which mutual inductance between selected non-adjacent sections of the filter is substantially suppressed.

In the accompanying drawings, Fig. 1 shows a simple low pass filter; Fig. 2 shows a low pass filter of the composite type; Figs. 3 and 4 are attenuation frequency curves for the filter shown in Fig. 1; and Figs. 5 and 6 show two methods of mounting the coils of the filter shown in Figs. 1 and 2, in accordance with this invention.

The type of low pass electrical wave filter illustrated in Fig. 1 comprises a number of similar inductances L_1, and L_2, etc. in series and equal capacities C_1, C_2, etc. in shunt thereof. As is well known, each section of this type of filter comprising an inductance and capacity will freely transmit currents of a frequency below a certain value known as the cut-off frequency and will more or less attenuate frequencies above this value. Each section of the filter will also shift the phase of the transmitted frequencies. The currents above the cut-off frequency will therefore decrease in strength from section to section, the total attenuation for the filter depending upon the number of sections, while the currents below the cut-off frequency will be transmitted in substantally undiminished strength, although with a shifting of phase from section to section. As noted above, it has been realized that the discriminating effect of the filter would be reduced by mutual inductance between adjacent coils, for instance, L_1 and L_2, since this would result in restoring to the frequency to be attenuated more or less of the energy which the first sec-

tion of the filter is intended to check, and in view of this the expedient has been adopted with some success of placing adjacent coils with their axes at right angles to each other.

According to the present invention, however, less attention in the arrangement of the straight core coils which constitute the inductances L_1, L_2, etc., is paid to possible mutual inductance between adjacent inductance coils than to mutual inductance between coils more or less widely separated in the filter. The arrangement shown in Fig. 5 is a preferred form. In this figure, the inductance coils used in the filter are arranged so that the first three, L_1, L_2 and L_3, have their axes parallel; the second three, L_4, L_5 and L_6, are arranged coaxially with their axes at right angles to the axes of the coils L_1, L_2 and L_3; while the last coil, L_7, is arranged with its axis perpendicular both to the axes of L_1, L_2 and L_3 and to the common axis of L_4, L_5 and L_6. If a larger number of coils were used, the same arrangement would be continued, that is, the eighth and ninth coils would have their axes parallel to that of coil 7, while the axes of the tenth, eleventh and twelfth coils would be parallel to the axes of the coils L_1, L_2 and L_3, which would be comparatively widely separated in the filter from the tenth, eleventh and twelfth coils. In the arrangement of Fig. 5, coils L_1, L_4 and L_7 may be regarded as a group of coils widely separated in the filter, the coils L_2 and L_5 may be regarded as a second group of widely separated coils and L_3 and L_6 as a third group. In each case it will be seen that the members of the group have their axes at substantially right angles to each other so that there will be no appreciable mutual inductance between the respective coils of the group.

The beneficial effect of this arrangement on the functioning of the filter will perhaps be more readily understood by a consideration of Figs. 3 and 4.

In Fig. 3, curve A indicates the normal attenuation of the filter on the assumption that there is no mutual inductance between the coils of the different sections; curve C represents the results upon the attenuation of mutual inductance between coils L_1 and L_7 when the normal current at a given frequency in the two coils is in opposition; while curve D represents the attenuation when the current in the two coils is in phase.

It will be noted that although under the conditions of curve C the attenuation is greater than normal at some frequencies, yet both curve C and curve D quickly approach an asymptotic value indicated by line B and that this represents, for most of the frequencies it is desired to suppress, a substantially lower attenuation than the normal attenuation of the filter. Under these circumstances the efficiency of the filter will be much reduced for frequencies a short distance beyond the cut-off frequency.

In Fig. 4 there is represented a condition when there is mutual inductance between two widely separated coils other than end coils. Curve E represents the normal attenuation of the filter, G the attenuation when the coils under consideration are in opposition for the particular frequency, and H the attenuation when these currents are in phase. The broken line F represents the asymptotic value to which the curves G and H approach. While the peaks in attenuation due to mutual inductance under the conditions represented by Fig. 4 are less than in Fig. 3, still it will be seen that the loss in efficiency is substantial.

By the present invention the curves C and D in Fig. 3 and curves G and H in Fig. 4 may be made to approach more or less closely the normal curves A and E, that is to say, the normal efficiency of the filter is substantially restored.

The mutual inductance between the coils may also reduce somewhat the strength of the currents which the filter is designed to transmit by bringing in opposition through phase differences the currents in different sections. The seriousness of this effect depends upon the phase differences of the currents in the coils involved, and this in turn, as noted above, depends upon the separation of the coils along the line of the filter. This undersirable effect is also substantially reduced by the present invention.

Fig. 2 represents a modification of the filter of Fig. 1, in which inductance L_1 and capacity C'_1 comprise a circuit anti-resonant to one of the frequencies it is desired particularly to suppress, L_2 and C'_2 are anti-resonant to another frequency it is desired particularly to suppress, and the remaining sets of inductance and capacity elements in parallel therewith are similarly adjusted to resonate at a selected frequency to be suppressed. In this arrangement, each section of the filter will to some extent attenuate all frequencies above the cut-off frequency but will be particularly efficient at the frequency at which its parallel arrangement of inductance and capacity is adjusted to resonate. The attentuation throughout the whole band beyond the cut-off frequency will therefore be made substantially greater and the cut-off sharper than in the case of the filter in Fig. 1.

The present invention is particularly effective in suppressing the detrimental effect of mutual inductances between coils of the filter of Fig. 2 where L'_1 and C'_1 for instance, resonate at a frequency above the cut-off frequency. It has been found in this case that mutual inductance between L'_1 and L'_7 results in a very considerable annulment

of the attenuation effect of the filter at the frequency for which the circuit L'_1, C'_1 is anti-resonant; the intervening sections of the filter may be in effect very effectively shunted so far as the attenuation of this particular frequency is concerned.

As in the case of the simple low pass filter of Fig. 1, the arrangement of coils shown in Fig. 5 is an effective embodiment of the present invention applied to the composite filter of Fig. 2. However, in the case of both forms of filters as well as other forms, practical considerations of economy of space may require a modification of the arrangement shown in Fig. 5. Fig. 6 shows one example of such a modified arrangement. This arrangement is adapted for a filter in which the coils L_2 and L_3 resonate near the cut-off frequency. It will be noted that the axes of other coils widely separated from coils L_2 and L_3 in the filter, such as L_5, L_6 and L_7, are at an angle of low mutual inductance to the axes of coils L_2 and L_3, and therefore undesirable inductive effects from these two coils will be minimized, or greatly suppressed. Mutual induction between a given pair of coils comparatively remote from each other in the network, such as L_1 and L_4, for instance, may be of minor importance, in which case these two coils may have their axes parallel. The arrangement in Fig. 6 is merely by way of example, and other modified arrangements of the inductance coils will, with the above explanation of the invention, be apparent to those skilled in the art.

It is obvious that although the invention has been particularly described as embodied in low pass filters, yet it is equally applicable to filters of other types.

What is claimed is:

1. The method of improving the operation of a multi-section electrical network having elements capable of interaction by their external magnetic fields, which comprises reducing to a greater extent the interaction between elements electrically more separated than the interaction between adjacent elements.

2. The method of improving the operation of multi-section electrical networks having inductance coils in a plurality of sections capable of interaction by their external magnetic fields, which comprises reducing the mutual inductance between the coils in sections electrically remote from each other to a greater extent than between adjacent coils.

3. The method of improving the operation of a multi-section electrical network having an inductance coil in each section, which comprises positioning said inductance coils in space with more consideration of substantial avoidance of inductive interaction between coils widely electrically separated in the network than of preventing inductive interaction between coils of electrically adjacent sections.

4. A wave filter comprising a plurality of sections, each containing an inductance element, one of said sections being adjusted to resonate at a frequency near the cut-off frequency of the wave filter, said section having its inductance element arranged in a non-inductive relation to the inductance elements of sections electrically remote therefrom in the network of the filter.

5. A wave filter comprising a plurality of sections, each containing a solenoidal inductance element one of said sections being adjusted to resonate at a frequency near the cut-off frequency of the wave filter, the inductance element of said section being particularly arranged to have no inductance mutual with elements of sections electrically remote therefrom in the filter.

6. In a wave selective network of the type having a plurality of sections, solenoidal inductance coils forming a group of more than three in number, whereby mutual inductances between certain coils are unavoidable, the coils of said group being arranged with their centers in line, the physical sequence corresponding generally to the electrical sequence, and being divided into three successive sub-groups, the coil axes in each sub-group being parallel to each other and perpendicular to the coil axes in each other sub-group.

In witness whereof, we hereunto subscribe our names this 2nd day of October A. D., 1924.

ROBERT W. DE MONTE.
TIMOTHY E. SHEA.