

April 15, 1952

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2,592,721

FILTER USING MAGNETOSTRICTIVE RING

Filed April 22, 1950

2 SHEETS—SHEET 1

FIG. 1

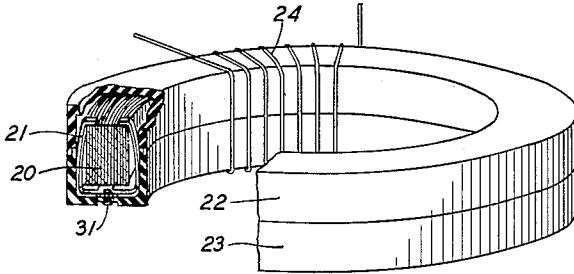


FIG. 1A

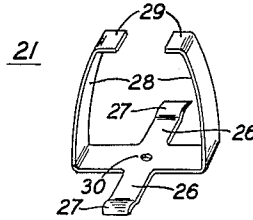


FIG. 2

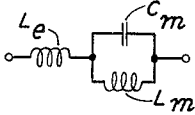


FIG. 3

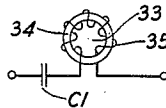


FIG. 4

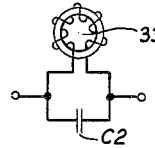


FIG. 5

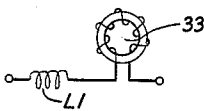


FIG. 6

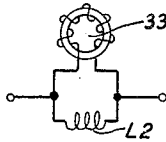


FIG. 7

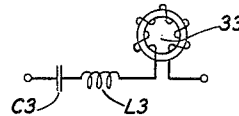


FIG. 8

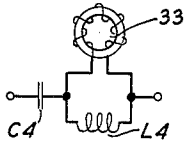


FIG. 9

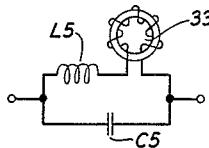


FIG. 10

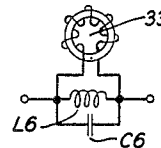


FIG. 11

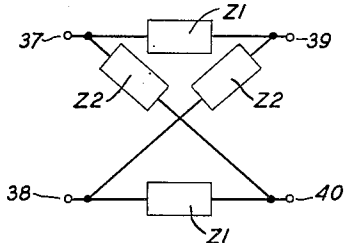
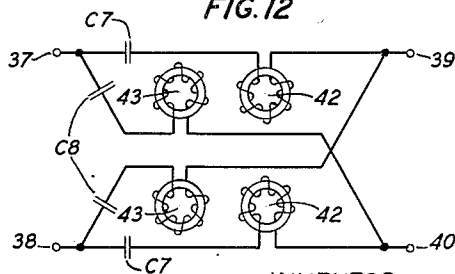


FIG. 12



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FIG. 13

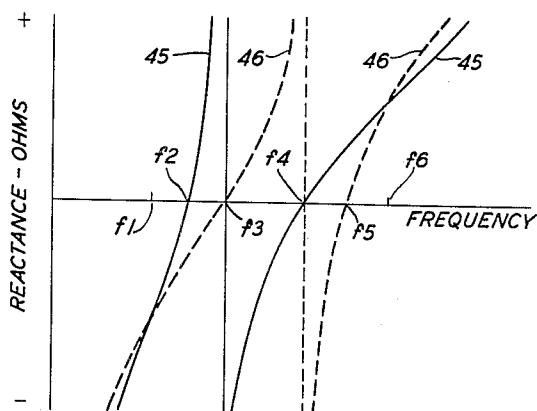


FIG. 14

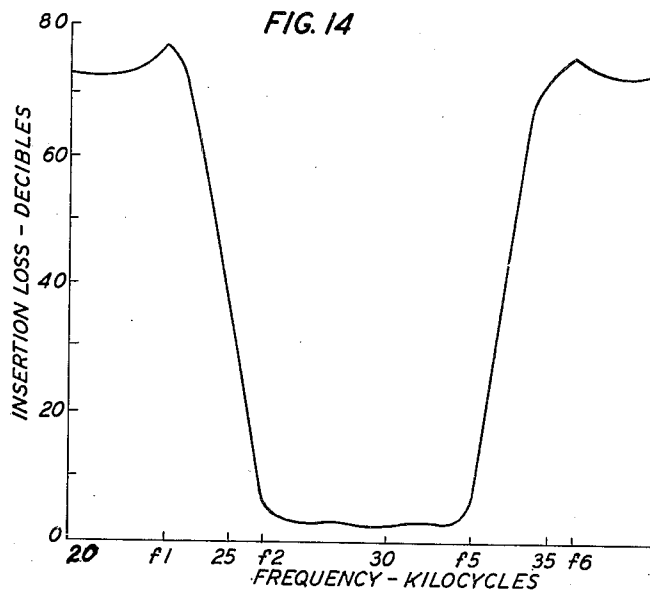
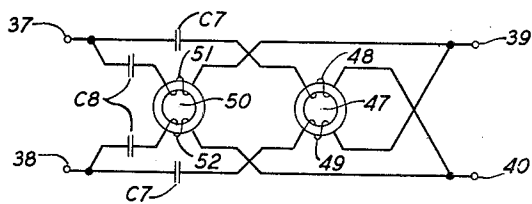


FIG. 15



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FILTER USING MAGNETOSTRICTIVE RINGS

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Application April 22, 1950, Serial No. 157,531

9 Claims. (Cl. 171-209)

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This invention relates to wave transmission networks and more particularly to wave filters which comprise vibratory impedance elements of the magnetostrictive type.

An object of the invention is to improve the transmission characteristic of a wave filter utilizing magnetostrictive vibrators by broadening and flattening the transmission band, increasing the discrimination, and reducing the loss within the band.

Other objects are to simplify the construction and reduce the size and cost of such filters.

The illustrative embodiment of the invention shown is a wave filter comprising a plurality of magnetostrictive vibrators arranged to form a lattice structure which will efficiently transmit a preselected band of frequencies while effectively suppressing frequencies on either side of the band. A separate vibrator may be used in each of the four branches of the lattice or, preferably, only two vibrators, each with two windings, may be used. In the latter case one vibrator furnishes a reactive impedance in each of the series branches of the lattice and the other vibrator supplies a reactive impedance in each of the diagonal branches. In order to get the desired transmission characteristics one or more capacitances or inductances, connected either in series or in parallel, may be associated with each of the impedance branches of the lattice network.

Each of the magnetostrictive vibrators comprises a closed, permanently magnetized core mounted within a hollow housing upon the outside of which one or more windings are placed. The use of a closed core results in a lower ratio of eddy current resistance to inductance than when an open core is employed. The quality factor, Q , of the vibrator is thus improved. The core is mounted out of contact with the inner walls of the housing in order to prevent mechanical damping of the core when it is in vibration. Three or more spring clips, circumferentially spaced on the core, may be used for this purpose. Such a construction further increases the Q of the vibrator. Increasing the Q increases the discrimination of the filter, widens the transmission band, and reduces and flattens the loss within the band. The core is made of a permanently magnetized alloy which has been subjected to a special treatment, comprising working and heating, to provide an efficient magnetostrictive element operating entirely on remanence without the aid of an external polarizing device. Thus, the filter is simplified

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in construction because it requires no permanent magnets or batteries for supplying polarizing flux. The core is preferably of laminated construction. It may be formed of thin spirally-wound tape, previously subjected to stretching to flatten it and thinly coated with insulating material. The core is consolidated by vacuum impregnating it in a resin or plastic of highly penetrating properties and is so cured that the composite structure is radially vibratile as a whole. With such a construction parasitic vibrations and unwanted modes of vibration are substantially eliminated, over a wide range of frequencies, and the transmission characteristic of the filter greatly improved.

The nature of the invention will be more fully understood from the following detailed description and by reference to the accompanying drawings, of which:

Fig. 1 is a perspective view, partly cut away, of a magnetostrictive vibrator of the type used in the invention;

Fig. 1A is an enlarged perspective view of a spring clip used to hold the core of the vibrator;

Fig. 2 is an equivalent electrical circuit representing the vibrator shown in Fig. 1;

Figs. 3 through 10 are schematic circuits of a variety of two-terminal impedance branches each comprising a magnetostrictive vibrator and a capacitance, an inductance, or both, connected in series or in parallel therewith;

Fig. 11 is a schematic circuit of a lattice-type transmission network in accordance with the invention, the branches of which may be constituted by any of the two-terminal impedances shown in Figs. 2 through 10;

Fig. 12 is a schematic circuit of a lattice network employing branches of the type shown in Fig. 3;

Fig. 13 gives the reactance-frequency characteristics of the impedance branches of the lattice of Fig. 12 when designed to provide a band-pass filter characteristic;

Fig. 14 is an insertion loss-frequency characteristic of a filter comprising two tandem-connected sections of the type shown in Fig. 12; and

Fig. 15 is a schematic circuit of a modified form of the lattice network of Fig. 12 employing two magnetostrictive vibrators each of which furnishes two equal reactive impedances.

Taking up the figures in more detail, Fig. 1 shows a magnetostrictive vibrator comprising a ring-shaped core 20 magnetized circumferentially to a predetermined flux density and

mounted by means of a plurality of spring clips 21 within a hollow, annular housing made of non-magnetic material in two halves 22 and 23 upon the outside of which are placed one or more toroidal windings 24. The magnetostrictive core 20 is made of an alloy comprising cobalt and iron, preferably with a small amount of vanadium added. A preferred composition of the alloy is 49 per cent by weight of cobalt, 49 per cent by weight of iron and 2 per cent by weight of vanadium, but these proportions may be varied. The alloy is rolled into a thin tape by cold working, and is flattened by heating to a temperature of between about 500° C. and about 600° C. and applying a tension of about 13,000 pounds per square inch. A very thin layer of silica dust, preferably not exceeding 0.00005 inch in thickness, is cataphoretically deposited upon the tape to provide insulation between adjacent turns, and then the tape is wound into a tight spiral to form the core 20. The core is then heat treated for from one to five hours in an atmosphere of hydrogen at a temperature between about 550° C. and about 600° C. The alloy treated as described above is characterized by an unusually high magnetostrictive constant at and below remanence, with a coercive force of about 20 oersteds or more. Therefore, magnetostrictive elements made of this material and permanently magnetized do not require battery supply circuits or permanent magnets to polarize them and will carry heavy alternating currents without demagnetizing, thus rendering them especially suitable for use as reactive elements in wave filters. The core is consolidated by vacuum impregnating it in a highly penetrating resin or plastic, such as a phenolic condensation product, and cured under heat for a period of about two hours. The core cured in this way is very rigid and it will, therefore, vibrate radially as a whole when an alternating electromotive force is applied to the winding 24. Undesired modes of vibration are thus substantially eliminated.

The clips 21 are made of thin, resilient spring metal. As shown to an enlarged scale in Fig. 1A, each comprises two oppositely-extending tongues 26, slightly turned up at their ends 27, and two oppositely-disposed fingers 28 the ends 29 of which are bent inwardly. A central hole 30 is provided for securing the clip 21 to the lower half 23 of the housing by means of a rivet 31, as shown in Fig. 1. Preferably three or more of the clips 21 are provided, with approximately equal circumferential spacing around the housing. With the upper half 22 of the housing removed, the core 20 is inserted within the clips 21 while the fingers 28 are sprung apart sufficiently. When in place, the core 20 rests upon the turned-up ends 27 of the tongues 26 and is gripped on top by the ends 29 of the fingers 28. Thus, the core 20 is securely held but does not touch or rub against the inner walls of the housing 22, 23 and is, therefore, free to vibrate.

Fig. 1 shows only a part of the toroidal winding 24, which ordinarily extends circumferentially all the way around the core. If additional windings are required, they may be placed on top of the one shown. For two equal windings, a bifilar construction may be employed.

Fig. 2 gives an equivalent electrical circuit representing the vibrator of Fig. 1 when its impedance is measured at the terminals of the winding 24. The circuit comprises an inductance L_e connected in series with the parallel combina-

tion of the capacitance C_m and a second inductance L_m . The inductance L_e is the electrical inductance of the winding 24 when the core 20 is blocked. The elements C_m and L_m are associated with the mechanical vibration of the core 20 and are related, respectively, to its mass and stiffness.

Other useful two-terminal impedances may be provided by associating one or more additional reactive elements with the magnetostrictive vibrator. These added elements may be either inductances or capacitances, or both, and they may be connected either in series or in parallel with the vibrator. Figs. 3 through 10 are schematic circuits showing examples of such reactances associated with a magnetostrictive vibrator 33 represented schematically as a closed core 34 with a single winding 35 thereon. In Fig. 3 a capacitance $C1$ is connected in series with the vibrator 33 and in Fig. 4 the vibrator is shunted by a capacitance $C2$. In like manner, Fig. 5 shows an inductance $L1$ in series with the vibrator and Fig. 6 shows an inductance $L2$ in parallel therewith. In Fig. 7 both an inductance $L3$ and a capacitance $C3$ are connected in series with the vibrator. Fig. 8 shows an inductance $L4$ shunting the vibrator, and a capacitance $C4$ connected in series with the combination. In Fig. 9 an inductance $L5$ is connected in series with the vibrator, and a capacitance $C5$ shunts the combination. Fig. 10 shows an inductance $L6$ and a capacitance $C6$ both connected in parallel with the vibrator 33.

In accordance with the invention any of the two-terminal impedance branches described above may be incorporated in any of the conventional transmission network circuits. For example, Fig. 11 shows schematically a four-terminal network comprising two equal series branches $Z1$ and two equal diagonal branches $Z2$ connected between a pair of input terminals 37, 38 and a pair of output terminals 39, 40 to form a lattice-type structure. The branches $Z1$ and $Z2$ may have any of the configurations shown in Figs. 2 through 10. The network of Fig. 11 may be designed to provide any desired transmission characteristic, such, for example, as a band-pass filter, by properly proportioning the impedances of the branches $Z1$ and $Z2$.

When each of the four impedance branches of the lattice network of Fig. 11 is of the type shown in Fig. 3, the circuit shown schematically in Fig. 12 results. Each series branch comprises a magnetostrictive vibrator 42 and a capacitance $C7$ connected in series, and each diagonal branch is made up of a vibrator 43 in series with a capacitance $C8$. The reactance-frequency characteristic of each branch has two resonant frequencies, at which the reactance passes through zero, and an intermediate anti-resonant frequency, at which the reactance is theoretically infinite. In order to provide a band-pass filter, the anti-resonance of each of the series branches is made to coincide with the lower resonance of each of the diagonal branches and the antiresonance of each diagonal branch is made to coincide with the upper resonance of each series branch. As is well known, both series branches may be interchanged with both diagonal branches, the only effect being a reversal of the output current.

Fig. 13 shows typical reactance-frequency characteristics for the series and diagonal branches of the network of Fig. 12 when designed as a band-pass filter. The solid-line characteristic 45, with resonances at the frequencies $f2$ and $f4$ and an antiresonance at $f3$, represents the

series branch, and the broken-line curve 46, with resonances at f_3 and f_5 and an antiresonance at f_4 , represents the diagonal branch, or vice versa. The transmission band occurs between the frequencies f_2 and f_5 , in the region where the reactances of the branches are of opposite sign, and attenuation peaks occur at the frequencies f_1 and f_6 , where the reactances are equal. A typical insertion loss-frequency characteristic for two tandem-connected filter sections of the type shown in Fig. 12 is given in Fig. 14. It is seen that the loss within the transmission band, between the frequencies f_2 and f_5 , is comparatively small and quite flat, that the cut-offs are sharp, and the discrimination large.

In designing a wave filter of the type just described, the cut-off frequencies f_2 and f_5 will ordinarily be given and the intermediate frequencies f_3 and f_4 may be estimated. As explained in connection with Fig. 13, each series impedance branch must be antiresonant at f_3 and each diagonal branch at f_4 . An antiresonance in the electrical impedance of the branch coincides with the frequency f_0 of natural resonance of the magnetostrictive core 20 when vibrating radially. The frequency f_0 is determined primarily by the mean diameter D of the core, Young's modulus E for the core material, and the density ρ of this material, in accordance with the formula

$$f_0 = \frac{1}{\pi D} \sqrt{\frac{E}{\rho}}$$

The axial height and radial thickness of the core do not affect materially the resonant frequency. Each core in the series branches will, therefore, have a mean diameter chosen to provide a natural resonance in the radial mode at the frequency f_3 , and each core in the diagonal branches will be resonant at f_4 . The values of the capacitances C_7 and C_8 and the windings 24 will then be adjusted to give the required reactance curves 45 and 46. By properly adjusting the mass of the core 20, the values of C_7 and C_8 , and the windings 24 which provide the inductances L_e , the filter may be designed to have any desired image impedance, within wide limits. In many cases this possibility dispenses with the need for providing matching impedance transformers at the ends of the filter.

As a specific example, a lattice filter of the type shown in Fig. 12 has been designed to have a transmission band 6.5 kilocycles in width with a mid-band frequency of 29.5 kilocycles, as shown in Fig. 14. The core 20 was made of an alloy comprising 49 per cent by weight of cobalt, 49 per cent by weight of iron and 2 per cent by weight of vanadium, with a Young's modulus of 24×10^{11} in centimeter-gram-second units and a density of 8.19. The core 20 in each series-branch resonator 42 had a mean diameter of 2.485 inches and a mechanical resonance at 27.4 kilocycles. In each diagonal-branch resonator 43 the core had a mean diameter of 2.165 inches, placing the natural resonance at 31.4 kilocycles. In each core the axial height and the radial thickness were approximately 20 per cent and 10 per cent, respectively, of the mean diameter D , which for this case gave a maximum value of Q . The coil winding 24 consisted of two hundred turns of No. 24 enameled copper wire.

Fig. 15 shows the lattice network of Fig. 12 modified to effect a saving in component elements. In Fig. 15 the two separate series-branch

vibrators 42, 42 have been replaced by a single vibrator 47, with two equal windings 48 and 49 connected, respectively, in each of the series branches. Similarly, the two diagonal-branch vibrators 43, 43 have been replaced by the vibrator 50, having equal windings 51 and 52 connected, respectively, in each of the diagonal branches. In order to keep these windings equal they may be applied as a bifilar winding. The capacitances C_7 in the diagonal branches and C_8 in the series branches in Fig. 15 are the same as the corresponding ones in Fig. 12. The network of Fig. 15 may be designed to have the same transmission characteristic as that obtainable with the one shown in Fig. 12. Because of the economy of elements, Fig. 15 is a preferred embodiment of the invention.

What is claimed is:

1. A magnetostrictive vibrator comprising a radially vibratile, ring-shaped, magnetic core composed of thin, spirally-wound, magnetic tape having thereon a layer of silica dust not exceeding 0.0005 inch in thickness, a hollow, annular housing surrounding but not touching said core, at least three spring clips circumferentially spaced around said housing and secured thereto for holding said core in position while permitting free radial vibration thereof, and a toroidal winding surrounding said housing, each of said clips comprising a spring member which bears upon one face of said core and a second spring member which bears upon another face of said core and said core being impregnated with a phenolic condensation product and magnetized circumferentially to a predetermined flux density, whereby it is polarized solely by its own residual magnetism.

2. A magnetostrictive device comprising an annular, radially vibratile core of magnetostrictive material, a hollow, annular housing surrounding but spaced from said core, a toroidal winding surrounding said housing, and resilient means located between and in contact with said core and said housing at a plurality of circumferentially spaced points for maintaining the spacing between said core and said housing for all positions of said device while permitting free radial vibration of said core.

3. A device in accordance with claim 2 in which said resilient means are located at at least three points with approximately equal circumferential spacing around said housing.

4. A device in accordance with claim 2 in which said resilient means comprise a plurality of clips secured to said housing, each of said clips comprising a spring member which bears upon one face of said core and a second spring member which bears upon a second face of said core.

5. A device in accordance with claim 2 in which said resilient means comprise a plurality of clips secured to said housing, each of said clips comprising a pair of oppositely extending tongues which bear upon one face of said core and a pair of oppositely disposed fingers which grip the opposite face of said core.

6. A device in accordance with claim 2 in which said core is magnetized circumferentially to a predetermined flux density, whereby it is polarized solely by its own residual magnetism.

7. A device in accordance with claim 2 in which said core is composed of thin, spirally-wound, magnetic tape having thereon a layer of silica dust not exceeding 0.00005 inch in thickness.

8. A device in accordance with claim 2 in which said core is impregnated with a phenolic condensation product.

9. A device in accordance with claim 2 in which said core is composed of an alloy of 49 per cent iron, 49 per cent cobalt and 2 per cent vanadium.

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