Aug. 22, 1939. W. P. MASON 2,170,206

ELECTRICAL AND ELECTROMECHANICAL SYSTEM EMPLOYING MAGNETOSTRICTIVE DEVICES

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FIG. 1

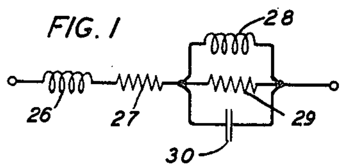

FIG. 2

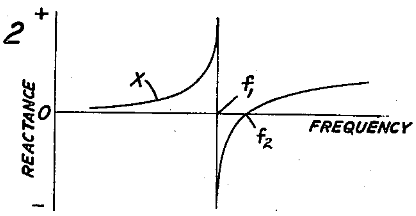

FIG. 3

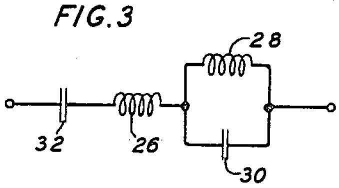

FIG. 4

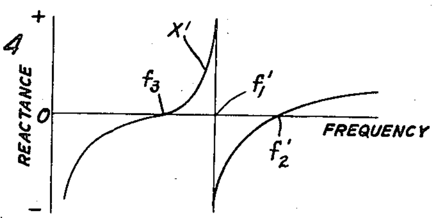

FIG. 5

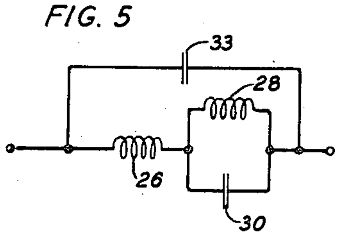

FIG. 6

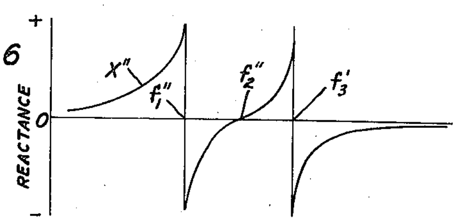

FIG. 7

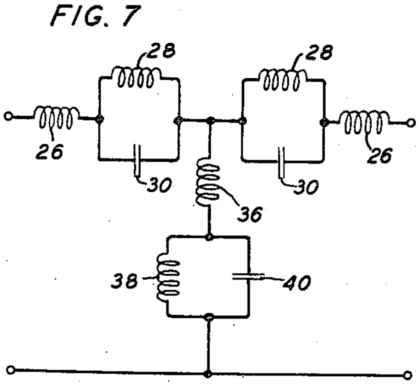

FIG. 8

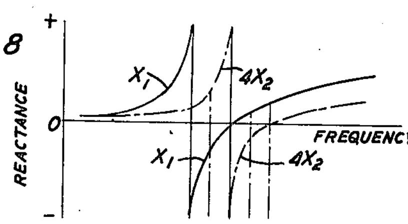

FIG. 9

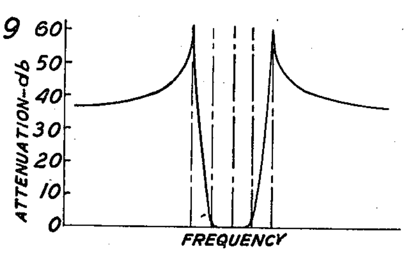

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FIG. 10

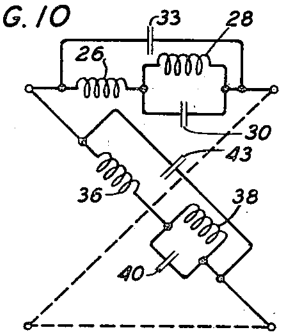


FIG. 11

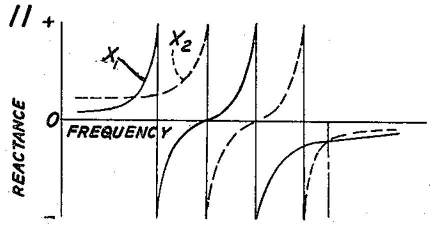


FIG. 12

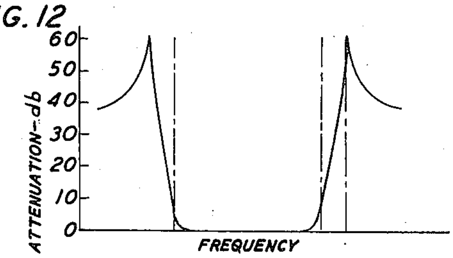


FIG. 13

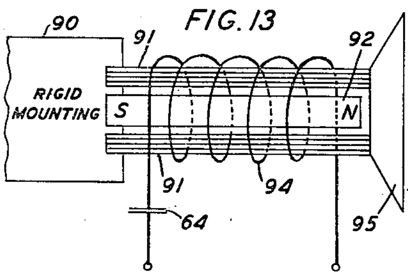


FIG. 14

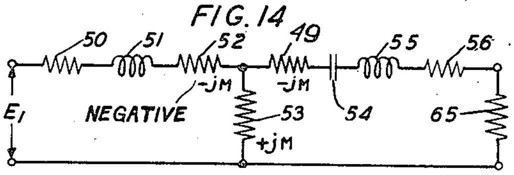


FIG. 15A

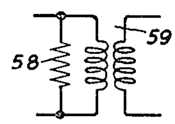


FIG. 15B

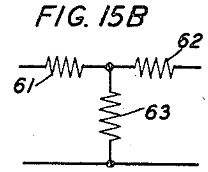


FIG. 16

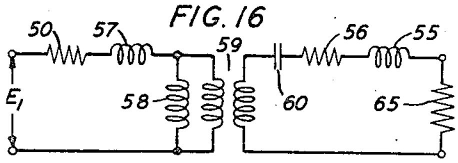


FIG. 17

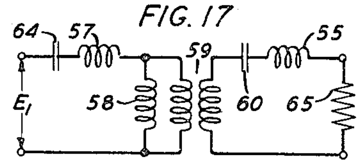
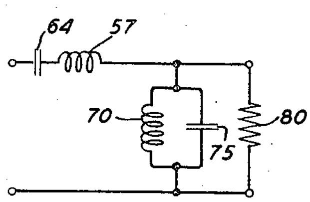


FIG. 18



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ELECTRICAL AND ELECTROMECHANICAL SYSTEM EMPLOYING MAGNETOSTRICTIVE DEVICES

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FIG. 19

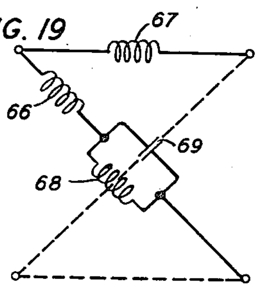


FIG. 21

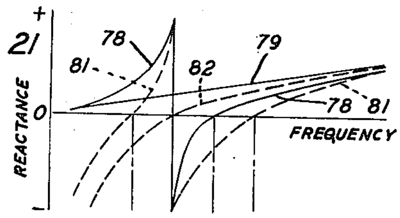


FIG. 22

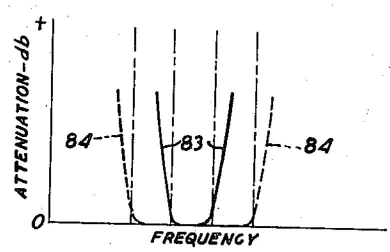


FIG. 20

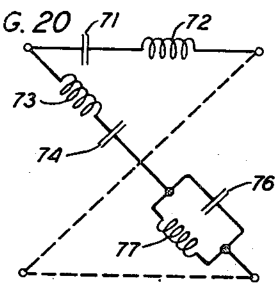


FIG. 26

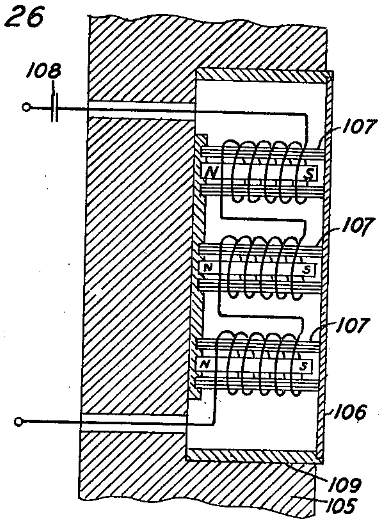


FIG. 23

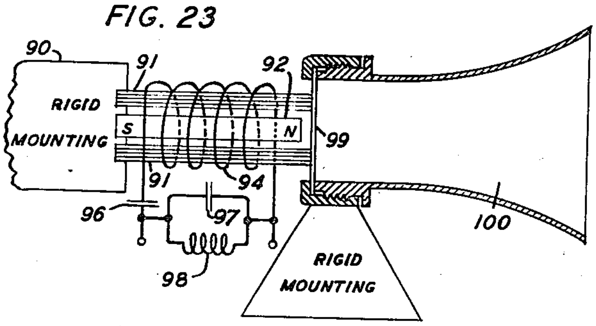


FIG. 24

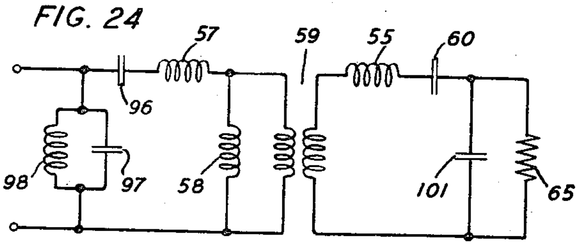
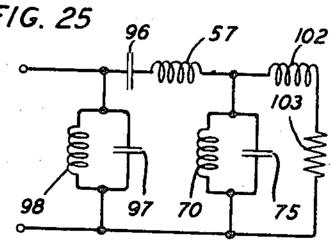


FIG. 25



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UNITED STATES PATENT OFFICE

2,170,206

ELECTRICAL AND ELECTROMECHANICAL SYSTEM EMPLOYING MAGNETOSTRICTIVE DEVICES

Warren P. Mason, West Orange, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application May 8, 1937, Serial No. 141,485

10 Claims. (Cl. 178—44)

This invention relates to the use of magnetostrictive devices in electrical and electromechanical systems.

In a copending application of E. Lakatos, Serial No. 133,837 of March 30, 1937 it is shown that by suitable construction and design magnetostrictive devices may be produced which will have highly reactive characteristics and relatively small dissipative tendencies.

It is an object of this invention to utilize magnetostrictive devices of the type described in the above-mentioned copending application to particular advantage in reactive systems.

Another object of this invention is to provide new means of converting electrical energy, distributed over a wide range of frequencies, into acoustic or mechanical energy of corresponding frequency distribution with relatively small attenuation and distortion of the energy within said range of frequencies.

A further object is to provide methods of cooperatively associating magnetostrictive devices with non-magnetostrictive devices and methods of extending the field of usefulness of magnetostrictive devices.

Other objects and advantages of the invention will be apparent during the course of the following description.

In the accompanying drawings:

Fig. 1 shows an equivalent electrical network of a magnetostrictive device of the type contemplated in this invention;

Fig. 2 shows the electrical reactance of the device of Fig. 1;

Fig. 3 shows an equivalent electrical network of a magnetostrictive device in series with an electrical condenser;

Fig. 4 shows the electrical reactance of the combination of Fig. 3;

Fig. 5 shows the equivalent electrical network of a magnetostrictive device in parallel with an electrical capacity;

Fig. 6 shows the electrical reactance of the combination of Fig. 5;

Fig. 7 shows the equivalent electrical network of a T section of a ladder type filter employing magnetostrictive devices as reactive arms thereof;

Fig. 8 shows the recurrent series (Z_1) and recurrent shunt (Z_2) reactance-frequency diagrams for the structure of Fig. 7;

Fig. 9 shows the attenuation frequency characteristic of the structure of Fig. 7;

Fig. 10 shows a filter section of lattice type employing combinations of the type shown in Fig. 5;

Fig. 11 shows recurrent series (Z_1) and recurrent shunt (Z_2) reactance-frequency diagrams for the structure of Fig. 10;

Fig. 12 shows the attenuation-frequency characteristic of the structure of Fig. 10;

Fig. 13 shows in diagrammatic form an electromechanical system employing magnetostrictive elements to actuate a loud-speaker diaphragm;

Fig. 14 shows an electrical representation in schematic form of the system of Fig. 13;

Figs. 15A and 15B are illustrative of the process of transformation from electrical into mechanical energy involved in the system of Fig. 13;

Figs. 16 and 17 are refinements of the system of Fig. 13 which facilitate the analysis of the latter;

Fig. 18 shows the all-electrical equivalent network of the system of Fig. 13 with an electrical condenser in series therewith;

Fig. 19 shows the equivalent lattice structure for Fig. 18 without the series condenser;

Fig. 20 shows the equivalent lattice structure for Fig. 18;

Fig. 21 shows the recurrent series (Z_1) and recurrent shunt (Z_2) reactance-frequency diagrams for the structures of Figs. 19 and 20;

Fig. 22 shows the attenuation frequency characteristics of the structures of Figs. 19 and 20;

Fig. 23 shows an alternative form of loud-speaker of the same general class as that of Fig. 13 but employing a horn;

Fig. 24 shows an electrical representation in schematic form of the system of Fig. 23;

Fig. 25 shows the schematic of the system of Fig. 24 transformed to an equivalent all-electrical system;

Fig. 26 shows a system of this invention suitable for use as a submarine sound radiator.

It is shown in the copending application of E. Lakatos mentioned above that magnetostrictive devices may be constructed to simulate the impedance of an electrical network of the type shown in Fig. 1, inductance **26** representing the damped inductance of the device and the anti-resonant combination of inductance **28** and capacity **30** representing the motional impedance. In the device disclosed by Lakatos the resistive components **27** and **29** are sufficiently small that the reactive characteristics may for the majority of practical purposes be assumed to be those of a dissipationless network.

The reactive characteristics of a nearly dissipationless network of the type of Fig. 1 are shown in Fig. 2. As explained in the copending application of E. Lakatos mentioned above, the separation between the so-called critical frequencies, that is, the anti-resonant frequency f_1 and the resonant frequency f_2 is a function of the coupling factor k of the magnetostrictive device and under some circumstances it becomes difficult if not impossible to obtain a sufficiently large coupling factor to permit the desired spacing of the critical frequencies.

However, when magnetostrictive devices are employed in conjunction with electrical capacities, not only is an additional critical frequency provided by the combination, but also the frequency spacing between the critical frequencies of the magnetostrictive device is increased.

Figs. 3 and 5 show series and parallel combinations, respectively, of an electrical capacity and a magnetostrictive device and Figs. 4 and 6 show the respective reactive characteristics of these combinations.

In Fig. 4 we find a new resonant frequency f_3 and a greater separation between the critical frequencies f_1' and f_2' contributed by the magnetostrictive device than occurs with the magnetostrictive device alone as illustrated in Fig. 2. This effect is obviously the result of resonance between the damped inductance of the magnetostrictive device and the added capacity **32**. The anti-resonance f_1' will occur at the same frequency as for the device alone, that is at f_1. The new resonance f_3 will occur below the anti-resonance and the resonance f_2 of the device alone will occur at a higher frequency, f_2' for the combination.

Similarly, in Fig. 6 we find a new anti-resonance f_3' occurring above the resonant frequency f_2'', the latter being at the same frequency as the resonance f_2 of the device alone. The anti-resonance f_1 of the device, however, is moved down to frequency f_1'' of the combination, as shown.

By means of the reactance theorem described by R. M. Foster in the Bell System Technical Journal, volume 3, No. 2, April 1924, pages 259 to 267, the values of the various elements including those representing the equivalent network of the magnetostrictive devices may be calculated and additional elements may be added to provide more complex reactive networks.

That complex networks of reactive elements may take any one of a number of equivalent forms is demonstrated in an article entitled "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, vol. 4, No. 1, January 1925, pages 52 to 83. This article also shows numerous methods of employing such complex reactive networks as component arms of electrical wave filters of the ladder type and on page 83 sets out relations by which equivalent lattice or bridge T type filter sections may be obtained. As will appear hereinafter it is frequently advantageous in analyzing a ladder type network to examine the properties of its equivalent lattice type section.

Fig. 7 of the accompanying drawings shows a T section of ladder type filter in which the three arms are magnetostrictive devices. Fig. 8 shows the relation between the full recurrent series arm reactance X_1 and the full recurrent shunt arm reactance X_2, for this type of filter, $4X_2$ is plotted to facilitate analysis of the attenuation characteristics of the filter in accordance with well-known principles. Fig. 9 shows the attenuation of the filter section of Fig. 7. (In the T section shown in Fig. 7, according to well-known theory, each series arm is

$$\frac{Z_1}{2}$$

and the shunt arm is Z_2 unless special terminations to improve impedance or permit use in parallel with other networks are employed.)

Similarly, Fig. 10 shows a lattice type filter section employing four combinations of the type shown in Fig. 5. The series arm, shunt arm, reactances X_1 and X_2, respectively, are shown in Fig. 11 and the attenuation of the filter section of Fig. 10 is shown in Fig. 12. U. S. Patent 1,828,454 issued November 20, 1931 to H. W. Bode and numerous other well-known publications give a thorough analysis of lattice type networks.

Numerous other combinations of magnetostrictive devices with non-magnetostrictive devices whose electrical reactive properties are suitable may obviously be made. Electrical networks of numerous varieties designed in accordance with well-known principles, can therefore employ magnetostrictive devices alone, and in suitable combinations, to advantage.

For example, from the equivalent electrical network of a magnetostrictive device it is apparent that it may, for a number of purposes, be considered as having reactive properties potentially the inverse of those of a piezoelectric crystal. This at once suggests that the two devices may be advantageously combined to realize reactive networks of numerous varieties.

Generally speaking, the frequency range of greatest usefulness is somewhat lower for magnetostrictive devices than for piezoelectric devices so that over certain intermediate frequency bands complex networks employing both devices severally and in combination as arms thereof appear entirely practicable. The principles involved are, of course, the same as would govern the use of the equipment combinations of simple electrical elements in purely electrical networks, and are well known.

When magnetostrictive devices are employed in lattice networks the principles explained in my Patent 1,969,571 of August 7, 1934 to overcome distortion resulting from dissipation may be utilized.

Magnetostrictive devices having the characteristics described in the above-mentioned appplication of E. Lakatos may also be used to advantage as the medium of converting electrical energy into acoustic or mechanical energy. It will now be shown that by building out the electrical circuit the over-all transmitting characteristics of a properly proportioned electromechanical system employing a magnetostrictive device of the type contemplated may be made that of a wide band electromechanical wave filter. Fig. 13 shows in diagrammatic form such an electromechanical system. It comprises the electrical capacity **64** in series with the electrical coil **94**. Within the coil are assembled about a centrally located polarizing magnet **92** a convenient number of magnetostrictive elements **91**, the magnet and elements conforming with the requirements described in the above-mentioned application of E. Lakatos. At the left end, as shown in Fig. 13, these elements and the magnet are held by the rigid support **90**. At the right end the elements are attached to the diaphragm **95**. Sufficient clearance is left between the diaphragm **95** and the right end of magnet **92** to avoid any interference with the motion of the former.

Fig. 14 shows in schematic form an elementary electrical representation for such an electro-magnetostrictive-mechanical filter by means of which electrical energy E; supplied to the input terminals of the magnetostrictive device is converted into mechanical force and applied to drive a mechanical resistive load **65**. Resistive load **65** may be for example the loud-speaker radiating diaphragm **95** of Fig. 13. In Fig. 14, resistance **56** represents the mechanical energy dissipation of the device exclusive of the mechanical load, inductance **55** represents the equivalent of the mechanical mass, capacity **54** represents the equivalent of the mechanical stiffness, negative series reactances **52** and positive shunt reactance **53**, all three of which have the value jM, where M is the coupling impedance between the electrical and pendent of frequency, taken together represent mechanical portions of the system and is independent the equivalent of the electromechanical transformer action of the device, inductance **51** represents the damped inductance of the electrical coil of the device and resistance **50** represents the electrical energy dissipation of the device. All of the elements appearing in Fig. 14 can be determined by direct electrical and mechanical measurements.

The resistance **50** and inductance **51** are the values which will be measured on the electrical side if the mechanical side is damped or prevented from moving. This is equivalent to making the resistance **65** infinite, in which case it is readily seen that the impedance on the electrical side is the resistance **50** and the inductance **51**.

On the other hand, the equivalent capacity **54**, inductance **55** and resistance **56** can be measured by mechanical means when the electrical portion of the circuit is left open. The capacity **54** is the inverse of the stiffness of the magnetostrictive element (or elements taken collectively if several are employed as in Fig. 13), the inductance **55** is the value required to resonate the capacity **54** at the resonant frequency of the magnetostrictive element, and the resistance **56** is the resistance measured at the resonant frequency of the magnetostrictive element.

All the quantities are accordingly determined except the coupling impedance jM. To determine this we oppose the motion of the magnetostrictive element by a force F when we send a known current i_0 through the electrical coil. It is then obvious that the ratio of the force on the mechanical side, which is just sufficient to prevent motion, to the current flowing in the electrical circuit will be equal to M, the absolute value of the coupling impedance. This ratio is often called the force factor of the system.

By the measurements just described the equivalent electrical schematic representation of a system, such as that diagrammatically represented in Fig. 13, may be completely determined.

The nature of the electromechanical transformer action of an electromagnetic device is explained in detail in U. S. Patent 1,681,554 issued to E. L. Norton on August 21, 1928. Since a magnetostrictive device is an electromagnetic device the reactive properties of which are accentuated and modified by the magnetostrictive activity of its core the analysis applies equally well to it provided the effects of the magnetostrictive activity are taken into account. In accordance with Norton's analysis the electromechanical transformer comprising negative series reactances **52** and positive reactance **53** may be replaced as illustrated in Figs. 15A and 15B by an "ideal transformer" **59** having the appropriate impedance ratio ϕ and having its input shunted by an impedance **58**. The conception designated by the term "ideal transformer" is well known and is explained in numerous publications including the book by K. S. Johnson entitled "Transmission Circuits for Telephonic Communication", Chapter VI, the fourth printing of which was published in 1929 by D. Van Nostrand Company of New York city.

From the nature of the electromechanical conversion effected by the magnetostrictive device it follows that

$$\phi^2=\frac{1}{\omega^2 L_0 C_M} \qquad (1)$$

where ϕ is the ratio of transformation, $\omega=2\pi f$, $f=$ frequency of the applied voltage, L_0=electrical inductance **51**, and C_M=mechanical stiffness **54**.

The equivalent T of the ideal transformer **59** and shunting impedance **58** represented by impedances **61**, **62** and **63** of Fig. 15B may be derived as shown in the above-mentioned patent to E. L. Norton. To make impedance **63** equal jM, that is the mutual impedance between the electrical and mechanical systems, impedance **58** must equal the quantity

$$j\omega M\sqrt{L_0 C_M}$$

This results in making impedance **61** equal to the quantity

$$j\omega M\sqrt{L_0 C_M}-jM$$

and impedance **62** equal to the quantity

$$\frac{jM}{\omega\sqrt{L_0 C_M}}-jM$$

For a given magnetostrictive device the quantity

$$M\sqrt{\frac{C_M}{L_0}}$$

is a constant which will be designated as k. This is the constant k donated by Lakatos in his above-mentioned application as the coupling factor.

Replacing the electromechanical coupling device of Fig. 14 by the equivalent T structure derived above for Fig. 15B and combining like series elements we obtain Fig. 16 in which inductance **57** equals $L_0(1-k)$, impedance **58** equals $L_0 k$ and condenser **60** equals

$$\frac{C_M}{1+k}$$

Neglecting for the present the electrical and mechanical dissipations represented by resistances **50** and **56** respectively, the system of Fig. 17 is obtained. As explained in the above-mentioned application of E. Lakatos these dissipations may be safely neglected if reasonably small since in such a case their effects upon the reactive properties of the network are slight. For the system of Fig. 17 the mesh equations are

$$E_I=i_I\left[-\frac{j}{\omega C_0}+j\omega L_0(1-k)\right]+E_1 \qquad (2)$$

$$i_I=i_1+i_2 \qquad (3)$$

$$i_1=\frac{E_1}{j\omega L_0 k} \qquad (4)$$

$$E_2=E_1\phi=\frac{E_1}{\omega\sqrt{L_0 C_M}} \qquad (5)$$

$$i_0=\frac{i_2}{\phi}=i_2\omega\sqrt{L_0 C_M} \qquad (6)$$

$$E_2=i_0\left[\frac{-j(1+k)}{\omega C_m}+j\omega L_M\right]+E_0 \qquad (7)$$

where i_I is the input current, E_1 is the primary voltage of transformer **59**, i_1 is the current through impedance **58**, i_2 is the primary current of transformer **59**, E_2 is the secondary voltage of transformer **59**, i_0 is the current in the output (secondary) circuit and E_0 is the voltage across the output that is across load resistance **65**.

Solving for E_0 and i_0 in terms of E_I and i_I gives:

$$i_0=i_I\left[\frac{\omega\sqrt{L_0C_M}}{k}-\frac{\sqrt{L_0C_M}}{\omega L_0C_0k}\right]+jE_I\frac{\sqrt{C_M/L_0}}{k} \quad (8)$$

and

$$E_0=E_I\left[\frac{\omega L_m\sqrt{\frac{C_M}{L_0}}}{k}-\frac{1}{\omega\sqrt{L_0C_Mk}}\right]-ji_I\left[\frac{1}{\omega^2C_0k\sqrt{L_0C_m}}-\sqrt{\frac{L_0}{C_M}}kM-\sqrt{\frac{C_M}{L_0}}\frac{L_M}{C_0k}+\frac{\omega^2L_m\sqrt{L_0C_m}}{k}\right] \quad (9)$$

Equations 9 and 8 may respectively be rewritten in the form

$$E_0=E_iA-i_IB \quad (10)$$

$$i_0=i_IC-E_ID \quad (11)$$

A, B, C and D being the coefficients shown in Equations 9 and 8 respectively.

By well-known principles for any dissymmetrical filter

$$\cosh\Theta=\sqrt{AC} \quad (12)$$

$$Z_{I_1}=\sqrt{\frac{BC}{AD}} \quad (13)$$

$$Z_{I_2}=\sqrt{\frac{AB}{CD}} \quad (14)$$

$$\phi^2=\frac{Z_{I_2}}{Z_{I_1}}=\frac{A}{C} \quad (15)$$

To make ϕ constant at all frequencies requires the further restriction that

$$\phi^2=\frac{L_M}{L_0}=\frac{C_0}{C_M} \quad (16)$$

whence

$$L_MC_M=L_0C_0 \quad (17)$$

and the expression for the image transfer constant becomes

$$\cosh\Theta=\frac{1}{k}\left[\frac{\omega}{\omega_m}-\frac{\omega_m}{\omega}\right] \quad (18)$$

The cut-off or limiting frequencies of the transmitted band occur when $\cosh\Theta=\pm1$ and are

$$f_1=\frac{f_m}{2}\left[\sqrt{4+k^2}-k\right] \quad (19)$$

$$f_2=\frac{f_m}{2}\left[\sqrt{4+k^2}+k\right] \quad (20)$$

In Equations 18, 19 and 20 subscript m refers to the mid-band frequency, ω_m being $2\pi f_m$ and f_m being said mid-band frequency.

The image impedances of the filter are

$$Z_{I_1}=\frac{1}{\omega C_0}\sqrt{-1+\left(\frac{\omega}{\omega_m}\right)^2(2+k^2)-\left(\frac{\omega}{\omega_m}\right)^4} \quad (21)$$

and

$$Z_{I_2}=\frac{1}{\omega C_M}\sqrt{-1+\left(\frac{\omega}{\omega_m}\right)^2(2+k^2)-\left(\frac{\omega}{\omega_m}\right)^4} \quad (22)$$

At the mid-frequency where $\omega=\omega_m$ the image impedances are

$$Z_{I_{10}}=\frac{k}{\omega C_0} \quad (23)$$

$$Z_{I_{20}}=\frac{k}{\omega C_M} \quad (24)$$

If the magnetostrictive member is free to vibrate the resulting impedance, equivalent to the short-circuited impedance of an all-electrical network, may be calculated by making $E_0=0$. The result is

$$Z_{SC}=-\frac{j}{\omega C_0}\left[\frac{1-\left(\frac{\omega}{\omega_m}\right)^2(2+k^2)+\left(\frac{\omega}{\omega_m}\right)^4}{1-\left(\frac{\omega}{\omega_m}\right)^2}\right] \quad (25)$$

The band width of the filter is therefore the same as the distance between the resonant points of the combination of Fig. 3 consisting of a magnetostrictive device in series with a condenser.

In the above analysis the inversion of the electrical equivalents of the mechanical portion of the system necessary to produce an equivalent all-electrical network was not carried out. The principles involved in such a conversion are described in U. S. Patent 1,642,506 issued September 13, 1927 to E. L. Norton.

Since the nature of the composite system may be more readily apparent to those familiar with all-electrical networks the conversion described in U. S. Patent 1,642,506 mentioned above has been carried out in Fig. 18. Fig. 18 shows the all-electrical equivalent network of the filter of Fig. 17, inductance **70**, condenser **75** and resistance **80** being now electrical elements the inverse of the mechanical stiffness **60**, the mechanical mass **55** and the mechanical resistive load **65** respectively, modified by the ratio

$$\frac{1}{\phi^2}$$

to allow for the impedance change introduced by transformer **59**.

Figs. 19 and 20 are lattice structures here introduced to facilitate analysis of the effect of adding series condenser **64** to the system represented by Fig. 18. Fig. 19 shows the equivalent lattice of the system of Fig. 18 without condenser **64** and Fig. 20 shows the equivalent lattice of the complete system shown in Fig. 18. The relations between the elements of the structures of Figs. 18, 19 and 20 are given on page 83 of the above-mentioned paper by Johnson and Shea.

Fig. 21, curves **78** and **79** are the recurrent shunt arm reactance-frequency characteristics for the structure of Fig. 19 and curves **81** and **82** are the corresponding characteristics for the structure of Fig. 20.

Fig. 22, curves **83** and **84** show comparatively the attenuation-frequency characteristics of the structures of Figs. 19 and 20 respectively. The difference between these characteristics represents effect of adding series capacity **64** to complete the system of Fig. 18. The increase in band width so obtained may, in not unusual instances, be in the order of tenfold.

Fig. 23 shows a loud-speaker similar to that of Fig. 13 except for the addition of a horn **100** which clamps the outer periphery of the diaphragm. Fig. 24 indicates the modification of the electrical schematic representation of the mechanical system comprising mainly shunt capacitance **101** (mechanical elastance) introduced by the necessity of flexing the diaphragm and on the electrical side the anti-resonant combination comprising inductance **98** and capacity **97** necessary in this instance in addition to the series capacity **96** to complete the building out of the system to the equivalent of a wide band all-electrical wave filter. Fig. 24 shows the schematic of the system converted to the all-electrical equivalent filter as explained above, the shunt mechanical elastance 101 becoming in the all-electrical system the series inductance 102.

Fig. 26 shows a plurality of magnetostrictive units of the type described in connection with Fig. 13 employed to drive a submarine radiator By means of a series capacity 108 the system may be built out to a wide-band electrical wave filter in the same manner as was the system of Fig. 13.

Numerous other arrangements within the spirit and scope of the invention may obviously be made and no attempt has here been made to be exhaustive.

What is claimed is:

1. In combination a magnetostrictive device comprising a single electrical coil electromagnetically coupled with a single vibrating element of magnetostrictive material, and a condenser in series with said electrical coil whereby said combination produces at one frequency an electrical anti-resonance and at two other frequencies electrical resonances, the anti-resonance occurring at a frequency lying between the frequencies at which resonance occurs, all of said frequencies being non-harmonically related.

2. In combination a magnetostrictive device comprising a single electrical coil electromagnetically coupled with a single vibrating element of magnetostrictive material, and a condenser in parallel with said electrical coil whereby said combination produces at one frequency an electrical resonance and at two other frequencies electrical anti-resonances, the resonance occurring at a frequency lying between the frequencies at which the anti-resonances occur, all of said frequencies being non-harmonically related.

3. An electrical wave filter comprising a plurality of impedance branches arranged between a pair of input terminals and a pair of output terminals to form a lattice network each lattice branch of said network including a magnetostrictive device in combination with a capacity, the reactances of the branches being proportioned with respect to each other to provide a single transmission band.

4. An electrical wave filter comprising a plurality of impedance branches arranged between a pair of input terminals and a pair of output terminals to form a T network, each impedance branch consisting of a magnetostrictive device, the reactances of the branches being proportioned with respect to each other to provide a single transmission band.

5. An electrical wave filter comprising a plurality of impedance branches arranged between a pair of input terminals and a pair of output terminals, a number of said branches bearing a series relation to the transfer of energy through said filter and the remainder bearing a shunt relation to said energy transfer, said remainder of impedance branches each including a magnetostrictive device, the reactances of all said branches being proportioned with respect to each other to impart definite predetermined transmitting, impedance and phase characteristics to said filter.

6. An electrical wave filter comprising a plurality of impedance branches arranged between a pair of input terminals and a pair of output terminals, a number of said branches bearing a series relation to the transfer of energy through said filter and the remainder bearing a shunt relation to said energy transfer, said first number of impedance branches each including a magnetostrictive device, the reactances of all said branches being proportioned with respect to each other to impart definite predetermined transmitting, impedance and phase characteristics to said filter.

7. An electrical wave filter comprising a plurality of impedance branches arranged between a pair of input terminals and a pair of output terminals, a number of said branches bearing a series relation to the transfer of energy through said filter and the remainder bearing a shunt relation to said energy transfer, a portion of said branches each including in combination a magnetostrictive device and a capacity, the reactances of all said branches being proportioned with respect to each other to impart definite predetermined transmitting, impedance and phase characteristics to said filter.

8. An electromechanical system comprising a magnetostrictive device arranged to drive a sound radiating device, an electrical capacity connected in series with the electrical coil of said magnetostrictive device and an electrical anti-resonant impedance connected in parallel with the series combination of said capacity and said coil, the impedances of all said component parts being so proportioned relative to each other that said system provides substantially distortionless wave transmission of energy, involving the conversion of electrical to acoustic energy, over a wide range of frequencies.

9. A magnetostrictive device including an electrical coil, a core of magnetostrictive material and a magnetizing member, said core being divided into a plurality of portions, said portions being assembled about said magnetizing member, the assembly so formed being inserted centrally through said coil whereby polarization of the core portion is attained while at the same time magnetic shielding of said magnetizing member from said coil and close coupling between said coil and said core portions are effected.

10. A magnetostrictive vibrator comprising a plurality of independent vibrating elements of magnetostrictive material, a polarizing member for said vibrating elements and an electrical coil enclosing all of said elements and said polarizing member, said vibrating elements being positioned between said coil and said polarizing member whereby said elements tend to magnetically shield said polarizing member from said coil thereby reducing electromagnetic coupling between said polarizing member and said coil.

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