July 13, 1937. R. B. BLACKMAN 2,086,597

WAVE FILTER

Filed April 20, 1935 3 Sheets-Sheet 1

FIG. 1

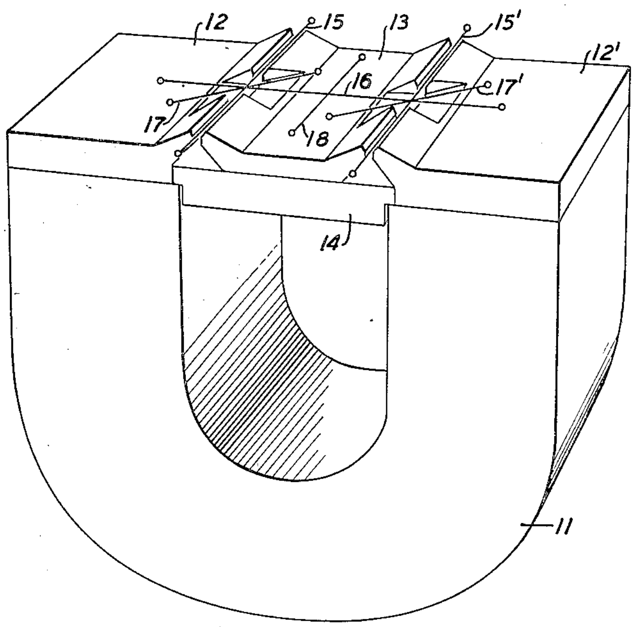


FIG. 2

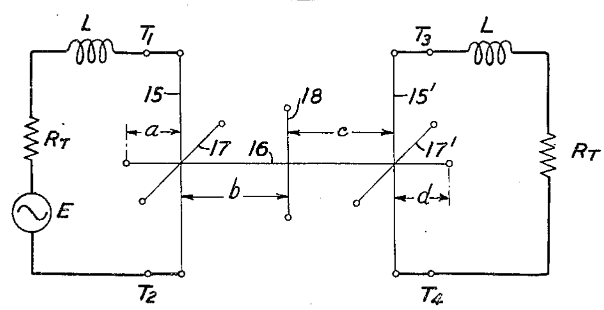
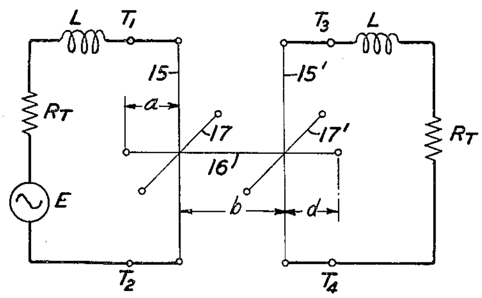


FIG. 12



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WAVE FILTER

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FIG. 3

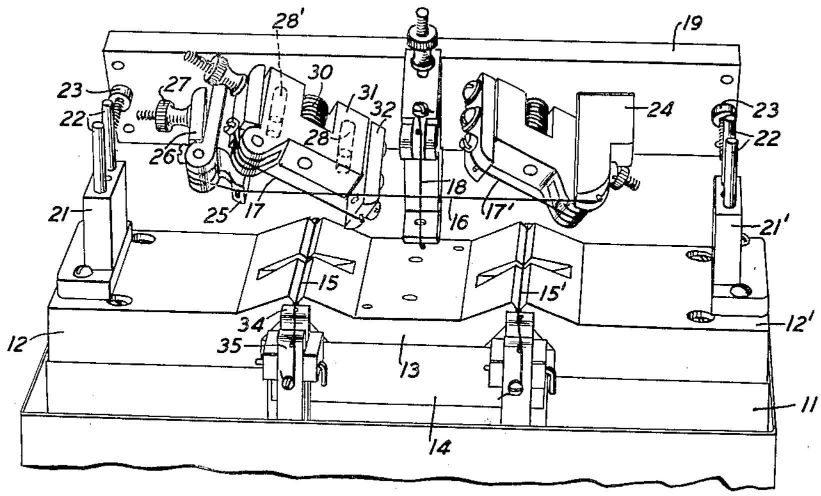

FIG. 5

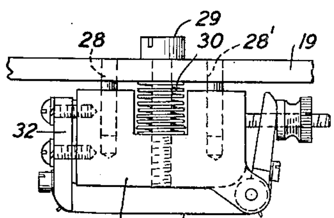

FIG. 4

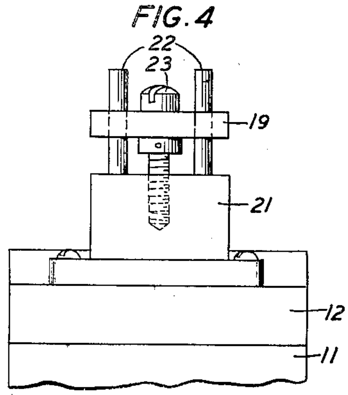

FIG. 6

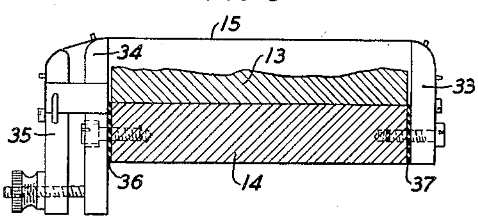

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FIG. 7

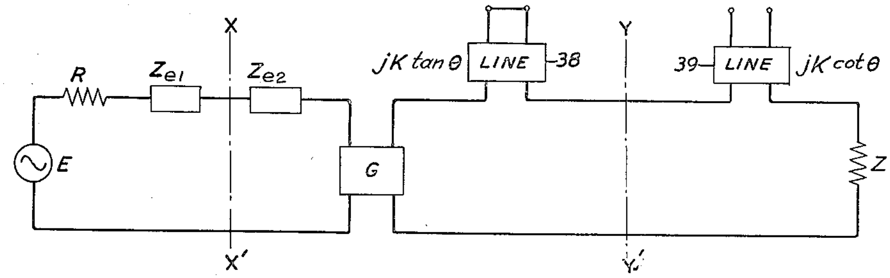


FIG. 8

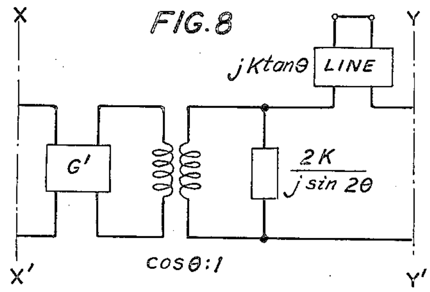


FIG. 9

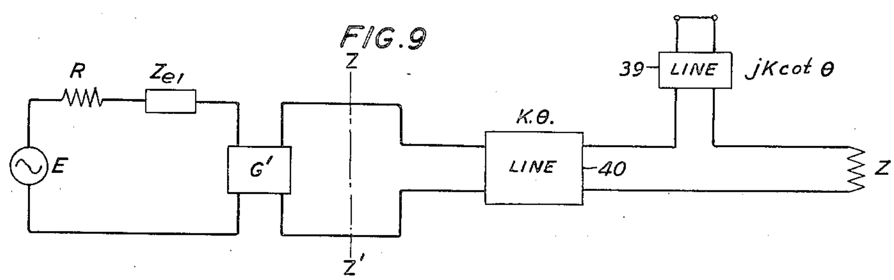


FIG. 10

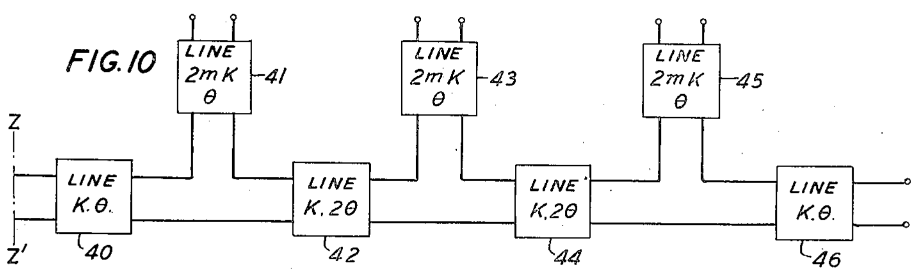
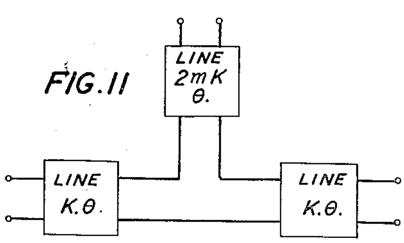


FIG. 11



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UNITED STATES PATENT OFFICE

2,086,597

WAVE FILTER

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Application April 20, 1935, Serial No. 17,431

14 Claims. (Cl. 178—44)

This invention relates to wave filters and more particularly to wave filters using mechanical vibratory elements.

The principal object of the invention is to provide a mechanical vibratory structure which is capable of transmitting vibrations in a wide frequency range and at relatively high frequencies such as are used for carrier telephone transmission. Another object is to reduce the cost of band selective filters for high frequency transmission systems.

In the wave filters of the invention the mechanical vibratory system comprises a longitudinal stretched wire which acts as a main transmission line and a plurality of stretched wires coupled transversely thereto which act as loading impedances. The end transverse wires are disposed in the air-gaps of electromagnets and are included in separate electric circuits whereby they can function as driving means for converting electrical oscillations into mechanical vibrations or as receiving means for effecting the reverse transformation.

Particular features of the invention relate to the tuning of the wires whereby a continuous transmission band may be provided and to the proportioning of the mechanical impedances of the wires for the control of the width of the transmission band.

The nature of the invention will be more fully understood from the following detailed description and the attached drawings, of which

Fig. 1 is a diagrammatic representation of one embodiment of the invention;

Fig. 2 shows schematically the arrangement of the electrical circuits and the mechanical vibratory system of the system of Fig. 1;

Figs. 3, 4, 5 and 6 illustrate the mechanical construction and details thereof of the system of Fig. 1;

Figs. 7, 8, 9, 10 and 11 are schematic diagrams illustrative of the principles of the invention; and

Fig. 12 is a schematic representation of a modified form of the invention.

Description of physical structure

Referring to the drawings, a schematic arrangement of the magnetic and mechanical vibratory systems of one embodiment of the invention is shown in Fig. 1, in which, for the sake of clearness, much of the detail structure has been omitted. The magnetic system comprises a permanent magnet 11 provided with three pole-pieces 12, 12', and 13 which are arranged to provide two separated air-gaps in the form of narrow slits parallel to each other. The vibratory system consists of a pair of stretched actuating wires 15 and 15' disposed in the respective air-gaps of the magnetic system, a stretched coupling wire 16 lying perpendicular to the actuating wires and contacting therewith at their midpoints, and a set of loading wires 17, 17', and 18 disposed transversely of wire 16 and in contact therewith at their midpoints. Wires 17 and 17' are arranged to contact with the coupling wire 16 at the same points as wires 15 and 15' and are disposed diagonally to avoid interference with these wires and also to remove them from the influence of the magnetic field. The supports for the stretched wires are not shown in Fig. 1, but are illustrated in Figs. 3, 4, 5, and 6, the details of which will be described later. Pole-pieces 12 and 12' may be secured by screws directly to the magnet. Pole-piece 13 is supported on a plate 14 of non-magnetic metal which in turn is rigidly secured to the magnet. The several pole-pieces are shaped to provide mechanical clearance for all of the wires of the vibratory system and are notched in the manner indicated in the drawings to accommodate diagonal wires 17 and 17' without subjecting them to the influence of the magnetic field.

Referring to Fig. 3, which shows the details of a practical construction partially disassembled for clarity, the coupling wire 16 and the transverse loading wires 17, 17', and 18 are carried on a removable plate 19 which is arranged to be supported from the magnetic structure by brackets 21 and 21' and guide pins 22. An end view of the structure with the plate 19 in position is shown in Fig. 4. Vertical adjustment of the plate 19 is provided for by means of collared screws 23, one at each end, which engage the plate and are threaded into brackets 21 and 21'. By this means an adequate mechanical contact between the driving wires and the coupling wire 16 can be assured. The coupling wire 16 is supported from plate 19 by bracket members 24 and 25 the latter of which includes a tensioning arrangement consisting of a hinged lever arm 26 to which the end of the wire is attached and an adjusting screw and nut 27.

The loading wires are all similarly mounted on tensioning holders such as 31 which are adjustably supported from plate 19. Details of these holders and of their supporting arrangements are shown in Fig. 5. At one end of the holder an anchor plate 32 is attached to which the stretched wire is secured. At the other end an adjustable tensioning lever is provided similar to that used for tensioning the coupling wire 16. The details of the tensioning lever and the adjusting screw and nut are clearly shown. The holder is carried on plate 19 by guide pins 28 and 28′ which are rigidly attached to the plate and engage in close fitting holes in the holder. Vertical adjustment is provided by means of screw 29 which is threaded into the holder and passes through a clearance hole in plate 19. Spring 30 which encircles screw 29 and abuts against the holder and the plate, serves to keep the holder in its adjusted position.

In the assembly of the coupling and loading wires it is preferable that diagonal wires 17 and 17′ should bear on the top side of the coupling wire and transverse wire 18 on the under side.

The driving wires 15 and 15′ are supported directly from the magnetic structure and are provided with adjustable tensioning means similar to those for the other wires. Details of the mounting are shown in Fig. 6, only the essential parts of the magnetic structure being indicated. The wire 15 is attached at one end to an anchor plate 33 mounted on plate 14 and at the other to a tensioning support comprising bridge piece 34 and tensioning lever 35. Anchor plate 33 and bridge piece 34 are insulated from plate 14 by plates 36 and 37 of insulating material and are attached to plate 14 by suitably insulated screws. This is necessary since the wires 15 and 15′ carry the input and output electrical currents. While the other wires of the system do not carry electrical currents it is preferable that they should be insulated in similar manner to the driving wires, at least at one end of each wire. The symmetry of the wire structure prevents the transmission of current from the one driving wire to the other through the coupling wire 16.

Theory of operation and design

Before discussing the detailed theory of the invention the operation of the filter will be described briefly with reference to Fig. 2. In this figure, which is a schematic of the stretched wire system and its connections to the cooperating electrical circuits, the filter is shown connected between electrical input terminals T_1 and T_2 and output terminals T_3 and T_4 to which are connected resistive terminal impedances R_T. In series with one of the terminal resistances is included a wave source of voltage E.

Current from the source causes the driving wire 15 to vibrate transversely to the direction of the magnetic field in the air-gap in which the wire is situated. The vibrations of wire 15 are transmitted to wire 15′ through coupling wire 16. Vibrations of wire 15′ in its magnetic field induce corresponding electromotive forces which cause currents to flow in the output circuit. The band-pass characteristic is obtained by proper dimensioning and tuning of the driving wires 15 and 15′ and coupling wire 16 and by loading the latter at suitable points by the transverse wires 17, 17′, and 18, also properly dimensioned and tuned.

The manner in which the several wires must be tuned and proportioned to provide a single broad-band transmission characteristic will be understood from the following analysis.

It will be observed that the transducing means, namely stretched wires 15 and 15′, whereby conversion of the energy from electrical to mechanical vibrations is effected, are flexible elements the different points of which partake of different motions. The reaction in the electrical system due to the motion and the resulting mechanical force at the middle point where coupling to wire 16 is effected will therefore have somewhat complex characters. For this reason it is desirable to examine first the theory of the stretched wire transducer.

The differential equations for the transverse motion of the driving wire differ from those of an ordinary stretched string or wire for the reason that each elemental length of the wire besides introducing a mass acceleration reaction is subject to a mechanical force due to the interaction of the current flowing in it with the magnetic field. This mechanical force is the same for each element of the wire.

Let

l=length of the wire in centimeters,
ρ=linear density of the wire in grams per centimeter,
τ=tension in the wire in dynes,
β=magnetic flux density in the air-gap in c. g. s. units, and
I=current in the wire in c. g. s. units.

An elemental portion of the wire of length dx at a distance x from the mid-point will move under the action of two forces, one a force $\beta I dx$ due to the current and the other a mechanical force p equal to the difference of the transverse components of the tension τ at the two ends of the element, that is, to the decrement $-dp$ of the transverse mechanical force. These forces are opposed by the mass-acceleration reaction of the element, giving rise to the relationship

$$\beta I dx - dp = \rho dx \frac{d^2y}{dt^2} \qquad (1)$$

where y denotes the transverse displacement. Assuming, the motion to be sinusoidal and of pulsatance ω, Equation 1 may be rewritten as

$$\frac{dp}{dx} = \beta I - j\omega\rho\dot{y} \qquad (2)$$

where $\dot{y}$ denotes the transverse velocity.

Due to the tension τ in the wire each elemental length has a transverse stiffness equal to τ/dx. The change in the lateral displacement from one end of the element to the other due to the transverse force p is therefore given by

$$dy = -p\frac{dx}{\tau}$$

and the change of the transverse velocity by

$$d\dot{y} = -\frac{dx}{\tau}\frac{dp}{dt}$$

Assuming p to vary sinusoidally with pulsatance ω, this equation becomes.

$$\frac{d\dot{y}}{dx} = -j\frac{\omega}{\tau}p \qquad (3)$$

From Equations 2 and 3 is obtained

$$\frac{d^2\dot{y}}{dx^2} + \frac{\omega^2\rho}{\tau}\dot{y} + j\frac{\omega\beta I}{\tau} = 0 \qquad (4)$$

which expresses the motion of the wire. In deriving Equations 3 and 4, it is assumed that the wire has a flexural stiffness, due to its dimensions and material, which is negligibly small in comparison with the flexural stiffness due to the tension. I have found that this assumption is justified in practice and that the effects of the flexural stiffness of the wire itself are negligible except at frequencies well removed from the operating frequencies of the filters of the invention.

Equation 4 may be solved for each half of the wire to give the total mechanical reaction at the mid-point due to that half. Since each half will contribute the same reaction as the other half the reaction of the whole wire is simply twice that of either half. Measuring x from the mid-point of the wire the velocity $\dot y$ at the point x is given by

$$\dot y=\dot y_0\frac{\sin\frac{\pi}{2}\frac{\omega}{\omega_0}\left(1-\frac{2x}{l}\right)}{\sin\frac{\pi}{2}\frac{\omega}{\omega_0}}-\frac{2\beta I}{j\omega\rho}\frac{\sin\frac{\pi}{4}\frac{2x}{l}\frac{\omega}{\omega_0}\sin\frac{\pi}{4}\frac{\omega}{\omega_0}\left(1-\frac{2x}{l}\right)}{\cos\frac{\pi}{4}\frac{\omega}{\omega_0}} \qquad (5)$$

where $\dot y_0$ is the velocity at the mid-point and

$$\omega_0=\frac{\pi}{l}\sqrt{\frac{\tau}{\rho}}=2\pi f_0 \qquad (6)$$

f_0 being the fundamental resonance frequency of the whole wire.

The mechanical reaction at the mid-point due to the half wire is obtained from Equation 5 by means of Equation 3. Denoting this reaction by p_0, Equation 3 gives,

$$p_0=j\frac{\tau}{\omega}\left[\frac{d\dot y}{dx}\right]_{x=0} \qquad (7)$$

Performing the differentiation indicated and substituting for ω_0, where it appears in the resulting coefficients, the value given in Equation 6, the mid-point reaction is found to be

$$p_0=-j\sqrt{\rho\tau}\left[\dot y_0\cot\frac{\pi\omega}{2\omega_0}+\frac{\beta I}{j\omega\rho}\tan\frac{\pi\omega}{4\omega_0}\right] \qquad (8)$$

Assuming that a driving force F is applied to the wire at its mid-point and that a mechanical load of impedance Z is attached at the driving point, the equation for the resultant motion of the mid-point is

$$F=\dot y_0 Z+2p_0 \qquad (9)$$

or

$$F=-I\frac{2\beta l\omega_0}{\pi\omega}\tan\frac{\pi\omega}{4\omega_0}+\dot y_0\left[Z+j\sqrt{\rho\tau}\left(\tan\frac{\pi\omega}{4\omega_0}-\cot\frac{\pi\omega}{4\omega_0}\right)\right] \qquad (10)$$

On the electrical side the electromotive force, at the wire terminals, is given by

$$E=RI+2\beta\int_0^{\frac{l}{2}}\dot y\,dx \qquad (11)$$

which, when the integration is performed becomes

$$E=\left[R+\frac{\beta^2 l}{j\omega\rho}\left(1-\frac{4\omega_0}{\pi\omega}\tan\frac{\pi\omega}{4\omega_0}\right)\right]I+\dot y_0\frac{2\beta l\omega_0}{\pi\omega}\tan\frac{\pi\omega}{4\omega_0} \qquad (12)$$

where R is the electrical resistance of the wire. Equations 10 and 12 have the form

$$F=A\dot y_0-GI$$

and

$$E=G\dot y_0+BI$$

where A and B represent mechanical and electrical impedances, respectively, and G is the force factor of the transducer. The force factor has the value

$$G=\frac{\beta l}{2}\frac{\tan\Theta}{\Theta} \qquad (13)$$

where

$$\Theta=\frac{\pi\omega}{4\omega_0}=\frac{\omega l}{4}\sqrt{\frac{\rho}{\tau}} \qquad (14)$$

Since the phase constant of the whole wire is equal to

$$\omega l\sqrt{\rho/\tau}$$

the angle Θ represents the phase constant of one-quarter of the wire. The electrical impedance B has the value

$$R+\frac{\beta^2 l}{j\omega\rho}\left(1-\frac{\tan\Theta}{\Theta}\right)$$

which, since

$$\tan\Theta=\frac{\sin 2\Theta}{2}(1+\tan^2\Theta)$$

may be written as

$$R+\frac{1}{j\omega}\cdot\frac{\beta^2 l^2}{4}\cdot\frac{4}{\rho l}\left(1-\frac{\sin 2\Theta}{2\Theta}\right)+j\frac{\beta^2 l}{\omega\rho}\cdot\frac{\sin 2\Theta}{2\Theta}\tan^2\Theta \qquad (15)$$

or

$$R+Z_{e1}+Z_{e2}$$

The mechanical impedance A consists of three parts, first the load impedance Z, second, a component

$$j\sqrt{\rho\tau}\tan\Theta$$

which is the impedance of a short-circuited uniform line of characteristic impedance

$$K=\sqrt{\rho\tau}$$

and of length corresponding to a phase angle Θ. The third component represents the impedance of a similar line open-circuited at its remote end.

The complete system of the transducer is shown schematically in Fig. 7. The mechanical portion, which is shown in accordance with equivalent electrical conventions, includes the load impedance Z and impedances **38** and **39** corresponding respectively to the components $jK\tan\Theta$ and $-jK\cot\Theta$. These are represented as sections of uniform lines of impedance K and phase constant Θ with their remote terminals respectively short-circuited and open-circuited.

A more convenient equivalent system is shown schematically in Fig. 9. This equivalent is arrived at from that of Fig. 7 by a transformation of the portion between the dotted lines xx' and yy'. The first step in the transformation is indicated by the schematic of Fig. 8. The force factor G is replaced by the equivalent combination of a new force factor G′ of value

$$G'=\frac{\beta l}{2}\frac{\sin\Theta}{\Theta} \qquad (16)$$

and an ideal transformer having a transformation ratio $\cos\Theta$:1. The electrical impedance Z_{e2} is replaced by an equivalent shunt impedance on the mechanical side of value

$$\frac{G^2}{Z_{e2}}=\frac{2K}{j\sin 2\Theta}$$

The combination of the ideal transformer with this shunt impedance and the series impedance $jK\tan\Theta$ is equivalent to a section of uniform line of characteristic impedance K and phase angle Θ included in the circuit as indicated at **40** in Fig. 9.

The electrical impedance Z_{e1} is of the character of a capacity, the value of which is proportional to the mass of the driving wire but variable with frequency in accordance with the inverse of the factor $(1-\sin 2\Theta/2\Theta)$. The magnitude of the impedance is small and may be neglected in most instances or, if desired, may be compensated by means of an inductance of appropriate value.

The line elements appearing in Fig. 9 have each a phase constant Θ and hence correspond in length to one-quarter of the driving wire.

The complete mechanical portion of the filter may be considered to include all the elements to the right of the vertical line ZZ' in Fig. 9, the load impedance Z being that due to the other wires of the system including wire **15'** of the second transducer.

A schematic of the complete mechanical portion is shown in Fig. 10, the various elements being represented as transmission lines in accordance with electrical conventions. The system comprises a series of sections of uniform lines **40**, **42**, **44** and **46**, connected in tandem, and intermediate series impedances **41**, **43** and **45**, consisting of sections of uniform line open-circuited at their remote ends. The principal parameters of the line elements are proportioned as follows. The reasons for these proportions and their relationships to the wire dimensions are discussed later. The tandem connected lines all have characteristic impedances of value K while the lines constituting the series impedances have characteristic impedances $2mK$, m being a numerical factor greater than unity. The phase constants of the intermediate lines **42** and **44** are equal to 2Θ and those of all the other line sections are equal to Θ.

With these proportions the whole filter consists of three tandem connected similar symmetrical sections, each of the type shown in Fig. 11 and consisting of two line sections of characteristic impedance K and phase constant Θ, separated by a series impedance constituted by an open circuit line of characteristic impedance $2mK$ and phase angle Θ.

The relationship of the various line sections of Fig. 10 to the several wires of the filter is as follows:

Line section **40** is contributed by the electromechanical transducer system as already described. Line section **46** is a corresponding element introduced by the second transducer comprising driving wire **15'**. Line sections **42** and **44** represent the two intermediate sections of coupling wire **16**, designated *b* and *c* in Fig. 2, through which the vibrations are transmitted from wire **15** to wire **15'**. Since sections **40** and **46** have characteristic impedances K and phase constants Θ, it follows sections **42** and **44** must have the same characteristic impedance and phase constants 2Θ to provide the symmetrical character of the individual filter sections. The characteristic impedance of the transducer wires thus determines the characteristic impedance of the coupling wire.

Line sections **41**, **43** and **45** correspond to the loading elements. Line section **41** represents a combination of the following components: first, the impedance $-jK \cot \Theta$ of element **39** contributed by transducer wire **15**; second, the impedance of the end portion *a* of the coupling wire, which also acts as a loading impedance; and third, the joint impedance of the two halves of diagonal wire **17**. All of these components correspond to uniform lines open-circuited at their outer ends.

The element **39** entering into the above combination from the transducer has a phase constant equal to Θ. If each of the other elements be proportioned to have the same phase constant, the resultant impedance of the combination will be that of a single open-circuited line of phase constant Θ and characteristic impedance equal to the sum of the individual characteristic impedances.

Line element **43** represents the sum of the impedances of the two halves of transverse wire **18**, each half being an open circuit line which, in accordance with the symmetry of the system, must have a phase constant Θ. Line element **45** represents a combination similar to element **41** involving the two halves of wire **17'**, end section *d* of the coupling wire and the series impedance contributed by transducer wire **15'**. The contribution by the transducer wires of effective loading impedances of value $-jK \cot \Theta$ determines the phase constants of the other loading elements. Further, since the end sections of coupling wire **16** also constitute loading impedances, the phase constants of the several sections of the coupling wire are likewise determined by the transducer wire proportions.

The characteristic impedances of the diagonal wires **17** and **17'** must be such that with their associated elements they contribute a characteristic impedance $2mK$ corresponding to that of line section **43**. This impedance is twice that of the wire **18** since each half of the wire contributes equally to the load. Since the transducer wires and the end sections of the coupling wire each contribute a characteristic impedance K it follows that wires **17** and **17'** must have characteristic impedances equal to $(m-1)K$.

The function of the loading wires in controlling the width of the transmission band of the filter may be seen from an examination of the image impedance, which is the same as that of the filter section of Fig. 11. The image impedance of the section can be computed by standard formulae from the open-circuit and short-circuit impedances, its value being given by

$$W=K\sqrt{\frac{1-m\cot^2\Theta}{m+1}} \qquad (17)$$

where W denotes the image impedance.

Equation 17 shows that the impedance has a real value, corresponding to a pure resistance when $m \cot^2 \Theta$ is less than unity. Since the impedance is resistive only in a transmission band, it follows that the band limits are given by the equation

$$\tan\Theta=\sqrt{m} \qquad (18)$$

The filter has an indefinite number of transmission bands all of uniform width and centered about the frequencies for which $\cot \Theta$ is zero or Θ is an odd multiple of $\pi/2$. From Equation 14 giving the value of Θ it follows that the mid-frequencies of the successive bands are $2f_0$, $6f_0$, $10f_0$, . . . and so on. The lowest frequency band is the only one of interest, the mid-band frequency in this case being twice the fundamental resonance frequency of the driving wires.

Equations 17 and 18 indicate that the width of the band is dependent on the value of m and decreases as m increases. The widest band is obtained when m is equal to unity, the band limits in this case being f_0 and $3f_0$. Since the characteristic impedances of diagonal wires **17** and **17'** are equal to $(m-1)K$, it follows that in the limiting case these wires would have zero characteristic impedance, that is, the diagonal wires would be absent. By the use of the diagonal wires and a correspondingly proportioned central loading wire, the band width is made subject to control.

While the mechanical portion of the system has an indefinite number of bands only the lowest frequency band appears in the over-all electromechanical system. The elimination of the higher frequency bands is due to the frequency characteristic of the electro-mechanical transducer. Referring to Fig. 9, it will be seen that the mechanical portion is coupled to the electrical circuits by force factors G′, the value of which is given by Equation 15 and is variable with frequency. At the mid-frequency of the first band the phase constant Θ has the value $\pi/2$, the force factor having the value G_1' given by

$$G_1'=\frac{\beta l}{\pi} \qquad (19)$$

and at the mid-frequencies of the successively higher bands being respectively ⅓, ⅕, 1/7, etc. as great. Since the efficiency of transmission is proportional to the square of the force factor, the loss in the higher frequency bands is very large.

The impedance Z_{e1}, which is added to the electrical circuit by the transducer has the value, given by Equation 15,

$$Z_{e1}=\frac{1}{j\omega}\frac{\beta^2l^2}{4}\cdot\frac{4}{\rho l}\left(1-\frac{\sin 2\Theta}{\Theta}\right) \qquad (20)$$

which at the mid-frequency of the lowest transmission band becomes

$$Z_{e1}=\frac{1}{j\omega}\frac{\beta^2l^2}{m} \qquad (21)$$

where m is the mass of the transducer wire. This is equivalent to the impedance of a capacity equal to m/β^2l^2. The effect of this impedance may be substantially neutralized throughout the band by the addition of a series inductance proportioned to resonate with the capacity at the mid-band frequency. The value of the neutralizing inductance is found from Equations 6 and 21 to be

$$L=\frac{\beta^2l^2}{4\pi^2}\cdot\frac{1}{\tau} \qquad (22)$$

Fig. 2 shows inductances L inserted in the input and output electrical circuits in series with the driving wires.

In the construction of the filter it is preferable to use aluminum alloy such as duralumin for the driving wires **15** and **15′**. Such materials have high tensile strength and, in addition to having low density, have relatively high electrical conductivity. Because of the low density, the length of the wire for a given resonance frequency and tension will be greater than for other materials and hence will permit greater values of the force factor. The other wires may be of the same material, but in many cases steel piano wire may be preferred because of its greater tensile strength. In the case of the loading wires, the greater density of steel permits the relatively high characteristic impedances to be obtained without resorting to excessively large mechanical tensions.

If all of the wires are made of the same material and subject to the same mechanical tension, wires **17**, **17′** and **18** will be of the same length, wires **15** and **15′** twice as long and wire **16** three times as long. Their fundamental resonance frequencies will be inversely proportional to their lengths. Loading wires **17**, **17′** and **18** will resonate to the mid-frequency of the first transmission band or twice the resonance frequency f_0 of the driving wires. Coupling wire **16** will resonate at a frequency two-thirds of the driving wire frequency.

When different materials are used for the several wires the required relationships of the phase constants and characteristic impedances can be maintained by appropriate adjustments of the lengths and diameters of the wires and of the mechanical tensions. The relationships of the fundamental resonance frequencies will remain unchanged. The lengths and diameters of the wires should be so chosen that the required resonances are obtained with mechanical tensions suitable for the material used.

The modified form of filter shown schematically in Fig. 12 differs from that of Figs. 1 and 2 in that the central loading wire **18** is omitted and the coupling wire is shortened by the length of one of the intermediate sections *b* or *c*. This modification is a two-section filter and represents the minimum number of sections that can be constructed. Obviously, as many additional sections as desired can be added by increasing the length of the coupling wire and adding transverse wires corresponding to wire **18**.

What is claimed is:

1. A wave filter comprising a longitudinal stretched wire and a plurality of transverse stretched wires coupled mechanically to said longitudinal wire at their mid-points and spaced apart along the length thereof, said wires being tuned with respect to each other and to a preassigned frequency whereby the system is responsive to vibrations in a frequency band centered about said preassigned frequency.

2. An electromechanical wave filter comprising a longitudinal stretched wire, a plurality of transverse stretched wires coupled mechanically thereto at points spaced apart along the length thereof, magnetic means providing magnetic fields perpendicular to two of said transverse wires and separate electric circuits connected to the ends of said two transverse wires, said wires being tuned with respect to each other and to a preassigned frequency whereby the system has a transmission band in a frequency range centered about said preassigned frequencies.

3. An electromechanical wave filter comprising a longitudinal stretched wire, a plurality of transverse stretched wires coupled mechanically thereto at points spaced apart along the length thereof, magnetic means providing magnetic fields perpendicular to the first and the last of said transverse wires, means for passing oscillatory electric currents through said first transverse wire whereby mechanical vibrations are produced, and means for deriving electric currents from said last transverse wire, said wires being tuned with respect to each other and to a preassigned frequency whereby the system has a transmission band in a frequency range centered about said preassigned frequencies.

4. An electromagnetic wave filter comprising a first electric circuit, a stretched wire included in series therein and disposed in a transverse magnetic field, a second electric circuit, a second stretched wire included in series in said second circuit and disposed in a transverse magnetic field, and mechanical coupling means between said stretched wires comprising a third stretched wire coupled to said first and second wires at the mid-points thereof, said first and second wires being tuned alike to a preassigned frequency and the portion of said coupling wire between said

first and second wires being tuned to a sub-harmonic of said preassigned frequency.

5. An electromechanical wave filter comprising a longitudinal stretched wire, a plurality of transverse stretched wires engaging said longitudinal wire at their mid-points and spaced apart on said longitudinal wire so that their separation from each other is twice the distance from each end of the longitudinal wire to the nearest transverse wire, magnet systems providing magnetic fields perpendicular to two, of said transverse wires and separate electric circuits connected to the ends of each of said two transverse wires.

6. A broad band wave filter comprising a longitudinal stretched wire, and a plurality of transverse stretched wires engaging said longitudinal wire at their mid-points and spaced at equal intervals therealong, the first and the last of said transverse wires being tuned alike to a preassigned frequency and said longitudinal wire being tuned to a lower frequency such that the fractional portions thereof between said transverse wires are resonant at twice said preassigned frequency.

7. A broad band wave filter comprising a longitudinal stretched wire and a plurality of transverse stretched wires engaging said longitudinal wire at their mid-points and spaced uniformly apart on said longitudinal wire at the mid-points of equal sections thereof, the first and the last of said transverse wires being tuned alike to a preassigned frequency and said longitudinal wire being tuned to a lower frequency equal to twice said preassigned frequency divided by the number of the coupling points to the transverse wires.

8. An electromechanical wave filter comprising a longitudinal stretched wire, a pair of transducer wires stretched transversely across said longitudinal wire at equal distances l from the opposite ends thereof and coupled thereto at their mid-points, additional transverse wires coupled to said longitudinal wire at their mid-points and spaced apart uniformly by distances $2l$, magnetic means providing magnetic fields transverse to said transducer wires, and separate electric circuits including said receiver wires, two of said additional transverse wires being coupled to said longitudinal wire at the same points as the said receiver wires and being disposed outside the fields of said magnetic means.

9. An electromechanical filter in accordance with claim 8 in which the transducer wires are tuned alike to a preassigned frequency and the additional transverse wires are tuned alike to a frequency twice as great.

10. An electromechanical wave filter in accordance with claim 8 in which the transducer wires are tuned alike to the mid-frequency of a preassigned transmission band and the additional transverse wires and the intermediate sections of the longitudinal wire are tuned alike to a frequency twice as great.

11. An electromechanical wave filter in accordance with claim 8 in which the transducer wires and the longitudinal wire have equal characteristic impedances of value K and in which the additional transverse wires are proportioned to provide loads of characteristic impedance $2mK$, m being a numerical factor greater than unity.

12. A broad band wave filter comprising a longitudinal stretched wire and a plurality of substantially coplanar transverse stretched wires coupled mechanically to said longitudinal wire at points spaced apart along the length thereof, said longitudinal and said transverse wires being so tuned that each of the free lengths thereof has a natural frequency of transverse vibration at a frequency integrally related to a preassigned frequency, whereby the system transmits freely vibrations in a frequency band centered about said preassigned frequency.

13. A broad band wave filter comprising a longitudinal stretched wire, a plurality of substantially coplanar transverse stretched wires coupled mechanically to said longitudinal wire at points spaced apart along the length thereof, means for applying transverse vibratory forces to one of said transverse wires, and means responsive to vibratory motion coupled to another of said transverse wires, said wires being so tuned that each of the free lengths thereof has a natural frequency of transverse vibration at a frequency integrally related to a preassigned frequency, whereby the system transmits freely vibrations in a frequency band centered about said preassigned frequency.

14. A wave filter comprising a longitudinal stretched wire, a plurality of substantially coplanar transverse stretched wires coupled mechanically at their mid-points to said longitudinal wire at the centers of equal sections thereof, means for applying transverse vibratory forces to one of said transverse wires adjacent one end of said longitudinal wire, and means responsive to vibratory motion coupled to another of said transverse wires, said wires being tuned to frequencies integrally related to a preassigned frequency whereby the system is adapted to transmit selectively vibrations in a frequency band centered about said preassigned frequency.

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