Nov. 20, 1928.

G. W. STEWART

1,692,317

ACOUSTIC WAVE FILTER

Original Filed July 25, 1922

Fig. 1.

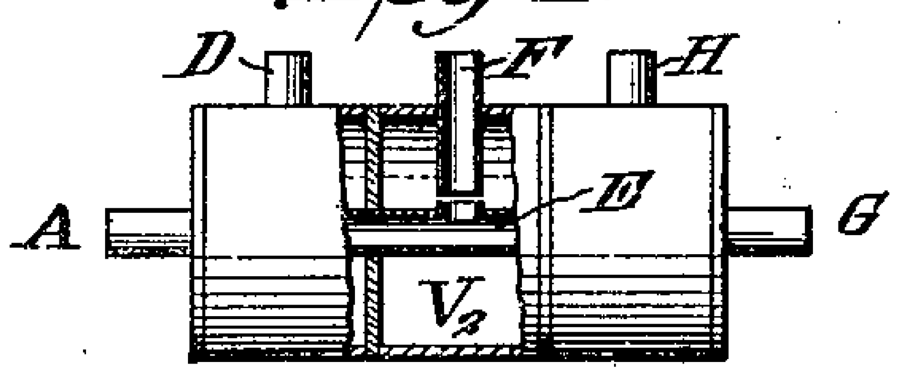



Fig. 2.

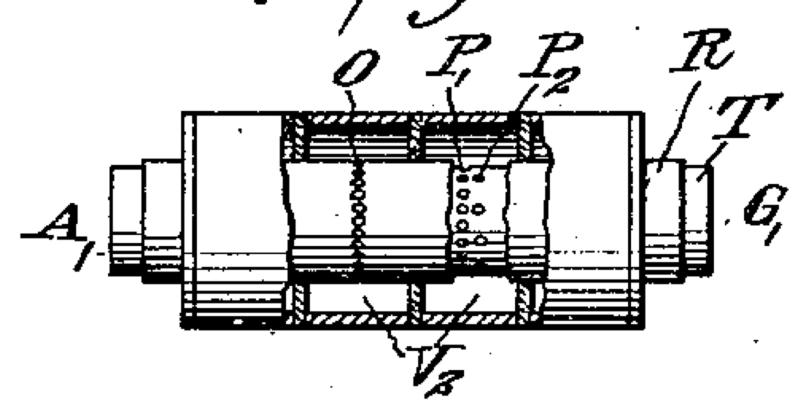
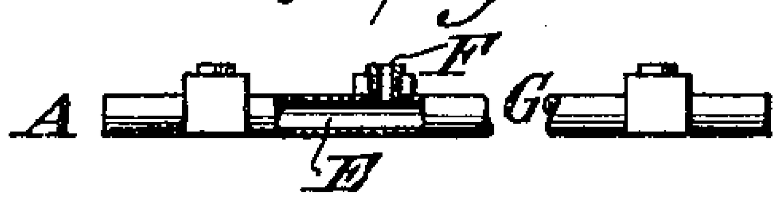



Fig. 3.



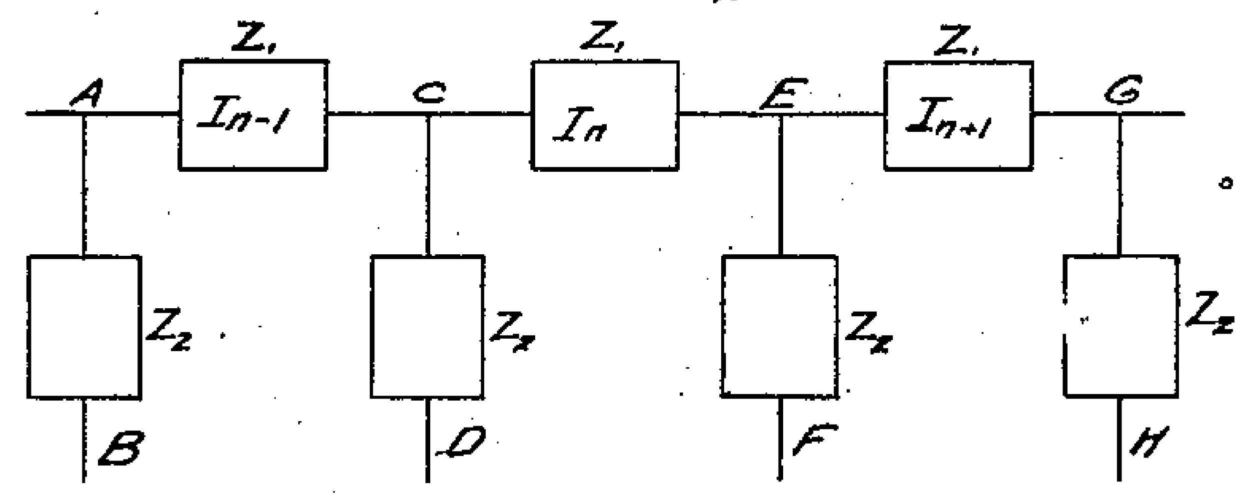




Fig. 4.

Fig. 5.

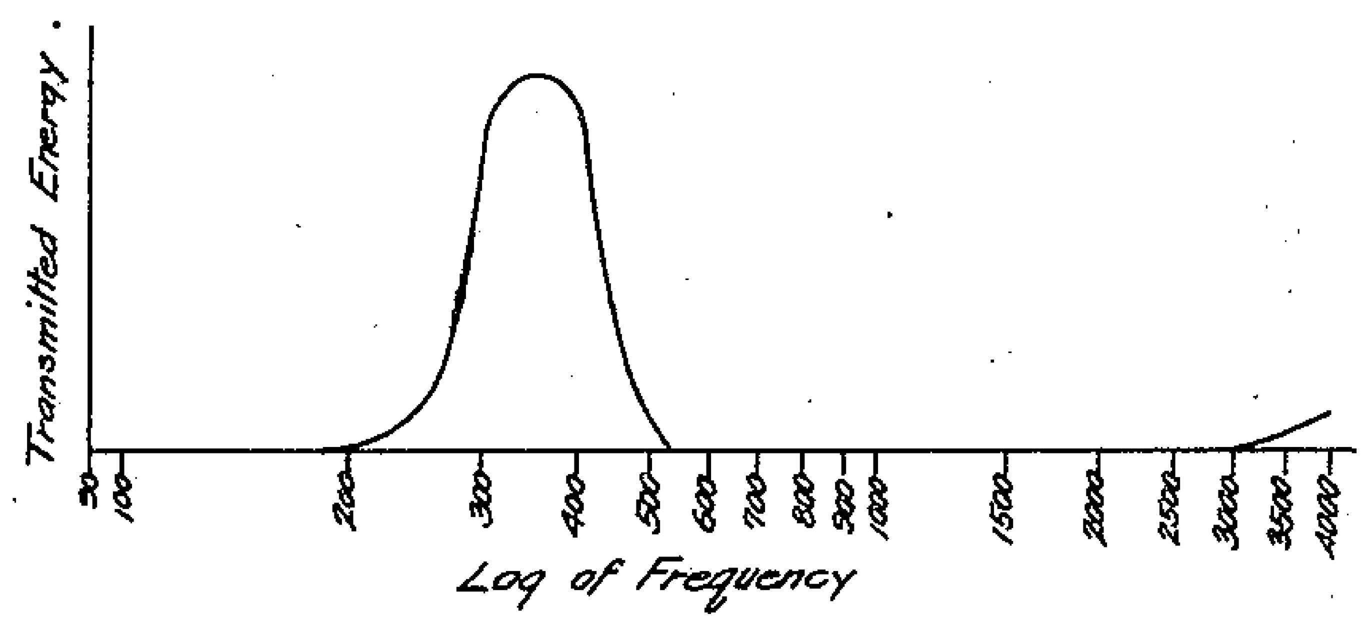



Fig. 6.

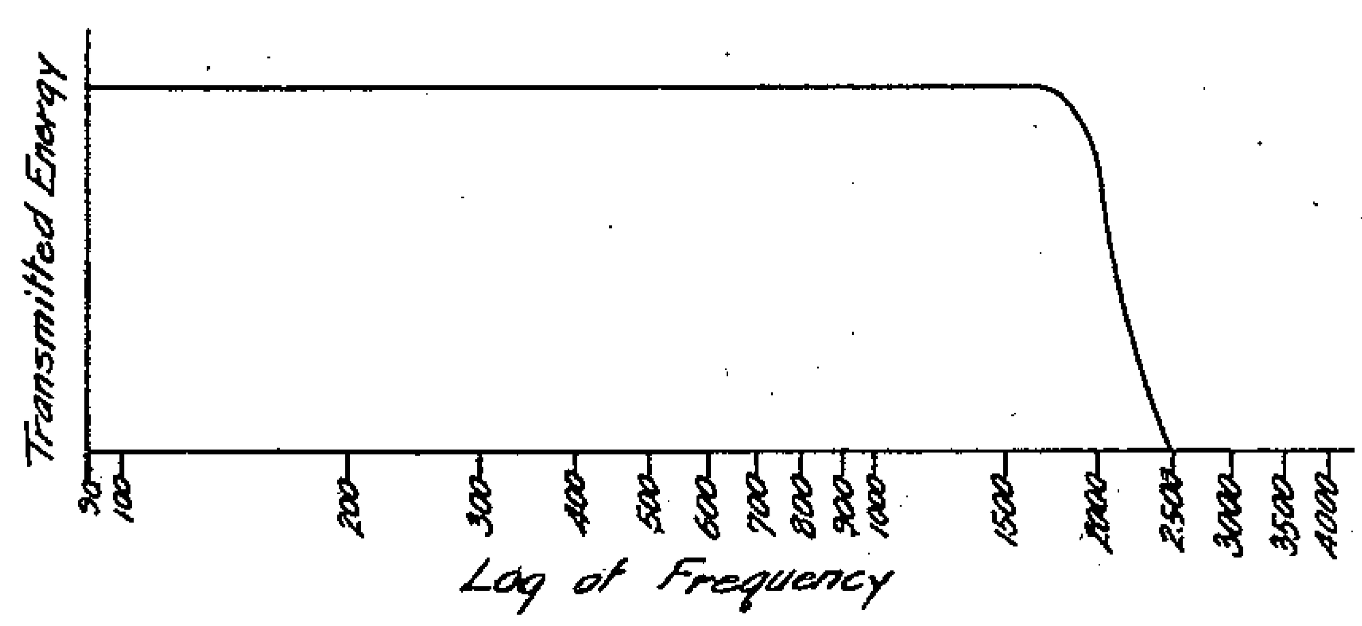
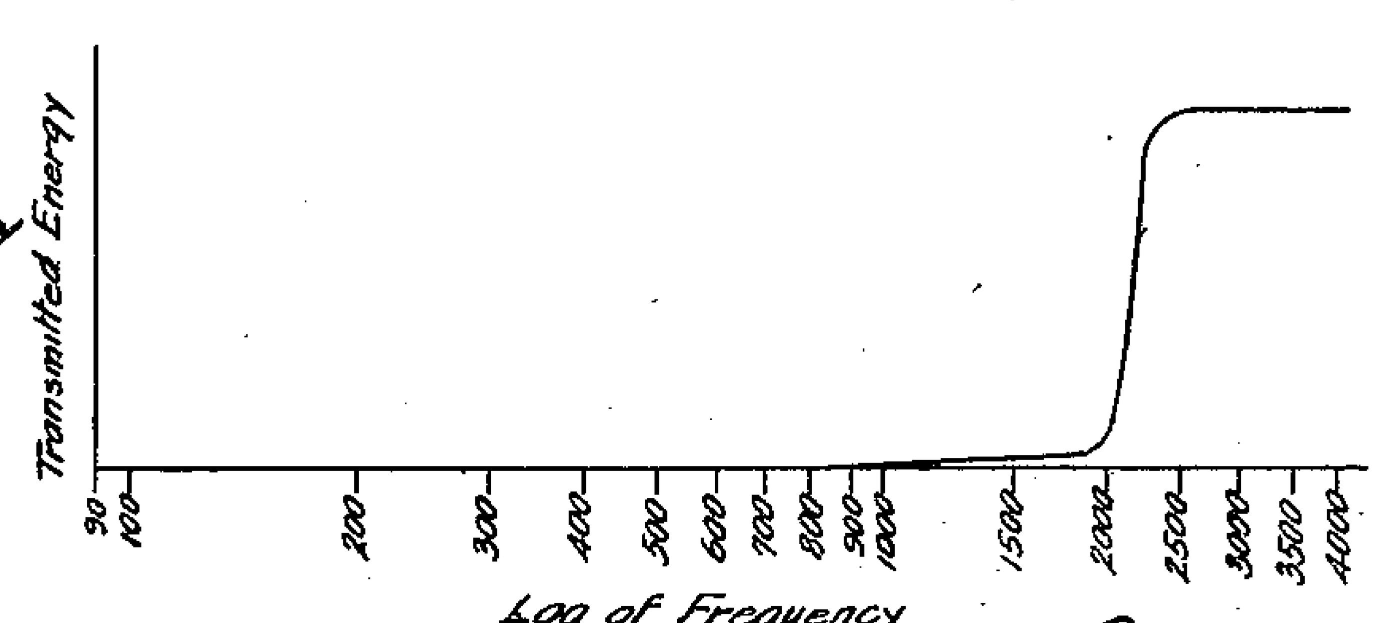



Fig. 7.

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# UNITED STATES PATENT OFFICE.

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## ACOUSTIC WAVE FILTER.

Application filed July 25, 1922, Serial No. 577,409. Renewed September 18, 1928.

This invention relates to an acoustic wave filter constructed to transmit without serious diminution sinusoidal waves of all frequencies lying within a range or ranges of preassigned limiting frequencies while attenuating and approximately extinguishing sinusoidal acoustic waves of frequencies lying outside the limits of the preassigned range or ranges.

The nature of the invention can be best presented by the use of the term, "acoustic impedance" which will be defined. In a column of gas confined in a tube, consider a portion which is short compared with the wave length of the acoustic sinusoidal wave passing through the gas in the tube. There will be a sinusoidally varying pressure difference acting upon the gas and a resulting sinusoidal variation in rate of change of volume displacement. These two sinusoidal variations will not be in the same phase. If they are expressed in the well-known complex notation, then their ratio will also be a complex quantity. The value of the acoustic impedance in this complex notation is the complex ratio of the pressure difference applied to the rate of change of volume displacement. The absolute value of the acoustic impedance is therefore the ratio of the maximum difference of pressure applied to the maximum rate of change of volume displacement. The acoustic wave may pass through the material or it may not as in the case of a confined volume of gas with one opening through which the gas vibrates. In view of the above definition, acoustic impedance is a term that can be applied to any vibrating portion of any material or medium whatsoever and is therefore the most convenient term to use in describing the basis of the invention.

By my definition, the value of the acoustic impedance is a ratio between two values, yet it is convenient to refer to a portion of a medium as possessing impedance and, indeed, to refer to that portion as an impedance. This is analogous to the usage of the terms "resistance", "inductance", etc., in electrical literature. (For reference to "acoustical impedance" in acoustical literature see "Acoustic impedance and its measurement" by A. E. Kennelly and K. Kurokawa, Proc. Am. Acad. of Arts and Sciences, vol. 56, No. 1, p. 3, 1921; and bibliography there given, and also to "Acoustical impedance, and the theory of horns and of the phonograph" by Arthur Gordon Webster, National Academy of Sciences, vol. 5, pp. 275–282, July, 1919.) It is further to be observed that, since impedances may be added, one or more when joined in series or in parallel may be regarded as a single impedance.

My invention, though it may find expression in many embodiments has common to all the broad idea of a wave filter in the nature of an acoustically conducting medium or conduit comprising a series of acoustic impedances along or through which the waves are transmitted to the desired point, and at junction points between these elements of impedance, branches each containing an acoustic impedance, the values of all these acoustic impedance elements being so proportioned that the conduit will transmit with small diminution sinusoidal acoustic waves of all frequencies lying within specified and preassigned limits or ranges and markedly extinguishing waves of all frequencies lying outside these limits.

My invention in one or more of its embodiments has important applications in all acoustic devices whether receiving or transmitting wherein it is desired to eliminate to a sensible or to a marked degree the flow of acoustic energy in specified groups of frequencies without seriously diminishing the flow of acoustic energy in other frequencies. Illustrations would be the sensible or the marked diminution in transmission of frequencies above a specified limit in the rendition of phonograph records, in the making of them, and in transmission to telephonic transmitters or from telephonic receivers. In fact, in any equipment whatsoever wherein acoustic transmission can be improved by the sensible or the marked diminution of the group of frequencies existing above a specified limit, below a specified limit, simultaneously both above and below specified limits, or finally between specified limits, all these limits being also preassigned, the acoustic wave filter, in one or more of its forms has an important and a unique application. Uniqueness of the acoustic wave filter rests in its ability to make the transmission practically zero in the frequencies intended to be eliminated without a serious diminution in the frequencies for which transmission is desired, in its ability to modify the degree of elimination and also in the fact that the frequently limits can be preassigned.

For a full comprehension of the principles upon which the invention is based and the application of such principles I make reference to the accompanying drawings which illustrate three typical forms of acoustical wave filters and their characteristics.

Fig. 1 is an elevation, partly in section of an acoustic wave filter according to the invention, which is representative of the types available for transmitting waves of frequencies lying between two preassigned limits while attenuating waves of frequencies lying outside the fixed range.

Fig. 2 is a similar view of a filter for transmitting waves of frequencies between zero and a predetermined limiting value.

Fig. 3 is a similar view of a filter for transmitting waves of frequencies above a certain preassigned value.

Fig. 4 is a diagrammatic representation of an acoustical path including impedances in the path and in branches laterally thereof, for facilitating the understanding of the theory on which the invention is based; and

Figs. 5, 6 and 7 are diagrams showing the characteristics of the wave filters illustrated in Figs 1, 2 and 3 respectively.

The form of the invention illustrated by Fig. 1 consists of a series of sections containing equal volumes $V_2$, and similar branch tubes, D, F and H. At the lower terminus of each of these tubes there is an opening into $V_2$ adjacent to an opening E into A G, which latter is the conduit or conducting line of the acoustic waves to be transmitted. The upper termini of D, F and H are in the undisturbed acoustic medium, which, in the illustration, is a gas. The openings E are preferably uniformly spaced. The elements of acoustical impedance referred to above, will now be described. In the conduit, A G, the portion of the gas between two consecutive openings E possesses impedance and may be properly called an impedance. The impedances in series are then, these two impedances between the branch openings in the conduit. The impedance in the branch is composed of two parts, one an enclosed volume of gas with an orifice and one a volume of gas terminating in the surrounding medium, which is assumed undisturbed. These two in parallel form the acoustical impedance in the side branch. This filter, as will be later pointed out, permits frequencies between two preassigned limits to pass but highly attenuates all other neighboring frequencies.

The form of the invention illustrated by Fig. 2 is essentially similar to that in Fig. 1, except that the tubular channels to the outside have been removed, leaving the volume $V_2$ the only branch impedance. The conduit $A_1$ $G_1$ is composed of two telescoping tubes R and T. The tube R has a plurality of circular series of openings O while the tube T has a plurality of double rows $P_1$, $P_2$. The tubes may be adjusted relative to each other to bring the series O in register with either the rows $P_1$ or $P_2$ to vary the number of openings from the conduit into the branches. The elements of impedances in series in $A_1$ $G_1$ are found between the openings into one side chamber and the openings into the next chamber, just as in Fig. 1. The branch impedances are the equal volumes $V_2$ with openings into A G. This filter, Fig. 2 will permit all frequencies between zero and a preassigned value to pass and will prevent all neighboring frequencies above this value from being transmitted. It is called a low-frequency-pass acoustic filter.

The form of the invention illustrated by Fig. 3, is similar to that in Fig. 1, except that the side column of gas is made the only part of the branch, the enclosed volume, $V_2$, having been removed. The impedances in series in the conduit $A_2$ $G_2$ are just as before and the branch impedances are now composed only of the columns defined by the branch tubes F extending outwardly from openings E in the conduit $A_2$ $G_2$. This filter will transmit through the conduit all frequencies above a certain preassigned value and will markedly attenuate all other frequencies.

It should be noted that the material used in construction in any one of these filters is not an essential feature, and that any of them can be readily built by one skilled in the art. In fact the walls serve the sole function of preventing the cross transmission of waves or of acoustically enclosing the vibrating medium, which in the drawings, is a gas. Any medium acoustically enclosed in a similar configuration would give similar transmitting and attenuating characteristics, as the accompanying theory will show.

It should be clearly understood at the very outset that my invention differs fundamentally both in structure and principle from random openings in acoustic conduits through which sound may pass. The effect is produced not by absorption of energy and dissipation, not by the well-known phenomenon of resonance but by the reactions and interactions of similar sections producing not dissipation but refusal to transmission. It is an interference phenomenon.

The fundamental principles underlying my invention and the manner of applying the same so as to provide a structure embodying the invention will now be set forth. For the purpose of deriving the mathematical formulæ pertaining to the theory of my invention, assume a structure represented by Fig. 4, consisting of a series of sections, each section having an acoustic impedance, $Z_1$, in series in the acoustic conduit, A C E G, and an impedance, $Z_2$, in a branch terminating either in a closed end across which transmission is negligible or in an otherwise undisturbed region of an acoustic medium. Let acoustic sinusoidal waves of a frequency $\frac{\omega}{2\pi}$ be transmitted through conduit A C E G, which is for the purposes of the theory, assumed to be a portion of a structure of infinite length. Assume the nature of $Z_2$ to be such that there is a common constant pressure at or near the termini of these branch impedances. Let $I_n e^{i\omega t}$ represent the rate of change of volume displacement in the conduit in the $n^{th}$ section, I being complex. If now it is assumed that the algebraic sum of the I's at any junction point is zero and apply the definition of impedance, we have the following equation:

$$Z_2(I_{n-1}-I_n)=Z_2(I_n-I_{n+1})+Z_1I_n \quad (1)$$

If $\Delta P$ is the (complex) pressure difference over a branch,

$$\left.\begin{aligned}\Delta P_{CD}&=I_n(Z_1+Z\infty)\\ \Delta P_{EF}&=I_{n+1}(Z_1+Z\infty)\end{aligned}\right\} \quad (2)$$

wherein $Z\infty$ is the impedance of the infinite network to the right in the figure of the section considered and therefore has the same value in both equations. Substituting the values,

$$\left.\begin{aligned}\Delta P_{CD}&=Z_2(I_{n-1}-I_n)\\ \Delta P_{EF}&=Z_2(I_n-I_{n+1})\end{aligned}\right\} \quad (3)$$

in (2) and dividing we have,

$$\frac{I_{n+1}}{I_n}=\frac{I_n-I_{n+1}}{I_{n-1}-I_n} \quad (4)$$
$$\frac{I_{n+1}}{I_n}=\frac{I_n}{I_{n-1}}$$

Thus the ratio of successive I's is constant, but, in general, complex. Let its value be $e^Y$. Substituting this value in (1) we have,

$$e^Y+e^{-Y}=2+\frac{Z_1}{Z_2} \quad (5)$$
$$\text{or } \operatorname{Cosh} Y=1+\frac{1}{2}\frac{Z_1}{Z_2}$$

From (4), if Y is a pure imaginary, the rate of volume displacements in two adjacent sections differ only in phase, that is, there is no attenuation. If Y is not a pure imaginary, the rate of volume displacement is diminished in transmission, obviously the diminution occurring away from the input end. If Y is a pure imaginary, since Cosh $ix$=Cos$x$, the condition must hold that,

$$+1>\left(1+\frac{1}{2}\frac{Z_1}{Z_2}\right)>-1 \quad (6)$$

and hence the limiting values of no attenuation are determined by the following:

$$\frac{Z_1}{Z_2}=0 \quad (7)$$

$$\frac{Z_1}{Z_2}=-4 \quad (8)$$

If the actual values of $Z_1$ and $Z_2$ are substituted in (7) and (8), the limiting values of frequencies for no attenuation are found. These considerations show that an acoustic wave filter having regions of attenuation and no attenuation can be constructed if the conduit and branches are composed of acoustic impedances, the magnitudes of which vary in different manners with frequency, so that their ratio passes through the range of values between zero and −4.

It can be shown that if two acoustic impedances are connected in parallel, one having inertia only and one having stiffness only, and if the pressure difference acting is $Pe^{i\omega t}$, and I is the resultant volumetric velocity in the main conduit at the junction of the two branches, then

$$I=Pe^{i\omega t}\left(\frac{1-MC\omega^2}{iM\omega}\right) \quad (9)$$

wherein $M=\frac{Ma}{S_a^2}$ and $\frac{1}{C}=\frac{f_b}{S_b^2}$, and $Ma$ is the mass of the branch $a$, $f_b$ is the stiffness of branch $b$, $Sa$ and $Sb$ are the areas of branches $a$ and $b$ respectively. $f_b$ is herein defined by the equality $\frac{f_b}{S_b^2}X=Pe^{i\omega t}$, X being the volume displacement. But in accordance with the definition of impedance, the impedance of the combined branches in parallel is, from (9),

$$Z=\frac{iM\omega}{1-MC\omega^2} \quad (10)$$

Similarly it can be shown that if these two acoustic impedances, M and C, are connected in series the resulting impedance is,

$$Z=i\left(M\omega-\frac{1}{C\omega}\right) \quad (11)$$

Further, if two acoustic impedances in series, $M_2^1$ and $C_2$, are connected in parallel with another impedance $M_2$, the resulting impedance is,

$$Z=\frac{M_2\omega\left(M_2^1\omega-\frac{1}{C_2\omega}\right)}{M_2\omega+M_2^1\omega-\frac{1}{C_2\omega}} \quad (12)$$

We shall hereinafter refer to the impedances $M_2$, as above defined, as an inertance, and to C as a capacitance.

In securing a practical construction we will assume that a piece of conduit or conducting material, short in comparison with wave length, is equivalent to an inertance and a capacitance connected in parallel. If the conduit is cylindrical M, from definition, becomes $\frac{\rho l}{S}$ where $\rho$ is the density of the medium, $l$ the length, and S the area of cross-section. In order to find the value of C, assume a volume of gas, V, acoustically enclosed except for a small opening. At any instant, $\frac{f_b}{S_b^2}X=\delta p$, where $\delta p$ is the excess pressure acting and $X$ is the volume displacement. But, from fundamental considerations, $\delta p=\rho a^2\frac{X}{V}$ where $a$ is the velocity of sound and V is the volume of the medium. Hence we find,

$$\frac{f^b}{S_b^2}X=\frac{X}{C}=\rho a^2\frac{X}{V}$$

and

$$C=\frac{V}{\rho a^2}$$

We shall also assume that if $M_2^1$ is the inertance of an orifice or channel it is synonymous with $\rho/K$, where K is the "conductivity" (see Rayleigh, Theory of Sound, vol. II, p. 172, 1896, Equation (1) and p. 181, Equation (1) of the channel and hence,

$$M_2^1=\frac{\rho\left(l+\frac{1}{2}\pi r\right)}{\pi r^2} \quad (13)$$

wherein $l$ is the length of the circular channel and $r$ its radius.

The application of these formulæ in a structure and the method by which anyone skilled in the art may construct a wave filter which will transmit with small attenuation a definite, preassigned band of frequencies while attenuating all outlying frequencies, will now be shown.

In Fig. 1, the cylindrical volume of gas is the acoustic conductor or conduit, transmitting acoustic waves say from A to G. $Z_1$, (referring to Fig. 4) is the volume between E and the adjacent junction. Its M is denoted by $M_1$, and its C by $C_1$. $Z_2$ consists of the branch $M_2^1$ and $V_2$ in series connected in parallel with another branch, a tube E F or $M_2$. $M_2^1$ is the inertance of the orifice of $V_2$ and $M_2$ the inertance of the tube.

For the sake of simplicity we will assume that we may neglect $C_1$ and with this provision and the application of (10) as $Z_1$, and (12) as $Z_2$, we have from conditions (7) and (8) respectively, the following:

$$f_1=\frac{1}{2\pi}\sqrt{\frac{1}{C_2(M_2+M_2^1)}} \quad (14)$$

$$f_2=\frac{1}{2\pi}\sqrt{\frac{M_1+4M_2}{C(M_1M_2+M_1M_2^1+4M_2M_2^1)}} \quad (15)$$

If now we substitute the values for $M_1$ and $M_2$, $\rho\frac{l_1}{S_1}$ and $\rho\frac{l_2}{S_2}$ respectively, for $C_2$, $\frac{V_2}{\rho a^2}$, and for $M_2^1$ the value in (13), we will have the limiting frequencies expressed in terms of the dimensions of the apparatus and the velocity of sound. Thus anyone skilled in the art can construct such a filter having a single transmission band with $f_1$ and $f_2$ the limiting frequencies thereof. Outside of the region of frequencies from $f_1$ to $f_2$, there will be an attenuation.

In Fig. 2 the wave filter may be regarded as a modification of Fig. 1, by the removal of the branch tube. This is the same in effect as making $M_2=\infty$. (14) and (15) therefore become,

$$f_1=0 \quad (16)$$

$$f_2=\frac{1}{\pi}\sqrt{\frac{1}{C_2(M_1+4M_2^1)}} \quad (17)$$

It is thus possible to construct a low frequency-pass filter, which will transmit all those frequencies from zero up to the value, $f_2$, and attenuate those above this limit. Formula (17), when the foregoing values of $C_2$, $M_1$ and $M_2$ are substituted, will enable anyone skilled in the art to construct a wave filter which will have the characteristics just stated, the value of $f_2$ being preassigned.

In Fig. 3, we have a construction similar to Fig. 1 except that $V_2$ and the opening into it have been removed. Heretofore we have assumed $C_1=0$ and have considered the inertance of the tube $M_1$, only, this proving to be in fair agreement with experiment. In Fig. 3, however, we are dealing with only inertance in the branch tube and hence $C_1$ now assumes an importance. Then $Z_1$ remains as in (10) and $Z_2$ becomes from (10)

$$Z_2=iM_2\omega.$$

Substituting these values in (7) and (8), we have,

$$=\infty \quad (18)$$

$$f_2=\frac{1}{2\pi}\sqrt{\frac{M_1+4M_2}{4M_1M_2C_1}} \quad (19)$$

$M_2$ may be expressed $\rho\frac{l_2}{S_2}$ or as an orifice according to (13), the latter being adopted if $l_2$ is short. $C_1=\frac{V_1}{\rho a^2}$. By substituting these values we have secured a value of $f_2$ in terms of the dimensions and of the velocity of sound and thus anyone skilled in the art is enabled to construct such a high frequency pass filter with the value of $f_2$ preassigned.

The foregoing derived practical equations give only approximately correct values for $f_1$ and $f_2$ and for the reason that the assumptions are approximations. But a fair agreement is had between computed and experimental values with wide variations in dimensions. Moreover the range of frequencies above $f_2$ in which there is a high theoretical attenuation will depend for its extent upon the number of sections used and upon the relative values of wave length and length of a section.

It is to be observed that in (14) $f_1$ can be modified by the change in orifice, or $M_2^1$, and that in (15) and (17), $f_2$ can be modified in a similar manner. Thus adjustable filters can be made either by providing for an alteration in the number of orifices as in Fig. 2 or by changing the size of one orifice.

It is to be understood that the general theory including (7) and (8) should be regarded as correct within the limits of the approximations used, but that in the derivation of later equations the assumptions are somewhat empirical and hence lead to equations semi-empirical in character but serviceable in actual filter construction. Notwithstanding the approximations all are clearly dependent upon the general theory which is basic. Thus, though the exact forms of these practical equations are not essential in the application of the principles herein set forth, they do aid one skilled in the art to construct a filter that will have approximately the preassigned values of $f_1$ and $f_2$.

It is also understood that in the successful design and construction of filters by these formulæ regard will be taken of the original assumptions that the junctions are virtually points, making the algebraic sum of the I's zero, and that the length of a section is small compared to a wave length. As the formulæ do not hold for relatively short wave lengths, additional transmission bands may pass filters such as shown in Figs. 1 and 2, which bands cannot be predicated by the formulæ given. Such additional and relatively high frequency bands may be determined empirically or may be predicted by theory and formulæ which are based upon assumptions additional to those specified above.

It will be further understood that the number of sections of the wave filter needed will depend on the degree desired for the attenuation of the frequencies to be filtered out. This control can also be obtained by modifying the size of the opening into the side branches, and by the insertion of a medium of different material in the openings from the conduit into the branches. Both methods produce a diminution in the vibrations in the branches and thus decrease the filtering action as such.

It should further be observed that though the theory provides for the use of but one medium in the acoustically enclosed region, it can be readily extended to include any number of media by the observation that these would merely introduce additional reflections at the surfaces of separation and thereby decrease the effect herein described. As an example may be cited the insertion of a thin diaphragm across the openings into the side branches. These diaphragms reflect the acoustic waves, transmitting only a fraction of the amplitude of vibration which would occur without the diaphragms.

By reference to the theory it can be seen that, in general, if Y is imaginary, or if the frequency is in the unattenuated region, there is a definite change of phase in passing from one section of the conduit to the next. Outside this region of frequencies Y is complex and hence, according to the theory, there is both change in phase and change in the value of I, the logarithm of the absolute values of the I's in adjacent sections being a constant. Thus the effect increases rapidly with the number of sections used.

It should be further understood that the performance of such filters shows that it is easy to produce in the regions of attenuation a transmission that is sensibly zero. Fig. 5, Fig. 6 and Fig. 7 show the nature of the transmission obtained experimentally by three filters, one of each type. The contrast in transmission in the attenuated and non-attenuated regions is unique in acoustics. As an illustration of the application of an acoustic wave filter, the phonograph will be cited. The filter may be applied anywhere in the conduit from the sound box to the broad flaring portion, but it may be readily applied by inserting the filter in the tube between the sound box or diaphragm and the crook. If the filter is that shown in Fig. 2, giving a transmission curve like that in Fig. 6, the effect upon the music is marked. The undesirable high frequencies are removed in the rendition of the music giving a more natural and more pleasing effect and simultaneously removing much of the harshness of the scratching sound.

In the foregoing I have evolved basic formulæ for the practical construction of wave filters adapted to attenuate sound waves of certain frequencies while permitting sound waves of different frequencies to pass substantially unattenuated. It is needless to say that within the scope of latitude of initially selecting one of the variable quantities in the formulæ as a starting point and evaluating the others from the formulæ, the number of specific constructions possible is infinite.

Although the diagrams illustrate the performance of filters which effect a complete suppression or extinction of ranges of frequencies, it is obvious that the invention is not limited to the provision of filters which effect a complete suppression of a range of frequencies. The invention may be applied to effect any desired degree of attenuation of a predetermined range or ranges of frequencies, the degree of attenuation depending upon the particular problem involved and varying from a relatively slight attenuation to complete suppression.

As has been pointed out, the invention has as its cardinal point the correlation of acoustic impedances in series and forming part of an acoustic line of transmission and acoustic impedances in lateral branches or in shunt, as it were, with the impedances in series, in close analogy to an electric circuit containing impedances in series with the line and in parallel or shunt with the line.

This application is intended as a continuation in part of my application Ser. No. 430,999, filed December 15, 1920.

I claim:

1. An acoustic wave filter, comprising a sound-conducting medium defining a sound-transmitting path and means defining an acoustic impedance so proportioned and arranged that waves of frequencies lying within a predetermined range are considerably more attenuated in passing along the said path than waves of frequencies lying within another range.

2. An acoustic wave filter, comprising means acoustically confining a fluid sound-conducting medium to define a sound-transmiting path and means defining an acoustic impedance so proportioned and arranged that waves of frequencies lying within a predetermined range are considerably more attenuated in passing through the said path than waves of frequencies lying within another range.

3. An acoustic wave filter, comprising a sound-conducting medium defining a sound-transmitting path and means defining an acoustic impedance so proportioned and arranged that waves of frequencies lying within a predetermined range are transmitted along said path without serious attenuation and that waves of frequencies lying outside said range are materially attenuated.

4. An acoustic wave filter, comprising means acoustically confining a fluid sound-conducting medium to define a sound-transmitting path and means defining an acoustic impedance so proportioned and arranged that waves of frequencies lying within a predetermined range are transmitted through said path without serious attenuation and that waves of frequencies lying outside said range are materially attenuated.

5. An acoustic wave filter, comprising a sound-conducting medium defining a sound-transmitting path and means defining an acoustic impedance so proportioned and arranged that waves of frequencies lying within a predetermined range are transmitted along said path substantially without attenuation and that waves of frequencies lying outside such range are materially attenuated.

6. An acoustic wave filter, comprising means acoustically confining a sound-conducting medium to define a sound-transmitting path and means defining an acoustic impedance so proportioned and arranged that waves of frequencies lying within a predetermined range are transmitted through said path substantially without attenuation and that waves of frequencies distinctly outside of such range are substantially extinguished.

7. An acoustic wave filter, comprising means defining a plurality of acoustic impedances in series forming part of an acoustic path and a plurality of impedances branching therefrom, said impedances being so proportioned and arranged that waves of frequencies lying within a predetermined range are transmitted along the said path without serious attenuation and that waves of frequencies lying outside such range are materially attenuated.

8. An acoustic wave filter, comprising means composed of a plurality of sections constituting a sound transmitting path, each section including a mass of the said medium and a volume of the medium disposed branching therefrom, said mass and volume being so proportioned that waves of frequencies lying within a predetermined range are transmitted along the said path without serious attenuation and that waves of frequencies lying outside such range are materially attenuated.

9. An acoustic wave filter, comprising means acoustically confining a fluid sound-conducting medium to define a plurality of sections constituting a sound-transmitting path, each section including a mass of the said medium and a volume of the medium disposed branching therefrom, said mass and volume being so proportioned that waves of frequencies are transmitted along the said path without serious attenuation and that waves of frequencies lying outside such range are materially attenuated.

10. An acoustic wave filter, comprising means defining an acoustic path and including acoustic impedances disposed at regular intervals in the direction of length of the path, said impedances being so proportioned and arranged that waves of frequencies lying within a predetermined range are transmitted along the path without serious attenuation and that waves of frequencies lying outside such range are materially attenuated.

11. An acoustic wave filter, comprising means constituting an acoustic path and including acoustic impedances in series in the path and impedances branching from and alternating with the impedances in series, said impedances being so proportioned that due to their interaction and reaction upon each other, waves of frequencies lying within a predetermined range are transmitted through the path without serious attenuation and that waves of frequencies lying outside such range are materially attenuated.

12. An acoustic wave filter comprising means defining a plurality of acoustic impedance elements in series and a plurality of acoustic impedance elements branching therefrom at the junction points in the series, said impedances being so proportioned and arranged that waves of frequencies lying within a predetermined range are transmitted substantially without attenuation and that waves

of frequencies lying distinctly outside such range are substantially extinguished.

13. An acoustic wave filter, comprising a tubular conduit having openings in spaced relation in the direction of its length and an acoustic enclosure surrounding each opening outside the tube, the openings and the enclosures being so proportioned and arranged that waves of frequencies lying within a predetermined range are transmitted through the conduit without serious attenuation and that waves of frequencies lying outside such range are materially attenuated.

14. An acoustic wave filter, comprising a circular tube having openings in spaced relation in the direction of its length and an acoustic enclosure surrounding each opening outside the tube; the openings and the enclosures being so proportioned and arranged that waves of frequencies lying within a predetermined range are transmitted without serious attenuation and that waves of frequencies outside such range are materially attenuated.

15. An acoustic wave filter, comprising two co-axially disposed tubular bodies, a plurality of axially spaced partition walls dividing the interspace into separate compartments and openings between the inner tubular body and the separate compartments, said openings and compartments being so proportioned and arranged that waves of frequencies lying within a predetermined range are transmitted through the inner tubular body without serious attenuation and that waves of frequencies lying outside such range are materially attenuated.

16. An acoustic wave filter, comprising two concentric tubes, a plurality of axially spaced partition walls defining annular interspaces and communications between the inner tube and the said spaces, said communications and interspaces being so proportioned and arranged that waves of frequencies lying within a predetermined range are transmitted through the inner tube without serious attenuation and waves of frequencies outside said range are materially attenuated.

17. An acoustic wave filter, comprising two co-axially disposed tubular bodies, a plurality of axially spaced partition walls dividing the interspace into separate compartments, openings between the inner tubular body and the separate compartments and tubes extending through the outer tubular body into the compartments into close proximity to the openings in the inner tubular body in axial alignment with said openings.

18. An acoustic wave filter, comprising two concentric tubes, a plurality of axially spaced partition walls defining annular interspaces, openings between the inner tube and the said spaces and tubes extending through the outer tube into the interspaces into proximity to the openings in the inner tube and in axial alignment with the said openings.

19. The combination with a sound-producing device, of a wave filter comprising an acoustic conduit including an impedance so proportioned and arranged that sound waves emitted by the producing device and of frequencies lying within a predetermined range are transmitted without serious attenuation and that waves outside such range are materially attenuated.

20. The combination with a sound-responsive device, of a wave filter comprising an acoustic conduit including an impedance so proportioned and arranged that waves passing to the sound-responsive device and of frequencies lying within a predetermined range are transmitted to the sound-responsive device without serious attenuation and that waves of frequencies outside such range are materially attenuated.

21. An acoustic wave filter comprising a tubular body enclosing an acoustically conductive medium, means around the tubular body acoustically confining a plurality of axially spaced volumes of an acoustically conductive medium and an acoustical communication between the medium in the tubular body and each of the volumes around it.

22. In an acoustic filter, a sound-conducting path, and means associated therewith for preventing the passage along said path of sound waves of a predetermined continuous range of frequencies.

23. In an acoustic filter, a sound conducting passage and means associated therewith for preventing the passage therefrom of sound waves of a predetermined range of frequencies.

24. In an acoustic filter, a sound-conducting path, and means associated therewith for effecting a material attenuation of sound waves of a predetermined continuous range of frequencies while effecting substantially no attenuation of sound waves of another continuous range of frequencies.

25. In an acoustic filter, the combination with a sound-conducting path, of means located outside of and cooperating with said path for preventing the passage along said path of sound waves of a predetermined continuous range of frequencies.

26. In an acoustic filter, the combination with a sound-conducting path, of means located outside of and cooperating with said path for selectively effecting sound waves traversing said path by attenuating in materially different degrees sound waves of two different and non-overlapping continuous ranges of frequencies.

In testimony whereof, I affix my signature.

GEORGE WALTER STEWART.