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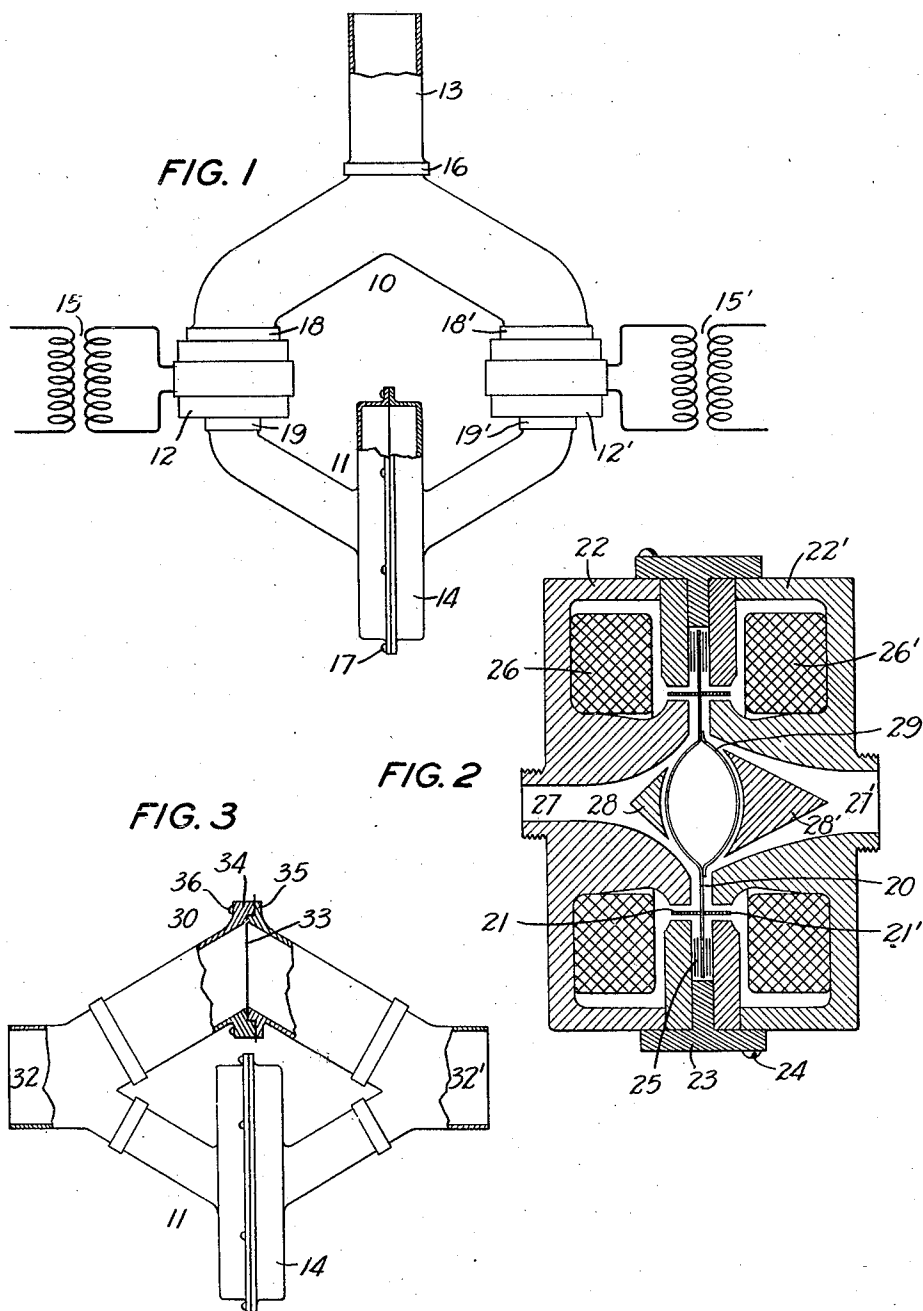
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ACOUSTIC PHASE SHIFTING DEVICE

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ACOUSTIC PHASE-SHIFTING DEVICE

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This invention relates to wave transmission, and more particularly to acoustic devices for controlling the response characteristics of speech transmission systems and the like.

An object of this invention is to correct phase, or transient distortion in speech transmission systems.

Another object is to obtain economy of space and material in the construction of phase distortion compensators.

A problem of great importance arises in connection with the transmission of speech or other signals, over coil loaded lines, wherein waves of different frequencies are in general transmitted with different effective velocities; which results in a form of distortion known as phase, or transient, distortion. The usual method of correction is to insert in the line an electrical network whose overall phase characteristic is complementary to the phase characteristic of the line, whereby the phase change in the combination is substantially proportional to the frequency. The use of an electrical network, however, requires a large number of coils and condensers, and for the compensation of lines of any considerable length, the expense involved is very great. In accordance with this invention the electrical network is replaced by an acoustic device which has the property of being able to transmit waves of all frequencies without attenuation, but with different effective velocities; and which can be proportioned so that the variable velocity characteristic substantially compensates that of a given transmission line. Telephone receivers or other suitable translating means, coupled to the ends of the acoustic device serve to connect it into the line it is desired to compensate.

In the device of this invention, sound waves are transmitted through two paths joined at each end either in a common sound channel or at the diaphragm of a telephone receiver. Each of these paths includes an acoustic filter, a characteristic of which is that throughout the frequency spectrum there occur alternately, transmission and attenuation bands. The filters are so proportioned that the trans-

mission bands of the one occur in approximately the same frequency ranges as the attenuation bands of the other. Waves can thus pass freely through the one path or the other, or at the edges of the bands may be transmitted through both channels. By properly proportioning the two paths the device may be made to pass waves of all frequencies without attenuation. In this respect the device acts like a simple uniform sound conduit, or any other type of uniform wave transmission line, but in the respect of the phase change produced in waves of different frequencies the properties of the device are quite different from those of a uniform line. In the attenuating band of a wave filter there is no change, with frequency, of the phase relation between input wave pressure and output waves, but throughout a transmitting band, there is a continuous change in the phase relation, this change being, in general, non-uniform with respect to frequency. This means that waves of different frequencies traverse the wave filter in different time intervals or with different effective velocities. In the devices of the invention the resultant frequency-phase shift characteristic is that of the combined paths, and since the transmission bands are approximately contiguous, it takes a form closely related to that obtained by adding the individual phase characteristics together. When the filters are so proportioned that the device is rigorously capable of passing waves of all frequencies a smooth phase shift characteristic is obtained which can be suited to the compensation of velocity distortion of loaded lines. The phase characteristic can also be adapted to simulate the phase characteristics of loaded lines and again, two or more structures, each an all-pass phase shifting device in itself, can be joined in tandem to furnish a composite phase characteristic which is more suitable than the phase characteristic of any of the individual structures.

A feature of the invention is that the component wave filters are made up of elements each of which is a short section of a uniform acoustic line, or has impedance properties similar to those of uniform acoustic line. In

one embodiment the impedance of a short length of line is simulated by an elastic membrane stretched across one of the sound paths, such a membrane having been found to have an impedance of substantially the same character at all frequencies as that of a closed air column. In another embodiment, the impedance of a length of line, or air column, is simulated by a hollow circular disc concentrically disposed in the sound path.

Fig. 1 illustrates a phase shifting device in accordance with the invention in which the two sound paths are joined together by telephone receivers;

Fig. 2 is a detailed illustration of a telephone receiver adapted to couple the sound paths in Fig. 1;

Fig. 3 shows a phase shifting device embodying the invention in which the two sound paths are coupled directly;

Fig. 4 shows typical phase shift characteristics obtainable in the devices of the invention;

Fig. 5 illustrates the phase characteristic of a loaded line and the compensating characteristics of phase shifting devices according to this invention; and

Fig. 6 illustrates an acoustic phase shifter comprising a plurality of sections.

Referring to Fig. 1, the phase shifting section comprises two sound paths or conduits 10 and 11 of equal length, joined at each end by means of telephone receivers 12 and 12'. Each of the sound paths is provided at its midpoint with a side branch which in path 10 is an open ended air column 13, and in path 11 is a hollow concentric cylindrical chamber 14. The air column 13 is a length of pipe which is fastened at the end to a threaded flange 16 at the midpoint of conduit 10. Path 11 is made in two equal parts which are joined together in assembling. Each part comprises a length of conduit and half of the enclosing walls of the associated cylindrical chamber. The two parts are joined by coupling together the two portions of the cylindrical chamber, which are fastened by screws 17 through flanges provided for the purpose around the rim. The round conduits are connected to the receivers by fitting them into tight fitting bushings 18, 18' and 19, 19' provided in the outlets of the receivers. The component parts of the device should be proportioned in a manner to be hereinafter described. The device is adapted to be connected between two portions of an electric line by means of impedance matching transformers 15 and 15'.

Fig. 2 is a detailed view in section of a telephone receiver suitable for joining the ends of the sound paths 10 and 11 in Fig. 1. This receiver is of the moving coil type, the driving force being applied to a diaphragm 20 by a pair of helical coils 21 and 21' rigidly

fastened thereto and located in air gaps between the poles of electromagnets 22 and 22'. These two electromagnetics are clamped together by a circular band 23 fastened to both pole pieces by machine screws 24. The circular band is provided on its inside with an integral tongue which acts as a spacer between the two pole pieces providing a space in which the diaphragm can move freely. The diaphragm is held lightly at its outer edge by means of rings 25 of paper or metal foil which provide a certain amount of frictional damping for the movement of the diaphragm. The pole pieces are excited by toroidal coil windings 26 and 26' which are to be connected to a source of direct current such as a storage battery. The receiver is provided with two sound outlets 27 and 27', one on each side of the diaphragm and, since the conduits which are coupled together by the receiver are in general of different sizes, the diameters of the sound outlets are made to correspond. The plunger portion of the diaphragm is made convex outward on both sides so that it is adapted to propagate waves equally well in each direction. This construction of the diaphragm is most easily obtained by making the diaphragm stamping convex on one side and then cementing an auxiliary convex plunger portion 29 on the other side. The sound is taken off from intermediate annular sections of the diaphragm, the sound passages through the centers of the magnets being made divergent and provided for this purpose with conical central plugs 28 and 28' attached to the magnets by webs.

Fig. 3 illustrates a modification of the phase shifting section of Fig. 1. It comprises two sound paths 11 and 30, the ends of which meet directly in common channels 32 and 32'. Path 11 is similar to path 11 in Fig. 1. Path 30, however, instead of having at its midpoint a side branch tube, has an elastic membrane 33 stretched across the channel. To enable the membrane to be put in place and stretched, path 30 is constructed in two parts which are joined at the membrane. Flanges 34 and 35 are provided at the ends of the component parts of the sound path, the flange 34 sliding over flange 35. The edge of the membrane is placed between the two flanges, which are fastened together by machine screws 36 so that the tension of the membrane can be regulated by tightening or loosening the machine screws. This embodiment requires no acoustical-electrical link to join the two paths, but if it is desired to incorporate the section into an electrical line, telephone receivers must be used in the common channels 32 and 32'. As will be seen, it is usually desirable to use more than one section of the structure of Fig. 1 or Fig. 3 in which case the telephone receivers need be used only in connection with the two end

sections, in a manner which will be shown later.

It can be shown that the propagation constants of the sections of both Fig. 1 and Fig. 3 are equal when certain conditions which will later be disclosed, are fulfilled, and are expressed by the equation:

$$\cos \frac{2\omega L}{c} \left\{ 3 - \frac{Z_{L_1}^2}{Z_{L_2}^2} \cot^2 \frac{\omega L}{c} - \frac{Z_{L_2}^2}{Z_{L_1}^2} \tan^2 \frac{\omega L}{c} \right\} + 4 \frac{Z_{L_1}}{Z_{L_2}} \cos^2 \frac{\omega L}{c} - 4 \frac{Z_{L_2}}{Z_{L_1}} \sin^2 \frac{\omega L}{c}$$

$$\text{Cosh } P = \frac{1 - \frac{Z_{L_2}^2}{Z_{L_1}^2} \tan^2 \frac{\omega L}{c} - \frac{Z_{L_1}^2}{Z_{L_2}^2} \cot^2 \frac{\omega L}{c}}{1} \quad (1)$$

where P denotes the propagation constant of the section;

Z_{L_1} denotes the acoustic characteristic impedance of the upper sound conduit;

Z_{L_2} denotes the acoustic characteristic impedance of the lower sound conduit;

L denotes half the length of each of the parallel sound conduits, i. e. the length from one end to the junction point of the midpoint impedance;

c denotes the velocity of sound in air; and

ω is 2π times the frequency of sound vibration.

The acoustic impedance as used herein is defined as the ratio of the excess pressure intensity to the volumetric flow of air per second over the cross section of the path at the point under consideration; the acoustic characteristic impedance of any uniform conduit is the impedance which would be measured at the input end of an infinite length of such a conduit and is equal to the quantity,

$$\sqrt{P_0 \gamma \rho}$$

divided by the cross sectional area of the conduit. Thus,

$$Z_{L_1} = \frac{\sqrt{P_0 \gamma \rho}}{S_1} \text{ c. g. s.} \quad (2)$$

$$\text{and } Z_{L_2} = \frac{\sqrt{P_0 \gamma \rho}}{S_2} \text{ c. g. s.} \quad (3)$$

in which P_0 denotes the atmospheric pressure;

γ denotes the ratio of the specific heats of air;

ρ denotes the density of air; and

S_1 and S_2 denote the cross sectional areas of the respective sound conduits corresponding to Z_{L_1} and Z_{L_2} .

The quantity, $\sqrt{P_0 \gamma \rho}$,

is a constant about equal to 43 when air is the medium.

The structures of Figs. 1 and 3 are very similarly arranged, Fig. 1 showing two sound paths joined in series by telephone receivers, and Fig. 2 showing two sound paths in parallel.

In accordance with this invention the impedances connected at the midpoints of the sound paths are so inter-related that the impedances as seen from the terminals of the structures are the same as though no impedances were connected to the main sound paths. Thus, the characteristic impedance, denoted Z_0 , of the section of Fig. 1 is expressed by

$$Z_0 = Z_{L_1} + Z_{L_2} = \frac{\sqrt{P_0 \gamma \rho} (S_1 + S_2)}{S_1 S_2} \quad (4)$$

while the characteristic impedance, denoted Z_0' of the structure in Fig. 3 is given by

$$Z_0' = \frac{Z_{L_1} Z_{L_2}}{Z_{L_1} + Z_{L_2}} = \frac{\sqrt{P_0 \gamma \rho}}{S_1 + S_2} \quad (5)$$

The conditions which must be fulfilled in order that Equations (1), (4) and (5) apply are, first, that the impedance located at the midpoint of each sound conduit shall be equal to that of an air column having a length L ; and second, that the impedances of the air columns or their equivalents must be related to the cross section of the upper and lower sound paths in a manner to be explained presently.

For the structure of Fig. 1, it has been found that the midpoint impedances must consist of an open ended air column in shunt with one path and a closed ended air column in shunt with the other, or else the equivalents of these air columns. For the structure of Fig. 2, it has been found that the midpoint impedance of one path must be a closed ended air column in series, and of the other, a closed ended air column in shunt, or their equivalents.

Each sound conduit together with its associated midpoint impedance constitutes an acoustic wave filter characterized by an infinite number of alternate transmitting and alternating regions throughout the frequency scale. In a transmitting region there is a change in the phase relationship between the input and the output waves, while in an attenuating region there is no phase change. In the structure of Fig. 1, the path including the open air column in shunt is a high-pass filter because it attenuates waves in the region around zero frequency and freely transmits waves of higher frequency. On the other hand the path including the closed air column in shunt is a low pass filter because it freely transmits waves around zero frequency. Considering Fig. 3, the path containing the membrane is a high pass filter while the other path is a low pass filter. In order that the

section as a whole shall freely pass waves of all frequencies, and in consequence have a uniform phase shift characteristic with frequency, it is essential that the transmitting regions of the two component filters overlap each other. This is the condition which exists when the filters are proportioned in the manner hereinafter disclosed.

The characteristic impedances which the air columns or their equivalents at the midpoints of the conduits of Fig. 1 must have in order to satisfy Equations (1), (4) and (5) are expressed by the equations:

$$Z_{L_1} = \frac{Z_{L_2}^2}{2(Z_{L_1} + Z_{L_2})} \quad (6)$$

and

$$Z_{L_2} = \frac{2(Z_{L_1} + Z_{L_2})}{Z_{L_1}^2} \quad (7)$$

in which Z_{L_2} denotes the characteristic impedance of the air column, or its equivalent, connected to the midpoint of the path having the impedance Z_{L_1} , i. e. the upper path in the figure; and

Z_{L_1} denotes the characteristic impedance of the air column, or the equivalent, connected to the lower path, having the impedance

$$Z_{L_2}$$

In the case of the section in Fig. 3, the midpoint impedances of the two sound conduits are given by

$$Z'_{L_2} = \frac{2Z_{L_1}^2}{Z_{L_1}^2 (Z_{L_1} + Z_{L_2})} \quad (8)$$

and

$$Z'_{L_1} = \frac{Z_{L_1}^2}{2(Z_{L_1} + Z_{L_2})} \quad (9)$$

where Z'_{L_2} and Z'_{L_1} denote the characteristic

impedances of the air columns, or their equivalents, connected to the midpoints of paths 30 and 11 respectively.

While it has been shown that the impedance connected at the midpoint of each sound conduit should be equal to that of an air column, nevertheless it is not always possible or practicable to employ an air column. Under such conditions an equivalent impedance which can be practically constructed, must be utilized. For instance, it is not possible to connect a closed ended air column in series with a sound conduit; nor is it practical to

connect as a side branch a column having a larger diameter than the diameter of the sound conduit. So to overcome these difficulties, equivalent impedance devices are employed. An elastic membrane stretched across the conduit has been found to be equivalent to a closed ended sound tube in series with the conduit, the equivalence being close for frequencies up to the first resonance of the membrane. Such an elastic membrane is what is used to furnish the impedance at the midpoint of path 30 in Fig. 3. The impedance of a stretched circular membrane of this type is expressed by the Bessel equation

$$Z_m = \frac{\sqrt{\rho_m T}}{2\pi R_m^3} \left[\frac{\left(\sqrt{\frac{\omega R_m}{T}} \right)^2}{J_1 \left(\omega \sqrt{\frac{\rho_m}{T}} R_m \right) - \omega \sqrt{\frac{\rho_m}{T}} R_m} - \frac{J_0 \left(\omega \sqrt{\frac{\rho_m}{T}} R_m \right)}{2} \right] \quad (10)$$

where Z_m denotes the impedance of the membrane;

J_0 and J_1 are Bessel functions of the first kind;

ρ_m denotes the surface density, i. e. the weight of one square centimeter of the membrane;

T denotes the tension per inch of length;

R_m denotes the radius of the membrane.

The impedance of the membrane can be made very nearly equal to that of the corresponding closed end tube in the range extending from a very low frequency up to the first resonant frequency by making the impedances of the membrane and of the tube equal at low frequency and by making the resonant frequencies equal.

Likewise, the hollow cylindrical chamber 14 in path 11 is used in lieu of a closed ended side branch tube when the tube would be too large. The impedance, denoted Z_d , of the chamber is expressed by the Bessel equation:

$$Z_d = \frac{j\rho c}{2\pi r_2 W} \left[\frac{J_0 \left(\frac{\omega}{c} r_2 \right) Y_1 \left(\frac{\omega}{c} R_d \right) - J_1 \left(\frac{\omega}{c} R_d \right) Y_0 \left(\frac{\omega}{c} r_2 \right)}{J_1 \left(\frac{\omega}{c} r_2 \right) Y_1 \left(\frac{\omega}{c} R_d \right) - J_1 \left(\frac{\omega}{c} R_d \right) Y_1 \left(\frac{\omega}{c} r_2 \right)} \right] \quad (11)$$

in which R_d denotes the radius of the disc; r_2 denotes the radius of the conduit to which the disc is attached;

W denotes the width of the disc in the axial direction;

Y_0 and Y_1 are Bessel functions of the second kind;

j is the imaginary operator.

In the same manner that the impedance of the membrane is made equivalent to that of a closed ended tube, the impedance of the cylindrical chamber is also made equivalent to a closed ended tube, namely, by constructing

the chamber so that it has the same resonance point and its impedance is equal to that of the corresponding tube at very low frequency.

Referring to the propagation constant P given in Equation (1), it can in general be expressed by

$$P = A + jB$$

in which A , the real component expresses the attenuation of the section; B , the imaginary component denotes the phase shift per section and is equal to

$$\frac{\omega L}{c}$$

An inspection of Equation (1) shows that the attenuation component is zero and that the propagation constant consists only of a phase shift, that is to say, the devices freely pass waves of all frequencies, but produce a change in the phase relation between the waves at the input and at the output ends of the section. This phase relationship changes with frequency and the actual phase characteristic is dependent upon the ratio

$$\frac{Z_{L_2}}{Z_{L_1}}$$

Fig. 4 illustrates the phase characteristics of a single section of either of the structures of Fig. 1 or of Fig. 3 for values of

$$\frac{Z_{L_2}}{Z_{L_1}}$$

ranging from

$$\frac{1}{3} \text{ to } 3.$$

The ordinates denote the degrees of phase shift of a single section and the abscissæ are measured in terms of

$$\frac{\omega L}{c},$$

which is the phase angle of a single arm of the structure extending from one end to the midpoint. The characteristics for which the ratio

$$\frac{Z_{L_2}}{Z_{L_1}}$$

ranges from 1 to 3 are the type suitable for compensating for the phase distortion of loaded lines, while the characteristics for which

$$\frac{Z_{L_2}}{Z_{L_1}}$$

ranges from

$$1 \text{ to } \frac{1}{3}$$

are generally suitable for simulating the phase characteristics of such lines.

The following example is given to show a method of designing a section of a phase shifter of the type of this invention. Suppose it is desired to obtain the phase characteristic for which

$$\frac{Z_{L_2}}{Z_{L_1}} = 3$$

and for which the phase shift is 540° at 3000 c. p. s., by means of the type of structure shown in Fig. 3. Suppose, further, that it is desired to make the common channels 32 and 32' 1.78 centimeters in diameter. This diameter will ordinarily be chosen to fit an existing telephone receiver. The length L is determined from the fact that

$$\frac{\omega L}{c} = \frac{\pi}{2}$$

when the phase shift of the entire section is 540° . Since the frequency is 3000 c. p. s. the length L is found to be 2.88 cm. Since

$$\frac{Z_{L_2}}{Z_{L_1}} = 3$$

and $S_1 + S_2 = S$, it follows that

$$\frac{S_1}{S_2} = 3; S_2 = \frac{S}{4}; \text{ and } S_1 = \frac{3S}{4}.$$

From these relations $S_1 = 1.86$ sq. cm. and $S_2 = .62$ sq. cm. Since the characteristic impedance of a uniform conduit is

$$\sqrt{P\gamma\rho}$$

divided by the area of the cross section, the characteristic impedances of the two paths are

$$Z_{L_1} = \frac{43}{1.86} = 23.1 \text{ ohms}$$

and

$$Z_{L_2} = \frac{43}{.62} = 69.4 \text{ ohms}$$

respectively. From Equation (9)

$$Z'_{L_1}$$

is found to be 2.88 ohms. If a closed ended tube were used to furnish

$$Z'_{L_1}$$

its area S_1 would be

$$\frac{43}{2.88} = 14.9 \text{ sq. cm.}$$

Obviously this tube would be too large to connect to a pipe whose cross section is only .62 sq. cm., so the equivalent cylindrical chamber will be used instead. The chamber will be made equivalent to the tube by making it resonant at the same frequency and by mak-

ing the low frequency impedance of the chamber and tube alike. It will then be assumed that the impedance of the chamber is equal to that of the tube up to the first resonance.

The cylindrical chamber is resonant when its impedance, given by Equation (11), is equal to zero. Letting $Z_d=0$, the solution of Equation (11) is

$$\frac{\omega R_d}{c} = 1.308.$$

Now the closed ended tube, the length of which is L , is resonant when

$$\frac{\omega L}{c} = \frac{\pi}{2}.$$

From these last two relations

$$\frac{R_d}{L} = \frac{1.308}{\frac{\pi}{2}},$$

or $R_d=2.39$ cm.

At low frequency, Equation (11) becomes

$$Z_d = -\frac{j\rho c}{2\pi r_2 W} \left[\frac{r_2}{\frac{\omega}{c}(R_d^2 - r_2^2)} \right]$$

Letting this equal the low frequency impedance of the closed ended tube which is

$$-\frac{j\rho c}{S_d} \frac{1}{\frac{\omega L}{c}},$$

and solving for the axial length W of the cylindrical chamber:

$$W = \frac{LS_d}{2\pi(R_d^2 - r_2^2)} = 1.24 \text{ cm.}$$

The series characteristic impedance

$$Z'_{L_3}$$

connected at the midpoint of conduit 30 is found from Equation (8) to be 20.57 ohms and the series impedance, which is furnished by a stretched membrane is to be equal to that of the closed ended tube whose impedance is

$$Z'_{L_3} \cot \frac{\omega L}{c}.$$

The membrane impedance as given by Equation (10) becomes zero when

$$\omega R_m \sqrt{\frac{\rho_m}{T}} = 2.4048,$$

while the closed tube impedance is zero when

$$\frac{\omega L}{c} = \frac{\pi}{2}.$$

The solution of the last two equations gives the membrane radius,

$$R_m = \frac{2L(2.4048)}{\pi c \sqrt{\frac{\rho_m}{T}}}. \quad 70$$

At very low frequency, the impedance of the equivalent closed ended tube is

$$Z'_{L_3} \frac{c}{\omega L} \quad 75$$

while the impedance of the membrane is equal to

$$\frac{8\sqrt{\rho_m T} \sqrt{\frac{T}{\rho}}}{\pi \omega R_m^4}. \quad 80$$

From these relations

$$T = \frac{Z'_{L_3} \pi c R_m^4}{8L} \quad 85$$

and

$$\rho_m = \frac{(2.4048)^2 R_m^2 L Z'_{L_3}}{2\pi c}. \quad 90$$

Substituting 20.57 for Z'_{L_3} , ρ_m is found to be equal to .001575 R_m^2 . It is best to choose a minimum thickness for the diaphragm and then solve for the radius, this being satisfactory as long as the radius works out to be equal to or greater than the radius of the tube across which it is stretched. The membrane thickness will be made one-half mil or .00127 cm., which is a thickness obtainable in a foil of aluminum. The specific density of aluminum is 2.75. The thickness is equal to surface density divided by the specific density, and from this relation the radius of the membrane is found to be 1.49 cm., which is somewhat larger than the radius of the conduit across which it is stretched.

For accurate simulation or compensation, it will often be found desirable to employ the composite phase characteristic of phase shifting sections having different individual phase characteristics, for by so doing, a greater control is obtainable over the composite characteristic than if all the sections are uniform. Fig. 5 illustrates phase characteristics which show how the phase distortion of six sections of loaded cable can be compensated by two sections of the acoustic phase shifters of this invention. Curve "a" represents the phase characteristic of the six sections of loaded cable, a section of cable being a loading coil and its associated span of cable. The cut-off frequency of the cable is about 3000 c. p. s. and this frequency corresponds to the value of

$$\frac{\omega L}{c} \quad 130$$

on the axis of abscissæ which is equal to 90°. The frequency is proportional to

$$\frac{\omega L}{c},$$

so the other frequencies as measured along the abscissæ bear the same relation to the value of

$$\frac{\omega L}{c}$$

that 3000 c. p. s. bears to an

$$\frac{\omega L}{c}$$

of 90°. It is well known, that a transmission line to be free from phase, or velocity, distortion, must have an over-all phase shift characteristic which increases uniformly with frequency, that is, the characteristic must be a straight line. It is found that two sections of the acoustic phase shifting devices of this invention, one section having the ratio

$$\frac{Z_{L_2}}{Z_{L_1}} = 1,$$

the other having

$$\frac{Z_{L_2}}{Z_{L_1}} = 3,$$

when connected in tandem with the six sections of loaded cable, will cause the over-all phase characteristic to be nearly a straight line. Curve "b" and "c" show respectively the characteristics of the acoustic sections with

$$\frac{Z_{L_2}}{Z_{L_1}} = 3$$

and

$$\frac{Z_{L_2}}{Z_{L_1}} = 1.$$

Since the sections are in tandem the phase angles are additive; the sum of the phase angles of the two acoustic sections is curve "d". Curve "e" is obtained by adding curves "a" and "d" and it represents the over-all phase shift. It is noted that curve "e" is nearly a straight line, so the system is practically free from phase distortion.

Loaded lines are generally of great length and so have many loading sections, inasmuch as the loading coils are usually spaced at intervals varying from one to two miles. It will usually be more convenient to situate the phase correcting devices at widely separated points than at intervals of only a few loading sections. When the phase correctors are very widely separated the number of phase shifting sections connected together will have to be much greater than if they were situated at every few miles. Fig. 6 shows a preferred arrangement of a plurality of phase shifting sections joined in tandem, this arrangement

being suitable for loading a line at long intervals. The sections are arranged in two groups designated 60 and 61 which are joined in tandem by a four-way pipe coupling 62. Group 60 comprises a plurality of sections of the type shown in Fig. 3 in which the ratio

$$\frac{Z_{L_2}}{Z_{L_1}}$$

is equal to 3, while group 61 comprises sections of the same type in which this ratio is unity. Any number of sections having the same ratio

$$\frac{Z_{L_2}}{Z_{L_1}}$$

can be arranged in a group such as 60. Sound path 63 includes in tandem all the

$$Z_{L_1}$$

arms while path 64 includes all the

$$Z_{L_2}$$

arms. It is noted that in this arrangement the lengths of sound conduit between successive membranes 65 and between successive side branches 66 are equal to 2L, since half of the length, that is, L, is associated with each membrane or side branch. The length of conduit from each end membrane or side branch to the common coupling is equal to L, as in Fig. 3. In this manner any number of sections of different proportions may be coupled, since any number of groups may be used and any number of sections may constitute a group. Sections of the type of Fig. 1 could be combined in the same manner, but instead of acoustic couplings between groups, telephone receivers would be necessary. Moreover, groups of the type of Fig. 1 could be combined with groups of the type of Fig. 2. Regardless of which type of phase shifter is used it is always necessary to use telephone receivers to connect the ends of the main conduit into an electrical line.

What is claimed is:

1. An acoustic phase shifting system comprising two sound channels, means for impressing sound waves simultaneously on one end of each channel, and means for receiving sound waves from the opposite ends of each sound channel simultaneously, each of said channels including branches, whereby said system has a non-linear phase shift characteristic.

2. An acoustic phase shifting section comprising two paths, each path including a filter having a branch in communication with the path whereby each path is characterized by an infinite number of alternate transmission and attenuation bands throughout the frequency spectrum, said paths being joined together at each end, one end being adapted

to receive wave energy, the other to deliver wave energy.

3. An acoustic delay system according to claim 2 in which one of said filters is a high pass filter, the other a low pass filter.

4. An acoustic relay system comprising two acoustical-electrical transducers and two sound paths communicating between said transducers, each path including a filter so related to each other that the transmitting regions of one overlap the attenuating regions of the other whereby the system is substantially an all-pass system over a wide range of frequency.

5. An acoustic phase shifting device comprising two channels joined at their ends each channel having at its midpoint an impedance equal to that of an air column whose length is equal to the distance along a channel from one end to the midpoint.

6. An acoustic phase shifting device comprising two parallel channels joined at each end, one channel including effectively an open circuited line in shunt, the other channel including effectively an open circuited line in series.

7. A acoustic phase shifting device according to claim 6 in which said shunt line is equivalent to a closed ended tube branching from the channel.

8. An acoustic phase shifting device according to claim 6 in which said series line is provided by a membrane stretched across the channel.

9. An acoustic phase shifting section comprising two parallel sound channels of equal length, there being a hollow disc situated at the midpoint of one channel, the impedance of said disc being equal to that of a closed ended tube having a length equal to half the length of the channel, and a stretched membrane across the other channel at its midpoint, which is equivalent to a closed ended tube of half the length of the channel effectively in series, whereby said section is an all-pass structure having a continuous phase shift characteristic.

10. An acoustic phase shifting section according to claim 9 in which the ratio of the cross section of the two sound channels is fixed by a preassigned phase shift characteristic which the device is to have.

11. An acoustic phase shifting system comprising a plurality of sections according to claim 2.

12. An acoustic phase shifting system comprising a plurality of sections according to claim 2, the ratio of the characteristic impedances of the branches of one section being different from the same ratio of another section.

In witness whereof, I hereunto subscribe my name this 1st day of October, 1929.