Dec. 8, 1931.

W. P. MASON

1,835,795

SOUND TRANSMISSION

Filed June 14, 1929

FIG. 2

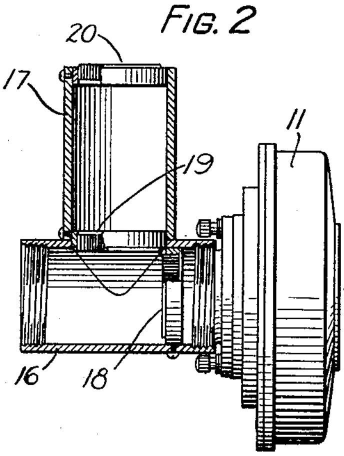


FIG. 4

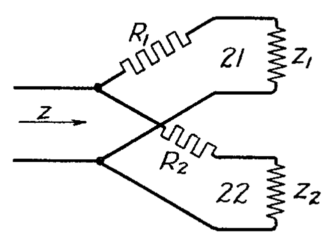


FIG. 3

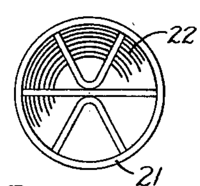


FIG. 3-A

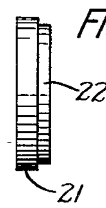


FIG. 5

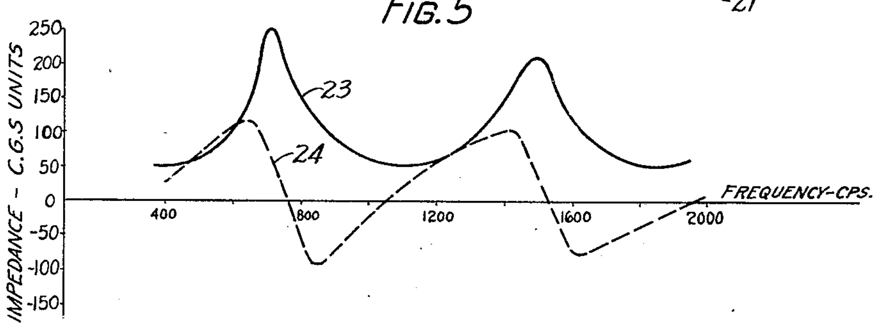
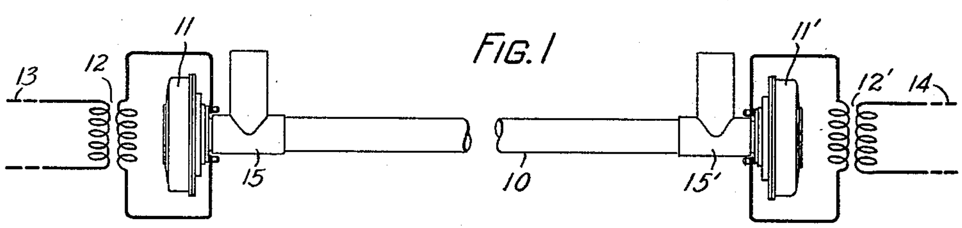


FIG. 1



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UNITED STATES PATENT OFFICE

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SOUND TRANSMISSION

Application filed June 14, 1929. Serial No. 370,815.

This invention relates to acoustic transmission systems and particularly to means for incorporating a sound wave channel into a telephone system.

An object of the invention is to improve the speech transmission characteristics of composite electrical-acoustic systems.

Another object is the elimination of wave reflection effects at the junctions of acoustical and electrical transmission lines.

A further object is to improve the acoustic damping in composite acoustical-electrical systems.

To produce a time delay in the transmission of speech through a telephone system, or to modify the transmission in other ways, acoustic devices such as delay channels or acoustic wave filters have been used, these being inserted into the line as acoustic links and coupled thereto by telephone receivers or other suitable translating devices. If the translating devices were able to transfer the wave energy from the electrical to the acoustical portion of the system, or vice versa, with perfect efficiency it would be possible to proportion the inserted acoustic device so that, without the use of additional elements, the impedances of the electrical and the acoustic lines would be matched at the junction points, forming a homogeneous system through which wave energy can flow without reflection and without loss. However it has not been possible to produce translating devices having efficiencies greater than fifty per cent and efficiencies of much lower values are the general rule except in specially constructed telephone receivers. As a result of this the impedances of the electrical and the acoustical lines cannot be directly matched and distortion of the speech transmission characteristic due to reflection occurs.

From another viewpoint the acoustic device together with the mechanical parts of the telephone receivers constitute a resonant vibrating system for which suitable damping must be provided to smooth out the resonance peaks in the transmission characteristic. With perfect efficiency of the energy transfer this damping can be provided by the electrical lines, but with low efficiency energy transfer the electrical damping is insufficient for this purpose. In acoustic systems like loudspeaking telephones, where a horn is provided to radiate the sound waves into the air, the radiation resistance of the horn mouth can be made to furnish the right degree of damping, but in acoustic links in a telephone line no damping of this kind is available.

In accordance with this invention acoustic damping means is provided at one or both ends of the acoustic link having an acoustic impedance complementary to that of the translating device and the connected line in combination, so that the acoustic link is terminated in an impedance equal to its own characteristic impedance. In this way the deficiency of the damping due to the connected electrical circuits is made up and the effects of resonance are eliminated. In the preferred embodiments of the invention the energy translating devices are telephone receivers of the matched impedance type, that is, receivers in which the diaphragm and the connected mechanical vibrating elements together with the air chamber in front of the diaphragm are proportioned to constitute a mechanical transmission line having a characteristic impedance equal to that of an air column of the same diameter as the outlet aperture in front of the diaphragm. The construction of matched impedance systems of this kind is described in the Bell System Technical Journal, vol. V, No. 3, July 1926, "Methods of high quality recording and reproducing of music and speech based on telephone research", by J. P. Maxfield and H. C. Harrison. It has been found that the acoustical impedance of a telephone receiver of this type corresponds very closely to the impedance of a short length of the uniform acoustic line defined by the receiver opening, terminated by a resistance of value considerably different from the characteristic impedance of the line. This property of the impedance leads to a simple type of compensating arrangement comprising a similar short length of conduit branching from the main acoustic line, in combination with actustic resistance elements proportioned and arranged in the manner hereinafter described.

A feature of the invention is that the impedance compensating means together with the translating device constitute an acoustic constant resistance structure.

Of the attached drawings,

Fig. 1 illustrates an acoustic transmission system in accordance with the invention;

Fig. 2 shows in detail the structure of the terminal devices of the system of Fig. 1;

Figs. 3 and 3A illustrate the construction of an element of the terminal device;

Fig. 4 is a schematic impedance diagram of the terminal device; and

Fig. 5 is a typical impedance characteristic of a sound translating device adapted to be used in the invention.

The system of Fig. 1 is a composite electrical acoustical line comprising a sound wave conduit 10 having similar telephone receivers 11 and 11′ coupled to its ends by means of which the conduit is included as an acoustic link between electrical lines 13 and 14. The receivers are preferably of the matched impedance type in which the vibratory elements from a mechanical line of characteristic impedance equal to that of the connected sound conduit described in the above mentioned article by Maxfield and Harrison. The windings of the receivers are connected to the electrical lines through impedance matching transformers 12 and 12′. At the junctions of the receivers with the sound conduit impedance compensators 15 and 15′ are provided in accordance with the invention to compensate for the impedance disparity due to the imperfect efficiency of the energy transfer in the receiver. In the figure the acoustic link is shown as a simple unifrom tubular conduit such as would be used for producing a time delay in transmission, but other types of acoustic link may be used within the scope of the invention, such, for example as the acoustic wave filters disclosed in U. S. Patent 1,692,317, issued November 20, 1928 to G. W. Stewart. The construction of the impedance compensating device is shown in detail in the sectional view of Fig. 2. It comprises a housing in the form of a T-shaped pipe section having a cross branch 16 which is threaded at each end for coupling to the face plate of the receiver and to the sound conduit, and a side branch 17 forming a wave path to the open air. In the cross branch, between the side branch and the receiver, is inserted an acoustic resistance element 18 and in the side branch additional resistance elements 19 and 20 are inserted, one at each end. These resistance lements are preferably of the type in which the resistance is provided by a multiplicity of air passages in the form of very narrow parallel slots, the width of the slots being such that the air motion therein is controlled solely by the viscosity of the air. One suitable form is illustrated in Fig. 3, comprising a spider frame 21 having a circular rim for mounting purposes, and a closely coiled spiral 22 of fine metallic ribbon mounted on one side of the frame. The resistance value is determined by the total slot area, the width of the slot, and the width of the ribbon. To obtain a desired resistance value the element may be constructed by winding a coated metallic ribbon of suitable dimensions and thickness of coating into a tight spiral and then dissolving off the coating.

With the impedance compensator inserted two sound wave paths are provided at each terminal point of the acoustic line, the one path being the direct path through resistance 18 to the receiver and the other path including resistance 19, the branch conduit 17 and the resistance 20. The manner in which these elements are proportioned is explained below.

In Fig. 4 the impedance relations of the terminal apparatus are illustrated by the schematic of the analogous electrical circuit. The system comprises two parallel circuits 21 and 22 corresponding respectively to the acoustic paths to the receiver and in the side branch. Circuit 21 consists of a resistance R_1 in series with an impedance Z_1, R_1 corresponding to the acoustic resistance 18 and Z_1 to the acoustic impedance of the telephone receiver 11. Circuit 22 consists of a resistance R_2 in series with an impedance Z_2, R_2 corresponding to the resistance 19 and Z_2 to the impedance of the branch tube 17 terminated by resistance 20.

The impedance Z of the system is expressed by:

$$Z=\frac{(R_1+Z_1)(R_2+Z_2)}{R_1+R_2+Z_1+Z_2} \quad (1)$$

To avoid wave reflections at the junction of the terminating device and the sound pipe to which it is connected, it is necessary that this impedance should be equal to the characteristic impedance of the sound pipe at all frequencies.

The characteristic impedance, denoted by Z_L, of the uniform sound conduit is the impedance which would be measured at one end if the conduit were infinitely long. It is a pure resistance, invariable with frequency, of value given by

$$Z_L=S\sqrt{P_o\gamma\rho}\ \text{mechanical ohms, or c. g. s. units,} \quad (2)$$

where P_0 represents atmospheric pressure;
γ represents the ratio of specific heats of air;
ρ represents the density of air;
S represents the cross-sectional area of the pipe.

The value of

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

is about 41 when air is used as the medium.

To match the characteristic impedance of the sound conduit the terminal impedance Z, as given by equation (1), should also be a pure resistance of value equal to Z_L. This result will be secured if the impedances of the elements are such that

$$R_1 = R_2 = Z_L \quad (3)$$

and

$$Z_1 Z_2 = Z_L^2 \quad (4)$$

The resistance elements 18 and 19 should therefore have resistances equal to the characteristic impedance of the sound conduit and the branch conduit 17 in combination with the terminal resistance 20 should have an impedance inversely related to the receiver impedance by the constant factor Z_L^2.

In a telephone receiver of the matched impedance type the vibrating elements constitute the equivalent of a uniform mechanical transmission line having a characteristic impedance which matches that of the uniform sound conduit of the same cross-sectional area as the opening from the air chamber in front of the diaphragm. The manner of proportioning the vibrating parts to obtain this result is described in the hereinbefore mentioned article by Maxfield and Harrison. It follows then that the mechanical portion of the receiver is substantially equivalent in impedance to some finite length of the sound conduit to which it is connected. The damping effect of the connected electrical circuits corresponds to a resistance termination, but, due to the imperfect efficiency of energy transfer, the value of the resistance is too small to provide the proper termination for impedance matching. The value of the receiver acoustic impedance Z_1 may be closely represented by the formula

$$Z_1 = Z_L \frac{\sinh Pl + \frac{1}{r} \cosh Pl}{\cosh Pl + \frac{1}{r} \sinh Pl}, \quad (5)$$

which is the expression for the impedance of a finite length of the sound conduit to which the receiver is coupled, terminated by a resistance. In the formula Z_L denotes the characteristic impedance of the conduit, Pl is the propagation constant for the length l and r is the ratio of the characteristic impedance to the terminal resistance.

The inversely related impedance required in the side branch of the compensator is found from equations (4) and (5) to be

$$Z_2 = Z_L \frac{\sinh Pl + r \cosh Pl}{\cosh Pl + r \sinh Pl} \quad (6)$$

This evidently represents the impedance of the same length of conduit, but with a resistance termination r times as great as the characteristic impedance. The compensation can therefore be accomplished by the structure shown in Fig. 1.

To determine the proper length of the branch conduit 17 and the proper value of the resistance 20 it is best to proceed by determining the acoustic impedance characteristic of the receiver and the connected electrical circuit. This may be done by the method described in U. S. Patent 1,795,647, issued March 10, 1931, to P. B. Flanders. The impedance characteristic of a typical high efficiency receiver is shown in Fig. 5 in which the solid curve 23 represents the resistance component and the dotted curve 24 the reactance component. This receiver had an air chamber opening of 0.7 inch diameter and was designed to operate with a sound conduit of this diameter or with a horn of the same throat diameter. The presence of the reactance and the variation of the resistance are due to the improper termination provided by the electrical circuits. The proportions of the equivalent sound conduit and terminal resistance are readily determined from the impedance curves. From equation (5) it can be shown that the resistance component varies between maxima of rZ_L and minima of $Z_L \div r$, the ratio of the maximum to the minimum values being r^2. A comparison of these values therefore leads at once to the value of the terminal resistance and also to the value of the terminal resistance 20 in the side branch of the compensator. The latter resistance is equal to the maximum resistance of the receiver impedance and the former to the minimum. The length of the equivalent conduit and hence also the length of the compensator conduit 17 is determined from the first resonance frequency of the receiver, that is, the first frequency at which the reactance passes through zero. At this frequency the sound wave is four times as long as the equivalent conduit.

For the particular case illustrated by the curves of Fig. 5, the maximum resistance, taking the average of the two peaks is 230 c. g. s. and the minimum is 50. From these values the characteristic impedance of the equivalent conduit is found to be 107 c. g. s., and the ratio r to be 2.14. The characteristic impedance is that of a conduit of 2.6 square cms. cross-sectional area, or approximately 0.7 inch diameter. The length of the equivalent conduit as determined by first resonance frequency, 750 c. p. s. is equal to 4.5 inches.

A compensator of the type of Fig. 1 for this receiver should therefore have a side branch 4.5 inches long and 0.7 inch diameter. Resistances 18 and 19 should each have the values 107 c. g. s., and resistance 20 should have the value 230 c. g. s.

For the design of acoustic resistances of the coiled ribbon type described above the following formula for the resistance value is convenient:

$$R_e = \frac{12\mu d}{t^2 A} \cdot A_1^2 \text{ c. g. s.}$$

where R_e is the resistance value,
μ is the coefficient of viscosity of air,
t is the transverse width of the slot,
d is the width of the ribbon,
A is the total slot area, and
A_1 is the area of the conduit in which the resistance is used.

It is convenient to design the resistance for a somewhat lower value than is desired and to adjust the element to its final value by blocking off part of the slots to reduce the area A.

What is claimed is:

1. In a wave transmission system an electrical line, a sound wave conduit, energy translating means coupling said conduit and said line and acoustic impedance means between said conduit and said translating device for compensating the disparity between the characteristic impedance of the sound conduit and the acoustic impedance of the translating device due to imperfect efficiency of energy transfer in said translating device.

2. In combination, an electrical line, a sound wave conduit, energy translating means coupling said conduit and said line, the impedance of the combination of the translating means and the connected line being different from the characteristic impedance of said conduit, and acoustic impedance means between said conduit and said translating means for compensating said impedance difference so that the sound wave conduit is terminated at the junction point with the translating means in an impedance equal to its own characteristic impedance.

3. In combination an acoustic transmission line, a terminal device therefor having an impedance different from the characteristic impedance of said line, and an acoustic impedance compensator between said line and said terminal device comprising an acoustic resistance directly in series with the terminal device and a side branch from the acoustic line including a second acoustic resistance in series with an acoustic impedance inversely proportional to the impedance of said terminal device.

4. A combination in accordance with claim 3 in which the said acoustic resistances each have values equal to the characteristic impedance of the acoustic line and in which the acoustic impedance included in said side branch is inversely related to the impedance of the said terminal device by the square of the characteristic impedance of the acoustic line.

5. In combination, an acoustic transmission line, a sound translating device connected to one end of said line, said device having an acoustic impedance corresponding to that of a finite length of said line terminated by a resistance different from the characteristic impedance of the line, and an acoustic impedance compensator between said line and said device, comprising an acoustic resistance in series with said device and an acoustic side branch consisting of a length of sound conduit equal to that defined by the impedance of the translating device, the inner and outer ends of said side branch being closed through acoustic resistances.

In witness whereof, I hereunto subscribe my name this 13th day of June, 1929.

WARREN P. MASON.