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Putnam et al.

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[54] **ACOUSTICAL DELAY LINE**

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[73] Assignee: **United Recording Electronics Industries**, North Hollywood, Calif.

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[52] **U.S. Cl.** **333/30**, 310/8.2, 333/34

[51] **Int. Cl.** **H03h 7/30**

[58] **Field of Search** 333/30, 33, 34; 310/8.1, 8.2

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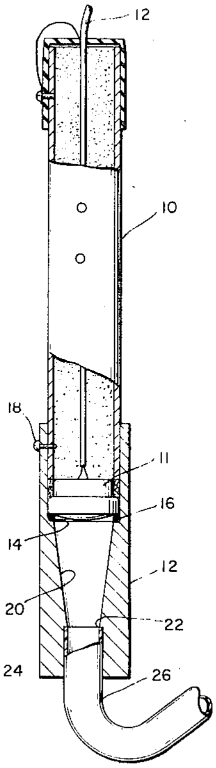
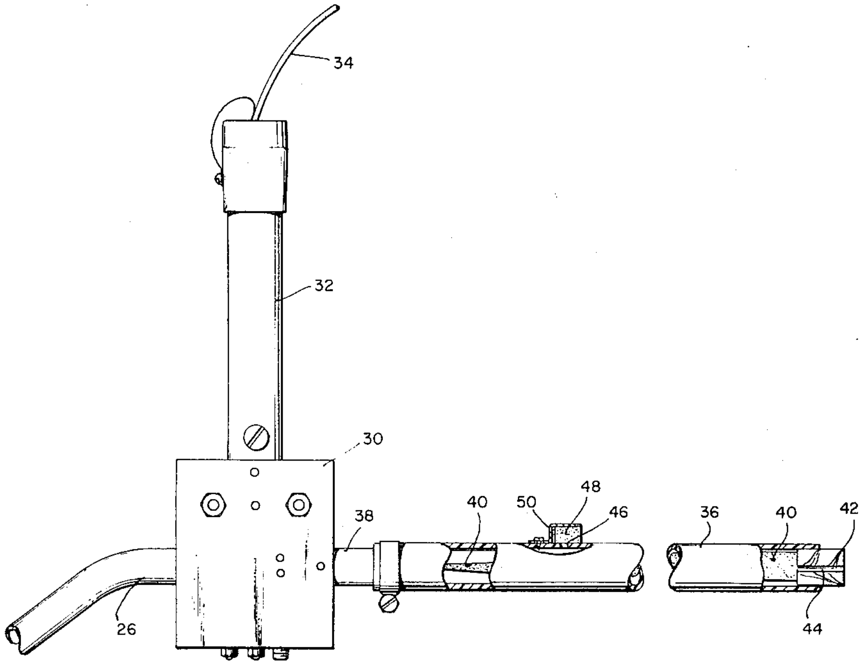
[57] **ABSTRACT**

Apparatus for terminating the transmitting line of an acoustical delay line in a tunable cavity having the characteristic impedance of the transmitting line. The cavity is terminated and tunable over the acoustical frequency range by means of selectively located helmholtz resonators operating upon the direct waves and the reflected waves from the terminating device for providing the selectively located resonators to compensate the frequency spectrum for both peaks and dips at different frequencies.

12 Claims, 6 Drawing Figures





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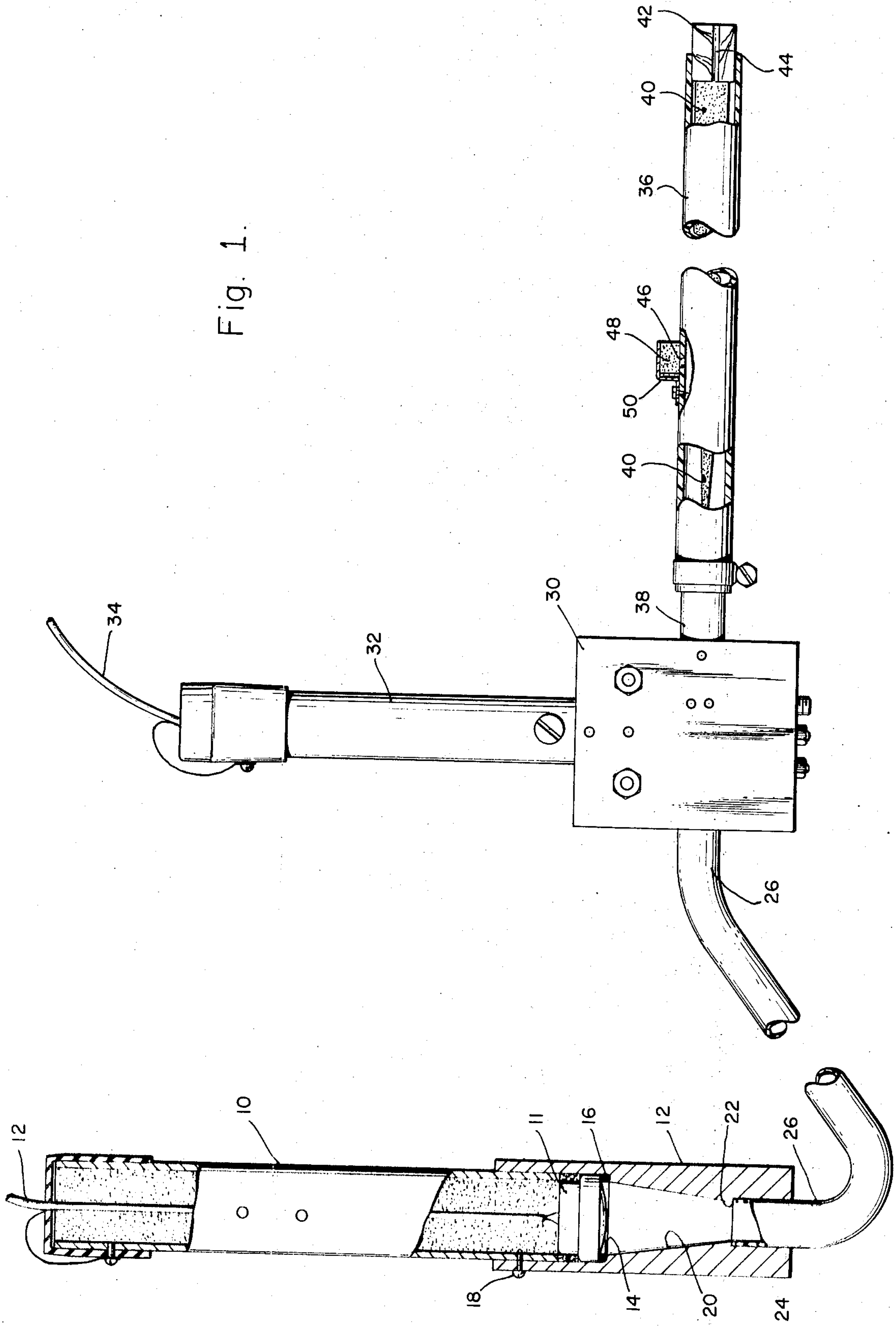

Fig. 1.

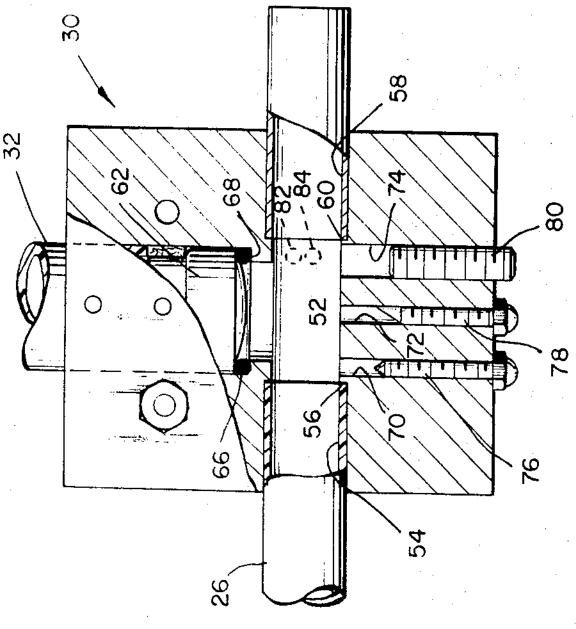

Fig. 2

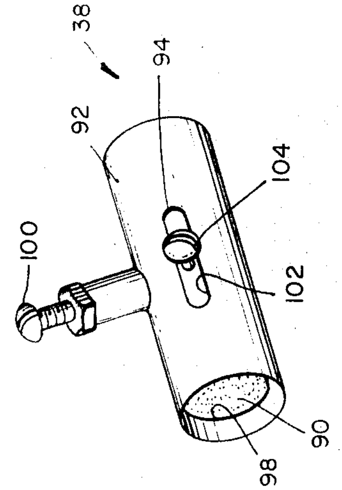

Fig. 3

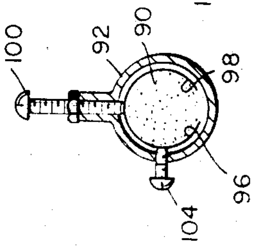

Fig. 4a

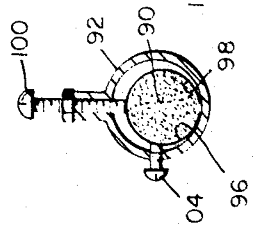

Fig. 4b

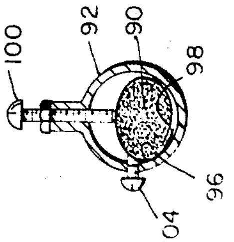

Fig. 4c

ACOUSTICAL DELAY LINE

This invention relates to an acoustical delay line and more particularly to a tunable delay line capable of being terminated in its chracteristic impedance for propagating a substantially flat audio spectrum.

The need for acoustical delay lines is well recognized in the art today and is used in sound systems and telephone systems to compensate for special effects as set forth in U.S. Pat. No. 2,291,555 to Harry Nyquist on July 28, 1942. Modernly new applications to acoustical delay lines have been suggested in an article by Duane H. Cooper in Audio dated April 1971 and entitled "Construction of a Madson System Delay Tube."

The prior art as evidenced by the referred to article and the prior Nyquist patent illustrate the need for a simple and practical acoustical delay line having a substantially flat response over the audio spectrum. The principle of operation is extremely simple in that energy is propagated down a first path having a length equal to the desired delay required in the system. For example, on a standard day having standard humidity and barometric pressure, sound will propagate at a speed of 1,130 feet per second. In order to obtain a delay of 14 milliseconds, it is necessary therefore for the sound to be propagated along a path having a length equal to 15.82 feet. In other words, propagating sound at one end of a tube that is 15.82 feet long will result in a 14 milliseconds delay in the sound being emitted at the other end.

Unfortunately, simply placing a microphone or other acoustical transducer at the opposite end of the propagating tube has the effect of abruptly terminating the line thereby causing reflections and standing waves to be generated in the transmitting tube. These standing waves have the effect of unbalancing the frequency response of the transmitting line causing anomalies and discontinuities that vary the frequency response spectrum and limit the use of the device.

The prior art has shown that in order to obtain a substantially flat frequency response over the audio spectrum that it is necessary to properly terminate the line in the characteristic impedance of the transmitting propagating tube or line. The conventional technique is to terminate the line in a quarter wave length terminating stub so as to minimize the reflected waves. The basic concept is shown in the Duane Cooper article in his FIG. 2 which illustrates the termination of the transmitting propagating line in a variable density plastic foam material with the receiving microphone located at right angles to the propagating tube for detecting the delayed acoustical energy.

Experience has shown however that the mere fact of placing a quarter wave length terminating stub at the end of the propagating transmitting tube and locating a receiving element at right angles to the tube for detecting the delayed acoustical energy and standing waves cause reflections that interfere and otherwise upset the desired flat response over the audio spectrum.

This invention is concerned primarily with apparatus and techniques for tuning the transmitting path to thereby compensate for mismatched mating surfaces and other irregularities inadvertently caused by the practical building of a system that result in reflective waves and unbalancing of the characteristic impedance of the transmitting line.

In the present invention a transmitting transducer such as an R–50 Shure microphone is used as the source of acoustical energy. The output of the microphone is coupled to a length of polyethelene hose that has a preferred length depending upon the acoustical delay desired. For a 14 millisecond delay line the hose has a length of 15.82 feet whereas a 16 millisecond delay line would have a length of 18.08 feet. The opposite end of the transmitting path is coupled to a tunable cavity that is substantially coaxial with the transmitting path.

A quarter wave length terminating stub is coupled to the cavity and arranged opposite the transmitting path and is also coaxial with the cavity. A receiving transducer such as the R–70 microphone manufactured by Shure is coupled at the centermost portion of the cavity intermediate the transmitting tube and the terminating stub. The cavity is symmetrical in that the receiver transducer is located in the centermost portion of the cavity with the transmitting propagating tube entering on one side of the cavity and the terminating stub entering on the opposite side also coaxially with the cavity.

The cavity is tunable so as to compensate for the aforementioned anomalies and discontinuities due to the mechanical construction and the physical placement of abutting parts next to each other. Tuning is accomplished by means of a plurality of slugs operating in holes that communicate with different portions of the cavity. The tuning slugs are actually helmholtz resonators that are used to tune the cavity to the characteristic impedance of the transmitting line. Normally the helmholtz resonators operate upon the incoming wave and hence, it is expected that a dip will result in the frequency spectrum as determined by the width and location of the resonator. The dip is expected since the terminating stub of the cavity is a quarter wave length long and the wave must travel to the termination point and back again making a total of a half wave length or a 180° change in the phase of the incoming wave. The helmholtz resonator is therefore adjusting the reflected wave which is a half wave length out of phase with the incoming wave and hence an interference or dip does in fact occur.

The conventional use of the helmholtz resonator for creating dips in tuning the cavity takes place only for those slugs operating in an area that is substantially opposite the receiving transducer and in the direction towards the incoming propagating line.

It has been discovered that locating one or more helmholtz resonators for tuning different frequencies in the cavity between the receiving transducer therefore acting on the reflected wave, and in the direction towards the terminating stub has the unobvious effect of providing a peak in the tuning of the frequency spectrum.

This discovery has provided a convenient means of tuning the transmission line cavity for different frequencies by judiciously located different helmholtz resonators in the line portion of the cavity as well as in the terminating portion of the cavity to thereby allow means for both peaking and dipping of selected frequency of the audio spectrum to now provide a means for generating a substantially flat response curve over the complete audio spectrum.

The various and many anomalies in the frequency spectrum unfortunately are not uniform nor consistent and hence, it is not only necessary to provide means for tuning out the undesired peaks and dips but also to provide a means for selectively controlling the Q of the individual peaks and dips that are being compensated when tuning the cavity. For example, it may be necessary to tune out a sharp spike at 8 kilohertz whereas the next requirement may require the tuning of a substantially lesser dip at 5.4 kilohertz. The degree of effectiveness of any of the helmholtz resonators is actually determined by the ratio of the direct to the reflected wave effected by the individual resonator. For example: if the individual resonator primarily acts upon the reflected wave, then a peak in the frequency spectrum is obtained, and the amount of magnitude of this peak is controlled by the designed location of the resonator. In other words, if only the reflected wave is present, the peak produced will be of great magnitude; if the wave passing over the resonator opening is constituted of a mixture of both direct and reflected wave, the magnitude of the peak will be less as a function of this ratio. Conversely, if the direct wave is in predominance, a dip will be produced, the magnitude of which will again be controlled by the ratio of the direct to the reflected wave.

A control of the Q and magnitude of the individual dip or peak to be compensated is also controllable by either placing different absorbing material on the terminating end portion of the individual resonators or by changing the geomatric shape of the terminating end portions of the individual resonators. In the preferred embodiment the same control over the Q is obtainable by varying the slope of the end portion from a flat end portion to a slope of approximately 80° which has the effect of providing a change in reflection from a maximum reflection for a flat head screw to a minimum reflection for a 80° angle screw.

It is possible therefore by using selective selective helmholtz resonators to not only tune for individual frequency anomalies both for peaks and dips but also to tune the same peaks and dips for different Q conditions.

Further objects and advantages of the present invention will be more apparent by referring now to the accompanying drawings wherein:

FIG. **1** illustrates a complete acoustical delay line comprising transmitting transducer, receiving transducer and a T block having the defined cavity constructed according to the present invention;

FIG. **2** is a cross section of a T block illustrated in FIG. **1** containing the cavity for matching the impedance of the transmitting line;

FIG. **3** illustrates a three kilohertz compensator connected between the T block and the quarter wave length terminating stub illustrated in FIG. **1**;

FIG. **4***a* illustrates an open unadjusted position of resilient material in the sheath;

FIG. **4***b* illustrates an adjustment of the resilient material by a screw in the sheath; and

FIG. **4***c* illustrates further adjustment of the resilient material by a screw in the sheath.

Referring now to FIG. **1** there shown a transmitter housing **10** containing a transmitting transducer **11** for converting electrical energy into acoustical energy. The transmitting transducer **11** is preferably a Shure microphone, R–50, that is electrically driven from an outside amplifier source through a pair of leads **12.** The interior of the transmitter housing **10** is filled with compressed foam material and packed to maintain a back pressure on the transducer **11** and thereby absorb any back radiation of sound that is generated and in this manner reduce the generation of standing waves caused by the re-reflection of the rearward waves generated from the back end of the transducer.

The complete assembly comprising the transmitter housing **10** and the transducer **11** are inserted into a lower housing **12** having a shoulder portion **14** and an O-ring **16** which holds the transducer **11** in place. The transmitter housing **10** is normally held in place in the lower housing **12** by means of a plurality of set screws **18.**

The maximun internal diameter of the lower housing **12** is at the shoulder **14** which holds the O-ring **16** in place. The internal opening has a taperer **20** which reduces to a minimal opening **22.** The lowermost portion of the lower housing **12** has a cylindrical opening **23** having a diameter greater than at opening **22** which creates a shoulder **24.**

The propagating tube **26** having a length determined by the delay desired is inserted against the shoulder **24.** In the preferred embodiment the internal diameter of the tube **26** is substantially equal to the minimum diameter **22** in the lower housing **12** so as to minimize irregularities and discontinuities and thereby minimize the generation of reflected waves which have the effect of producing standing waves and anomalies in the frequency response pattern.

The opposite end of the transmitting tube **26** is coupled into a T block **30** which communicates coaxially with the cavity located within the T block. The structure of the cavity and the tuning means is more fully described in connection with FIG. **2** which illustrates the internal configurations of the cavity and the helmholtz resonators. A receiver housing **32** containing a Shure R–70 microphone transducer is located within the receiver housing and is backloaded with compressed absorbing material in the same fashion as described in connection with the transmitter housing **10.** The receiver transducer within the receiver housing **32** is coupled with the cavity within the T matching block **30** for converting the delayed acoustical energy into electrical energy which is fed from the receiver housing **32** by means of a plurality of wires **34.**

Located at the opposite end of the cavity within the matching T block **30** and coaxial with the input line and the cavity is a quarter wave length terminating stub **36.** In the preferred embodiment the terminating stub **36** is made exactly 4 feet 3 inches long when measured from the center of the cavity within the matching block **30** to the end of the terminating line **36.** The terminating stub **36** also includes a 3 kilohertz compensator **38** located intermediate the terminating stub **36** and the matching block **30.** Tuning of the 3 kilohertz compensator **38** is obtained by varying the distance of the compensator from the receiver line **32.** In the simplest from the 3 kilohertz compensator is composed of an absorbent material capable of being compressed to thereby provide a variable range of absorption. In the preferred embodiment it was found necessary to provide an unobstructed passageway to frequencies below 3 kilohertz. The unobstructed passageway contains an absorbent material whose density may be varied for controlling the amount of the 3 kilohertz signal to be absorbed. A suitable 3 kilohertz compensator is described in connection with FIGS. **3** and **4.**

The quarter wave length terminating stub **36** contains a tapered absorbent material **40** whose absorption is greatest at the end portion of the terminating stub **36**.

A plug member **42** such as cork having a centrally located hole **44** is located in the end portion of the quarter wave length terminating stub **36** to effectively terminate the line. The diameter of the centrally located opening **44** is used to control the **30** hertz response of the tuning cavity located in the matching T **30**. Tuning of the cavity at 30 hertz is achieved by using plugs having different sized openings until the desired broad band tuning characteristics at 30 hertz is achieved. Different terminating means may be used and a terminating device having an adjustable iris control similar to that found on a camera have been suggested as a means for varying the size of the central opening during the tuning procedure.

The over-all length of the terminating line **36** is measured from the centerline of the cavity in the matching T **30** to the terminating cork **42** and for optimum results has been selected to be 4 feet 3 inches. The low frequency tuning of the cavity is materially enhanced by means of an opening **46** located on the periphery of the terminating stub **36** a distance of 39 inches from the centerline at the cavity in the matching T **30**. In the preferred embodiment the opening **46** is 1/4 inch in diameter and is covered by an absorbent material **48** held in place by an adjustable clamp **50**. Increasing the pressure on the clamp **50** has the effect of increasing the density of the absorbent material **48** thereby providing a measure of control in the tuning of the cavity in the range of 50 to **70** hertz. Typically, increasing the density over the hole **46** has the effect of removing a peak at substantially 70 hertz. However, due to the interaction of adjustments and other undefined anomalies a range of approximately 50 to 70 hertz is usually possible.

Referring now to FIG. **2** there shown a cut-away illustration of the matching T **30** containing a cavity **52**. Communicating with the cavity **52** on one side is a larger diameter opening **54** which forms a shoulder **56** with the cavity **52**. The thickness of the shoulder **56** is selected to be substantially equal to the thickness of the transmitting tube **26** illustrated in FIG. **1** in order to provide a continuous opening with the minimum of discontinuities when the transmitting tube is inserted into the opening **54**. In this fashion the inside diameter of the transmitting tube **26** will be coaxial with the defined cavity **52** and the chance for standing waves being generated from discontinuities or obstructions is kept to a minimum.

Located on the opposite side of cavity **52** and coaxial with the cavity is a second opening having a diameter larger than the diameter of the cavity **52** which defines a shoulder **60**. In a similar fashion as described before the shoulder **60** is substantially equal to the thickness of the wall of the 3 kilohertz resonator **38** as shown in FIG. **1**. In this manner the internal diameter of the 3 kilohertz resonator **38** is coaxial with the cavity **52** thereby reducing the chance for discontinuities and the generation of reflected waves back into the cavity.

A third opening **62** located at right angles to the cavity **52** has a diameter sufficient to accept the receiver transducer housing **32** and the receiver transducer **64** located in the bottom-most portion of the housing. The receiver housing **32** is inserted into the opening **62** until the receiver transducer **64** abuts against an O-ring **66** located on the bottom-most shoulder **68** defined by the opening **62**. In this fashion the receiver transducer **64** is held in close proximity to the cavity **52** and at right angles to the cavity for detecting the delayed acoustical energy.

Tuning of the cavity **52** is achieved by means of a plurality of helmholtz cavity resonators such as **70, 72** and **74** having individual tuning slugs **76, 78** and **80** adapted for movement within the respective openings. Tuning slug **76** is located between the receiving transducer **66** and the transmitter propagating tube **26**. Tuning slug **78** is aligned with the receiving transducer **66** and is on the centerline of the cavity **52**. On the other hand, tuning slug **80** also communicates with the cavity **52** but is located between the centerline of the receiving transducer **64** and the terminating stub **36**.

It has been discovered that the diameter of the tuning slug and the placement of the slugs within the cavity **52** have different effects upon the frequency range and also different effects with respect to peaking or dipping when adjusting and tuning the cavity **52**.

The adjustment screw **80** is is located between the terminating stub **36** and the receiving transducer **66** was found to cause a peaking of the frequency spectrum. Similarly, other tuning slugs such as adjustments **82** and **84** which are located at right angles to the tuning adjustments **76, 78** and **80** were found to create peaks in the audio spectrum. A wide variety of diameters is incorporated to cover anomilies providing a constant Q over a wide range of frequencies.

Investigation has shown that adjustment screws located between the receiving transducer **64** and the terminating stub **36** will generate peaks in the frequency spectrum of the acoustical energy. It is now possible by selectively locating helmholtz resonators on either side of the receiving transducer **64** and of varying diameters to thereby construct tuning slugs capable of tuning the frequency range of the acoustical energy over the complete range and thereby effectively tune and compensate for any anomalies that may be present in the audio spectrum.

The amount of the dip or peak desired is actually defined as the Q of the individual helmholtz resonators and is actually determined by the diameter/length ratio and the hardness of the reflecting surface of the indiviaual adjustment. Normally the Q may be varied by changing the absorption of the tuning slug used or by closing the diameter/length ratio. These prior art techniques of adjusting the Q of the helmholtz resonator is at best time consuming and difficult.

In the present invention it was discovered that a variable Q adjustment could be achieved in a simple and direct manner by changing the geometric shape and hence the amount of reflection of the resonator. For example, the flat head screw **80** was found to have a maximum reflection coefficient whereas a 45° tip angle such as on screw **76** was found to have less reflection and specifically about 3 db less reflection when compared to the same diameter and hardness adjusting screw having a flat face. Similarly it was discovered that a tip angle of 60° produced less reflection whereas an 80° tip angle produced even less relfection or maximum absorption.

In tuning the cavity **52** it was found desirable to have approximately three different resonators of the same material and diameter but of different tip angles varying between a flat angle, 45° angle, a 60° angle and an 80° angle to thereby obtain a plurality of Q adjustments for a given frequency adjustment.

Referring now to FIGS. **3** and **4** there shown in more detail a 3 kilohertz compensator **38** located between the impedance matching block **30** and the quarter-wave length terminating line **36** which is more fully illustrated in FIG. **1.**

The 3 kilohertz compensator **38** actually covers a range of from 3 kilohertz to 4 kilohertz by controlling the density of an absorbent material **90** located within the interior of an outside casing **92.** Frequencies below 3 kilohertz are not affected by the compensator **38** since the absorbent material **90** is transparent to the lower frequencies. It is necessary, however, to provide a straight through path for these lower frequencies in order to prevent an arbitrary termination with resultant standing waves.

As shown in FIG. **4** the resilient material **90** is located within a beryllium copper sheath **94** that is open ended on one side as at **96** and **98** and which is shown in an open unadjusted position in FIG. **4**a. Under the action of an adjusting screw **100** the beryllium copper sheath **94** is pushed in a downward direction causing the open ends **96** and **98** to approach each other as shown in FIG. **4***b* and ultimately to overlap as shown in FIG. **4***c* thereby effectively compressing the absorbing material **90** and thereby providing a means for adjusting the density of the absorbing material **90.**

A review of FIG. **4** will show that in the unadjusted position, FIG. **4***a*, that a space is provided between the sheath **94** and the interior of the outside casing **92** for the passage of the lower frequency. Similarly as shown in FIG. **4***b* and FIG. **4***c* that increasing the lateral movement of the adjustment screw **104** to control the frequency range of 3 kilohertz to 4 kilohertz similarly increases the opening between the sheath **94** and the outside casing **92** thereby effectively providing an increased passage for the lower frequency signal.

The compensator **38** is normally inserted into the opening **58** in the matching impedance block **30** as shown in FIG. **2.** Coupling of the compensator **38** is achieved by means of a slotted opening **102** illustrated in FIG. **3** and a tuning screw **104** which is attached to the copper sheath **94.** Coupling is achieved by loosening adjusting screw **104** and sliding the screw and hence the sheath **94** together with the absorbent material **90** in a direction close to or further away from the cavity **52** in order to get a measure of control over the tuning of the frequency spectrum to the desired range.

Moving the adjustment screw **100** has the effect of compressing and thereby increasing the density of the absorbent material **90** which varies the Q of the resonant frequency determined by the position of screw **104.** Hence there is provided independent adjusting screws in a given compensator for independently tuning the frequency range and for adjusting the Q of the selected range.

Improvements in the over-all operation and tuning of the acoustical delay line can be achieved by following good manufacturing principles in having mating joints align as closely as possible to prevent anomalies and surfaces that may cause reflecting waves and hence standing waves. Additionally, both the transmitting transducer and the receiving transducer should be backloaded with high density absorbing material to prevent anomalies in the frequency spectrum usually below a thousand kilohertz.

What we claim is:

1. An acoustical delay line comprising:

a transmitting transducer for converting electrical energy into acoustical energy,

means coupled with said transducer for propagating said acoustical energy along a first path having a predetermined length,

an acoustical tuneable cavity coupled to the output of said first path and coaxial with said path,

an external quarter wave length terminating stub coupled to said cavity opposite said first path and coaxial with said cavity for absorbing unwanted resonant acoustical signals, and,

a receiving transducer coupled to a centermost portion of said cavity for converting said acoustical energy into electrical energy.

2. A delay line according to claim **1** which includes a plurality of helmholtz resonator cavities communicating with said cavity and each containing a tuning slug for tuning said cavity by absorbing unwanted resonant acoustical signals.

3. A delay line according to claim **2** in which said tuning slugs are of different diameters for maintaining the same Q over a wide range of frequencies.

4. A delay line according to claim **2** in which said tuning slugs have end portions that vary from a flat end to a pitch of 80° for varying the Q of the frequency range being adjusted.

5. A delay line according to claim **2** in which at least one resonator communicates with said cavity intermediate said first path and said receiving transducer for selectively tuning dips in the frequency spectrum of said cavity by absorbing unwanted resonant acoustical signals.

6. A delay line according to claim **2** in which at least one resonator communicates with said cavity intermediate said terminating stub and said receiving transducer for selectively tuning peaks in the frequency spectrum of said cavity.

7. A delay line according to claim **1** in which said terminating stub contains a variable density material varying in density from a minimum in the area of said cavity to a maximum at the furthermost position from said cavity,

said stub being terminated by a closed member having a calibrated central opening for absorbing acoustical energy from said cavity over a frequency range including 30 hertz.

8. A delay line according to claim **1** in which said terminating stub is 4 feet 3 inches long measured from the center of said cavity to the end portion of said stub.

9. A delay line according to claim **1** in which said terminating stub contains an opening on the periphary wall a distance of 32 inches from said cavity and which includes a variable density material over said opening for adjusting the Q over the frequency range.

10. A delay line according to claim **1** which includes a 3 kilohertz absorbing filter located intermediate the cavity and said tuning stub.

11. An acoustical delay line according to claim **10** in which said 3 kilohertz absorbing filter comprises an unobstructed passageway for passing substantially lower frequencies,

an absorbent material, and

means for varying the absorption coefficient of said absorbent material to control the Q over the acoustical frequency range.

12. An acoustical delay line according to claim **10** which includes an open ring of resilient metal surrounding an absorbent material, and

means for closing said ring thereby compressing said absorbent material to control the Q over the acoustical frequency range.

* * * * *