United States Patent [19]
Whitney et al.

[11] 3,806,840
[45] Apr. 23, 1974

[54] CONTOURED ULTRASONIC DELAY LINE

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[73] Assignee: **Sanders Associates, Inc.**, Nashua, N.H.

[22] Filed: **June 14, 1973**

[21] Appl. No.: **370,196**

[52] **U.S. Cl.** .... **333/30 R**
[51] **Int. Cl.** **H03h 9/26**, H03h 9/30
[58] **Field of Search** .... 333/30 R, 30 M, 72; 310/8.1, 8.3, 8.5, 8.6

[56] **References Cited**

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3,041,556 6/1962 Meitzler .... 333/30 R

Primary Examiner—Archie R. Borchelt
Assistant Examiner—Marvin Nussbaum
Attorney, Agent, or Firm—Louis Etlinger; Seligman, Richard I.

[57] **ABSTRACT**

A delay line comprising a strip of ultrasonic solid material having a pair of elongated and generally convex major surfaces to form a contoured cross section. Acoustic wave propagation between the major surfaces is confined to a region which extends a distance A in both directions from the center of the strip along the width or transverse dimension, where A is less than one-half of the width and is a function of the acoustical wavelength.

8 Claims, 10 Drawing Figures

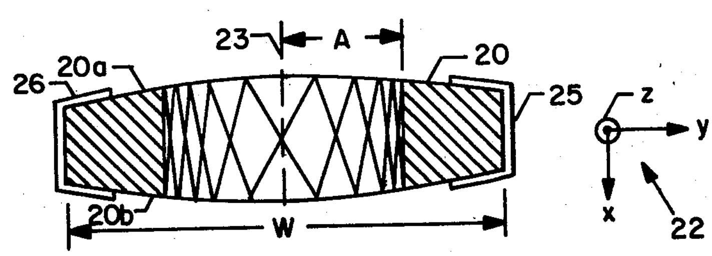


FIG. 1

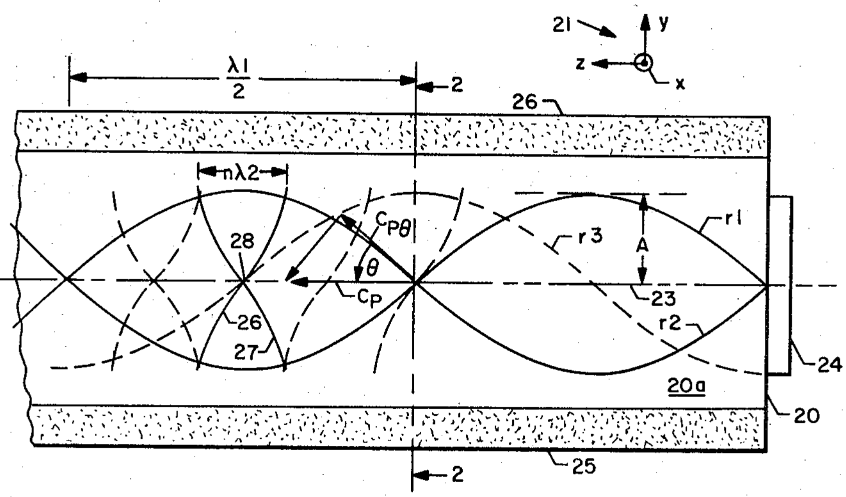


FIG. 2

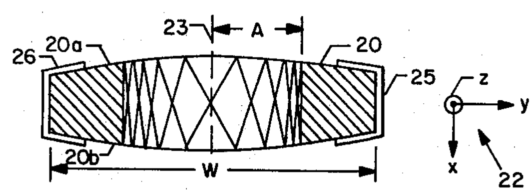
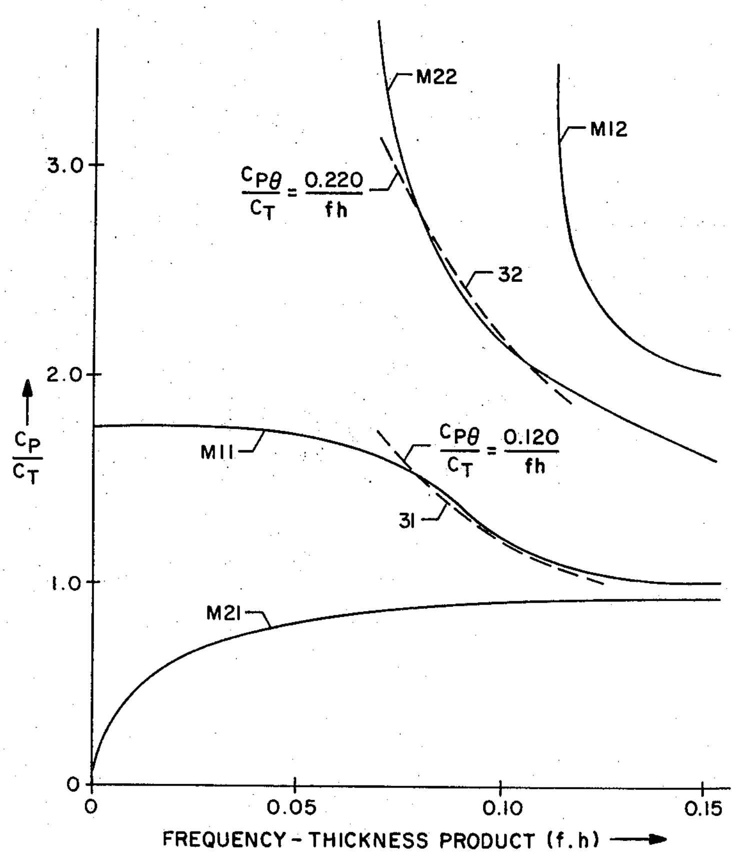


FIG. 3



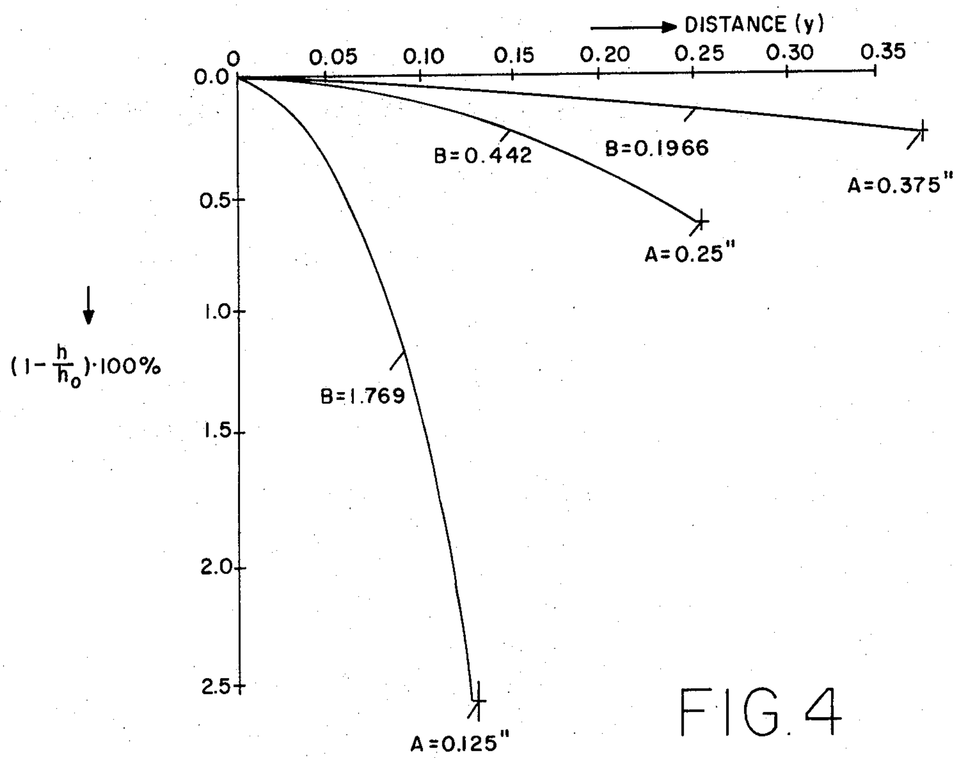

DISTANCE (y)
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.0
0.5
1.0
1.5
2.0
2.5
(1- h/h0)·100%
B=0.442
B=0.1966
A=0.375"
A=0.25"
B=1.769
A=0.125"

FIG. 4

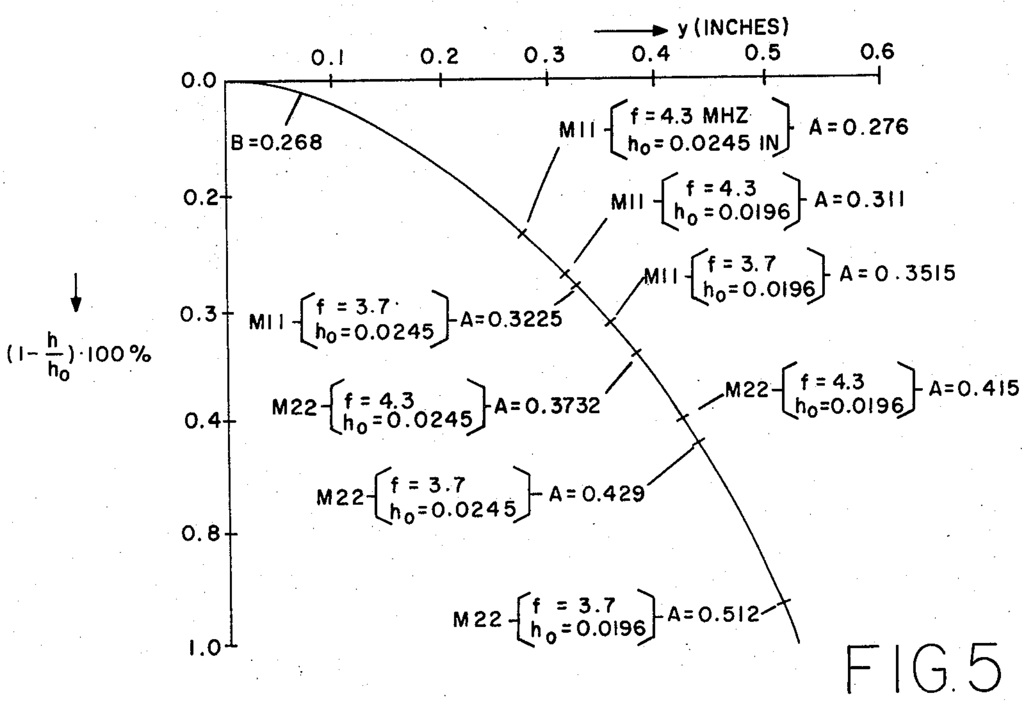

y (INCHES)
0.1
0.2
0.3
0.4
0.5
0.6
0.0
0.2
0.3
0.4
0.8
1.0
(1- h/h0)·100%
B=0.268
M11 {f = 4.3 MHZ, h0=0.0245 IN} A=0.276
M11 {f = 4.3, h0=0.0196} A=0.311
M11 {f = 3.7, h0=0.0196} A=0.3515
M11 {f = 3.7, h0=0.0245} A=0.3225
M22 {f = 4.3, h0=0.0245} A=0.3732
M22 {f = 4.3, h0=0.0196} A=0.415
M22 {f = 3.7, h0=0.0245} A=0.429
M22 {f = 3.7, h0=0.0196} A=0.512

FIG. 5

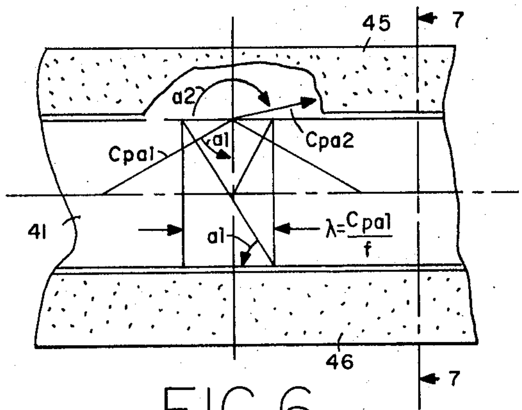


FIG.6

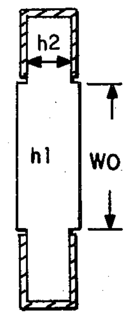


FIG.7

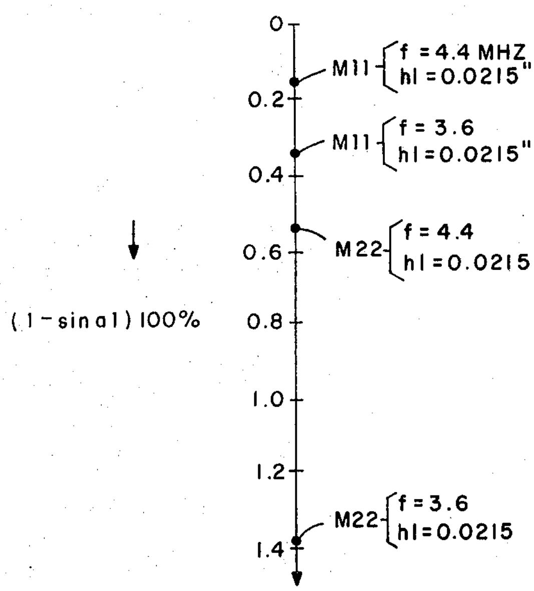


FIG.8

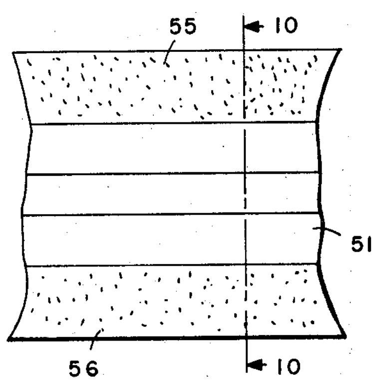


FIG.9

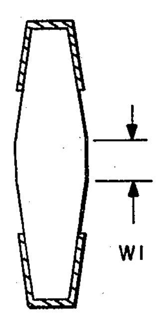


FIG.10

CONTOURED ULTRASONIC DELAY LINE

BACKGROUND OF THE INVENTION

A. Field of the Invention

This invention relates to delay devices and in particular to solid ultrasonic delay lines.

Ultrasonic delay lines are generally operable to provide either a nondispersive or a dispersive delay of continuous wave or pulse type signals. The terms dispersive and nondispersive refer to the delay versus frequency characteristic of a delay line. If delay changes with frequency, the line is said to be dispersive. On the other hand, if the delay is constant, or nearly so, for all frequencies, the line is termed nondispersive.

B. Prior Art

The propagation of continuous waves in solid plates is described in chapter 5 of the reference book "Mechanical Waveguides" by Martin Redwood, Pergamon Press, 1960. This description is based upon the premise that in a uniform thickness sheet of infinite width there is no variation of acoustical particle displacement in the width of y direction. A close approximation of actual performance to this theory has been realized by the application of absorbing tape to the edges of a finite width metallic strip (e.g., aluminum or aluminum alloy) such that there are no edge reflections which interfere with wave propagation in the central (untaped) portion of the strip. Such a delay line is described by T.R. Meeker in an article entitled "Dispersive Ultrasonic Delay Lines Using the First Longitudinal Mode in a Strip," IRE Transactions, Volume UE-7, No. 2, June, 1960. A disadvantage of this strip design is that in accordance with diffraction theory, there is appreciable beam spreading in the width or y direction such that a large amount of acoustic energy is absorbed by the tape, thereby resulting in relatively high acoustic losses.

Acoustic delay lines or waveguides of various cross sections, such as circles, rectangles and elipses, not employing absorbing means along the length thereof, have been studied as exemplified by Chapter 6 of the aforementioned Redwood reference. Dispersive delay lines have also been made of wire as evidenced by the article of J.E. May entitled "Wire Type Dispersive Ultrasonic Delay Lines," IRE Transactions, Volume UE-7, No. 2, June, 1960. While these delay lines do not suffer the loss due to absorbing tape, other problems have been encountered. For example, the very small area of the piezoelectric transducers on wire type dispersive lines have limited their use to relatively low frequencies. In addition, the interference of unwanted modes of propagation have prevented smooth transmission over a wide band of frequencies.

BRIEF SUMMARY OF THE INVENTION

An object of the present invention is to provide a novel and improved acoustic delay line.

Another object is to provide a novel and improved delay line in which there is negligible beam spreading loss.

Yet another object is to provide a novel and improved acoustic delay line of high efficiency in which unwanted modes of wave propagation are suppressed.

Briefly, an acoustic delay line embodying the present invention is comprised of a strip of ultrasonic transmission material having a pair of elongated and convex major surfaces to form a contoured cross section with a width W many times greater than the thickness h. When a beam of acoustic waves is applied to the strip, the wave propagation between the major surfaces is confined to a region which extends a distance A in both directions from the center of a strip along the width dimension. A is less than one half of the width and is a function of the acoustical frequency and phase velocity of the acoustic waves. Since the phase velocity characteristics of the undesired modes differ from those of the desired mode, the parameter A is generally larger for the unwanted or spurious propagation modes. By properly positioning the inside edge of the absorbing tape, it is possible to suppress the unwanted modes of propagation.

BRIEF DESCRIPTION OF THE DRAWING

In the accompanying drawings like reference characters denote like elements of structure; and

FIG. **1** is a plan view of a portion of an acoustic delay line embodying the present invention;

FIG. **2** is a cross sectional view taken along the lines **2—2** of the FIG. **1** delay line;

FIG. **3** is a plot of the ratio of phase velocity to transverse velocity versus the frequency and thickness product for an aluminum strip delay line;

FIG. **4** is a graph showing exemplary contours for delay lines embodying the present invention;

FIG. **5** is a plot of another exemplary contour for a delay line embodying the present invention;

FIG. **6** is a plan view of a portion of a contoured delay line which is a further embodiment of the invention;

FIG. **7** is a cross sectional view taken along the lines **7—7** of FIG. **6**;

FIG. **8** is a line graph illustrating the boundaries of wave propagation for different longitudinal modes;

FIG. **9** is a plan view of a portion of another contoured delay line embodiment of the invention; and

FIG. **10** is a cross sectional view of the FIG. **9** embodiment.

DESCRIPTION OF PREFERRED EMBODIMENT

Referring now to FIGS. **1** and **2** there is shown a portion of a contoured delay line **20** embodying the present invention. The length, width and heighth of the line **20** extend in the z, y and x directions, respectively, which directions are depicted at **21** and **22** in FIGS. **1** and **2**, respectively. The width W (FIG. **2**) is many times greater than the maximum height along the x direction. Although the line **20** may consist of any ultrasonic transmission material, it preferably takes the form of an elongated thin strip of aluminum or aluminum alloy. The total length of the strip is a function of delay required in any desired application. Preferably, the line thickness is tapered throughout the length of the strip so as to enhance the frequency range over which linear dispersive operation occurs.

Conventional piezoelectric ceramic transducers in the form of rectangular bars are bonded to the end faces of the strip, only one of which is shown at **24** in FIG. **1**. These transducers are poled in the thickness direction, electroded, and soldered to the line with the poling direction parallel to the length of the strip so as to produce and respond to vibrations in a thickness-longitudinal-mode. Accordingly, when one of the transducers is excited by an alternating voltage applied to the electroded areas of the major surfaces thereof, a thickness-longitudinal-mode of vibration is induced therein. This vibration in turn produces an elastic wave motion in the strip which propagates down the line. When the propagated energy reaches the transducer at the opposite end, a thickness-longitudinal-mode of vibration is induced therein and converted by the transducer to electrical energy. As will be clear to those skilled in the art, the electrical and physical connections at each of the ends of the line are similar and therefore either transducer can be used as the input or output, i.e., the line is completely reciprocal.

In accordance with the present invention, the strip thickness is given a contour in which the maximum thickness occurs at the center of the strip. In the embodiment illustrated in FIGS. **1** and **2**, the contour takes the form of a convex continuous shape in which the maximum thickness occurs at the center line **23** of the strip. Due to the contour, the elastic wave propagation in the z direction is confined to an area which extends a distance A on either side of the center line **23.** As best seen in FIG. **2,** the reflection angle of an elastic wave between the contoured major surfaces **20***a* and **20***b* is maximum at or near the center line **23** and becomes gradually smaller until at a distance A it becomes zero and reverses itself. That is, the contouring of the major surfaces tends to set up points of reflection at a distance A on either side of the center line **23** so that the propagation of an elastic wave is confined to this region.

As will become apparent thereinafter, the distance A turns out to be smaller for wave propagation in the first longitudinal mode **M11** than for propagation in the undesired modes **M12, M21** and **M22.** As a result, the placement of the edges of a pair of absorber tapes **25** and **26** can be chosen so as to suppress wave propagation in the undesired modes.

In the discussion which follows, it is assumed that the x, y and z coordinate axes are superimposed upon the strip **20** so that the center line **23** becomes the x - z plane. Using a ray method of analysis, assume that two rays, r_1 and r_2, shown in FIG. **1,** are symmetrical about the center line **23.** These rays travel in three dimensions as follows: (a) move in the x direction by alternate reflection between the major surfaces **20***a* and **20***b* of the strip in a manner shown in FIG. **2**; (b) progress from side to side of the strip (y direction) as shown in both FIGS. **1** and **2**; and (c) have an overall resultant propagation along the length of the strip (z direction).

The lateral or y position of each ray at any instant of time can be expressed as a sine function of the distance along the strip length or z direction as follows:

$$y = A \sin\beta z \tag{1}$$

where $\beta=2\pi/\lambda 1$, $\lambda 1$ is the wavelength of the sine wave along z and A is the amplitude of the sine function and distance to extremity of a particular mode of acoustic propagation from the centerline **23** or x - z plane.

The phase velocity directed along the sine curve of FIG. **1** and parallel to the y - z plane of the strip is designated $C_{p\theta}$. The phase velocity directed along the strip length (z - axis) is designated C_p. C_p also represents the phase velocity of the acoustic wave propagation along the strip.

As the phase front **26** of the ray r_1 moves along the sine curve, the longitudinal phase velocity C_p is larger than the tangential phase velocity $C_{p\theta}$ along the sine curve and is related to it in the following way:

$$C_{p\theta} = C_p \cos\theta \tag{2}$$

where θ is the angle of the phase velocity vector, $C_{p\theta}$, relative to the z-axis.

A necessary condition for single-mode propagation in a wave guide of any sort is that the phase velocity C_p be uniform over the entire cross sectional area of the guide. It is hence necessary that the phase velocity along a third ray, r_3, be the same as C_p. However, since for r_3 at the line **2—2,** $\theta=0$, $C_{p\theta}=C_p$, so that the condition is fulfilled. In other words, for constant C_p, $C_{p\theta}$ must be a cosine function of θ in accordance with equation (2).

By inspection of the $C_{p\theta}$ and C_p vector diagram in FIG. **1,** $\tan\theta = dy/dz$. The first derivative of equation (1) with respect to z is $\beta A \cos\beta z$. From equation (1) $\sin\beta z = y/A$. Accordingly, $\tan\theta$ can be expressed as follows:

$$\tan\theta = dy/dz = \beta\ \sqrt{A^2 - y^2} = \beta A\ \sqrt{1 - y^2/A^2} \tag{3}$$

From equation (3) it is evident that $\cos\theta$ can be expressed as follows:

$$\cos\theta = \sqrt{\beta^2 (A^2 - y^2) + 1} \tag{4}$$

Substituting equation (4) into equation (2), the ratio $C_p/C_{p\theta}$ can be expressed as follows:

$$C_p/C_{p\theta} = \sqrt{\beta^2 (A^2 - y^2) + 1} \tag{5}$$

The mode of propagation described herein is assumed to be symmetrical about the x - z plane as well as about the y - z plane. Referring to FIG. **1,** this requires that the phase fronts **26** and **27,** which intersect at the center line **23** at point **28,** be in phase with each other. This requires at $y = \pm A$ that the phase fronts **26** and **27** be separated by $n\ \lambda 2$, where n is any positive integer and $\lambda 2 = C_p/f$ and f is the acoustic frequency.

The analytic formula for the phase front (**26** or **27**) may be obtained in the following manner. Since, for any value of y, the phase front must be orthogonal to the direction of a ray, the slope of the phase front must be the negative inverse of the slope of the ray. Since the slope of the ray is given by equation (3), the curve zl for the phase front is given by

$$dzl = -\beta\ \sqrt{A^2 - y^2}\, dy \tag{6}$$

Integrating both sides of equation (6);

$$zl = -\beta[y/2\ \sqrt{A^2 - y^2} + A^2/2 \sin^{-1} y/A] \tag{7}$$

Assuming that the origin of the coordinate axes **21** coincides with the point **28** in FIG. **1** so that the phase fronts **26** and **27** are symmetrical about the x - y plane and setting $y =$ to A in equation (7), the following expression can be written for zl

$$zl = -\beta[\pi A^2/4] = n\lambda 2/2 \tag{8}$$

Ignoring the minus sign and setting $n=1$ for the first mode, β can be expressed as follows:

$$\beta = 2\lambda 2/\pi_A 2 \tag{9}$$

Substituting $\beta = 2\pi/\lambda 1$ into equation (9), $\lambda 1$ is given by

$$\lambda 1 = \pi^2 A^2/\lambda 2 \tag{10}$$

The phase velocity of the first and second longitudinal acoustic modes in a strip of uniform thickness, h, and a radian frequency, w, has been shown in the aforementioned Meeker reference to be obtainable from a solution of the following frequency equation:

$$\frac{\tan\left[\frac{wh}{2C_t}\left(1-\frac{C_t^2}{C_p^2}\right)^{1/2}\right]}{\tan\left[\frac{wh}{2C_d}\left(1-\frac{C_d^2}{C_p^2}\right)^{1/2}\right]} = \frac{-4\left(\frac{C_p}{C_d}\right)\left(\frac{C_p}{C_t}\right)\left(1-\frac{C_d^2}{C_p^2}\right)^{1/2}\left(1-\frac{C_t^2}{C_p^2}\right)^{1/2}}{\left(2-\frac{C_p^2}{C_t^2}\right)^2} \tag{11}$$

In FIG. 3 the curves designated M11 and M12 are plotted solutions for the first and second longitudinal (symmetric modes) **M11** and **M12.** Also plotted in FIG. **3** are curves representing the first and second asymmetric modes **M21** and **M22.** These modes are described and the frequency equations given in Chapter 5 of the aforementioned Redwood reference. The curves in FIG. 3 are plotted for Poisson's ratio $\rho = 0.355$, and transverse velocity $C_t = 0.1215$ in/μscc.

If C_p in FIG. **3** and in equation (11) is replaced by $C_{p\theta}$, the dependence of $C_{p\theta}$ on thickness for any frequency can be found. Also in FIG. **3** it can be seen that in the frequency-thickness product range of interest (0.072 – 0.105), the curves for the **M11** and **M22** modes can be closely approximated by the dashed hyperbolic curves **31** and **32,** respectively. These approximate hyperbolic curves for the M11 and M22 modes may be expressed in equations (12) and (13) respectively, as follows:

$$C_{p\theta}/C_t = 0.1200/fh \tag{12}$$

$$C_{p\theta}/C_t = 0.220/fh \tag{13}$$

Utilizing either equation (12) or equation (13) and allowing the thickness at $y=A$ to be h_A, the ratio of h to h_A can be given by:

$$h/h_A \cong C_p/C_{p\theta} = 1/\cos\theta = \sec\theta = \sqrt{\beta^2(A^2-y^2)+1} \tag{14}$$

When the thickness h has its maximum value of h_O at $y=0$, equation (14) can be rewritten as follows:

$$h_O/h_A = \sec\theta_{max} = \sqrt{\beta^2 A^2+1} \tag{15}$$

The thickness h at any value of y can be related to the center thickness h_O as follows:

$$h/h_O = h/h_A \cdot h_A/h_O = \sec\theta/\sec\theta_{max} = \sqrt{\beta^2(A^2-y^2)+1}/\sqrt{\beta^4 A^2+1} \tag{16}$$

Both A and β are fractions such that $\beta^2 A^2$ is much less than 1 so that terms including A^4 and/or β^4 can be neglected. As a result, the radical expression of

$$\sqrt{\beta^2 A^2+1}$$

can be simplified as follows:

$$\sqrt{\beta^2A^2+1} \cong \sqrt{1+\beta^2A^2+\beta^4A^4/4} = 1+\beta^2A^2/2 \tag{17}$$

A still further approximation of equation (17) can be made as follows:

$$\frac{1}{1+\frac{\beta^2A^2}{2}} = \frac{\left(1-\frac{\beta^2A^2}{2}\right)}{\left(1+\frac{\beta^2A^2}{2}\right)\left(1-\frac{\beta^2A^2}{2}\right)} = \frac{1-\frac{\beta^2A^2}{2}}{1-\frac{\beta^4A^4}{4}} \cong 1-\frac{\beta^2A^2}{2} \tag{18}$$

Utilizing equations (17) and (18), equation (16) can be rewritten as follows:

$$h/h_O \cong (\beta^2A^2/2 - \beta^2y^2/2 + 1)(1-\beta^2A^2/2) \tag{19}$$

Multiplying out the two terms on the right hand side of equation (19) and neglecting terms including β^4 and/or A^4, equation (19) can be written as follows:

$$h/h_O \cong 1 - \beta^2y^2/2 \tag{20}$$

The percentage reduction from the center thickness h_O is found from equation (20) to be:

$$(1-h/h_O)\cdot 100\% = \beta^2y^2/2 \cdot 100\% \tag{21}$$

Equations (20) and (21) basically describe a parabolic function such that the contour is approximately parabolic in shape and independent of the distance A. The percent reduction from the center thickness as given by equation (21) is plotted in FIG. **4** for a frequency-thickness product of 0.085 MHz inches (the frequency being equal to 4 MHz.) for values of $A=$ 0.125, 0.250 and 0.375 inches and corresponding values of $\beta = 1.769$, 0.442 and 0.1966, respectively. The points on these curves can be calculated as follows. First, C_p is calculated from equation (12) by employing a measured value of the transverse velocity $C_t = 0.1215$ inches/microseconds. Next, the value of β is calculated from equation (9) with the value of $\lambda 2$ being equal to C_p/f or 0.0434. Then, equation (21) can be employed to calculate different values of the quantity $(1-h/h_0)$ 100 percent for different values of y. Having once selected a value of β, and thus established a desired contour (e.g., one similar to one of the three curves in FIG. 4) at a midband frequency, it is, of course, desirable to find the values of A at the extremes of the frequency range of interest. The value of A for each new wavelength or frequency is then computed directly from equation (9).

With reference again to **FIG. 3**, two additional or spurious modes **M21** and **M22** exist in the range of interest. The first asymmetric mode **M21** has a positive slope in this range and, hence, is subject to the normal beam spreading loss occurring in a flat or uncontoured delay line strip. However, the reasoning developed above for the **M11** mode applies equally to the **M22** mode except that the latter mode is asymmetric about the cener y - z plane. In addition, this mode is closely approximated by the inverse relationship given in equation (13).

In **FIG. 5** there is plotted a contour for $\beta = 0.268$, utilizing equation (21). It is assumed that this contour is to be employed for all sections of a tapered delay line strip, the extreme thicknesses of which are: $h_0 = 0.0245$ and 0.0196 inches. The values of A have been calculated and plotted on the contour for frequency values of 4.3 and 3.7 MHz. for both thickness values in both the **M11** and **M22** modes, utilizing equations (9), (12) and (13). By inspection, it can be seen that all the points representing the A values of the spurious mode **M22** lie further from the center line than all the points representing the A values of the desired mode **M11.** It is therefore possible, by positioning the inside edge of the absorbing tapes **25** and **26** (**FIGS. 1** and **2**) to cover the extremities of the undesired spurious mode (while not covering the extremities of the desired mode), to selectively absorb out the unwanted acoustic wave propagation in the **M22** mode. For the example given, the edge of the absorbing tape **25** or **26** should be placed at a distance of about 0.36 inches from the center of the strip for both of the delay line sections.

When different thicknesses are employed to accomplish a more linear delay change over a wider frequency bandwidth, it is possible to change the lateral position of the absorbing tape for different thicknesses of the strip so as to more effectively separate the wanted from the unwanted signals. That is, the edge of the absorbing tape need not be at the same distance from the center line of the strip for different thicknesses thereof.

The foregoing analysis is heuristic in nature and is not presented as a rigorous treatment of three dimensional wave motions. Experimental results, however, have agreed closely with results predicted from the graphs. Improvements in the continuous wave loss at center frequency of a 4 MHz., 2,500 micro-second aluminum strip dispersive delay line have been as much as 10 decibels as compared to an uncontoured delay line strip of similar design.

The contouring of a delay line strip may be accomplished by etching in from the edges of the strip by laying a loosely coiled delay line strip in an empty tank and filling the tank with the etchant at a slow linear rate up to the center line of the strip. The coil is turned over and the operation repeated for the other edge. In using this technique, the transverse taper produced in one example was 0.0003 inches at plus or minus 0.375 inches from the center of the strip.

It has been further discovered that a workable contour can be achieved by rolling 1.75 inch wide and 0.05 inch thick aluminum strip stock through a two high rolling mill which is set for 40 to 50 percent reduction in thickness of the strip and which has a roll diameter of four inches and an axial roll length of six inches. The contour thus achieved can then be measured and plotted to produce a graph similar to that shown in **FIG. 5.** The values of β and A can then be calculated for the frequency range of interest.

In other embodiments of the invention, the contour need not be continuous by may have discontinuities. Thus, the delay line strip portion shown in **FIG. 6** has a transverse stepped contour such that the central portion of width Wo has a thickness **h1** and the two edge sections have a thickness **h2** which is smaller than **h1.** The two edge sections are also covered with absorbing tape **45** and **46.**

If a ray of an acoustic wave traveling at a phase velocity C_{pa1} in the strips strikes the step at an angle of incident **a1**, it may continue to travel in the edge section at a refracted angle a2 and phase velocity C_{pa2} or be totally reflected into the central portion at the angle **a1.** Snell's Law applies in this case as follows:

$$\sin a_1/\sin a_2 = C_{pa_1}/C_{pa_2} \tag{22}$$

In addition, the phase velocities C_{pa1} and C_{pa2} are related to the frequency and thicknesses $h1$ and $h2$ in accordance with **FIG. 3.** The angle a1 beyond which total reflection occurs is found by setting $\sin a2 = 1$. Also, if the inverse relationships shown in **FIG. 3** are assumed, the thickness ratio in terms of **a1** is given as follows:

$$\sin a1 = C_{pa1}/C_{pa2} = h2/h1 \tag{23}$$

In **FIG. 8** the percentage thickness reduction, $(1 - \sin a1)$ 100 percent is plotted on a line graph for two frequencies (3.6 and 4.4 MHz.) for both the **M11** and **M22** modes with $h1 = 0.0215$ inches. Thus, by controlling the thickness ratio $h2/h1$ (as for example, a reduction of 0.45 percent), the acoustic wave propagation in the desired **M11** mode may be guided into the central portion of the strip while the suprious **M22** mode wave propagation can be made to excape into the edge sections and be absorbed by the tape.

In **FIGS. 9** and **10** there is illustrated a portion of another delay line strip **51** having a further discontinuous type contour embodying the present invention. In this contour, the edges of the strip are reduced with a linear taper leaving a flat width **W1** in the center of the strip. This type of contour also includes the case where the width of the flat section **W1** is reduced to zero. It should be evident that other contours having curvatures somewhat different from the embodiment shown in **FIGS. 1, 2, 6, 7, 9** and **10** may be employed so long as the center thickness is larger than the thickness at the edges of the strip.

What is claimed is:

1. A delay line comprising

a strip of ultrasonic transmission material having a pair of elongated and generally convex major surfaces to form a contoured cross section with a width W many times greater than the thickness *h*; and

means for applying a beam of acoustic waves to said strip whereby acoustic wave propagation between the major surfaces is confined to a region which extends a distance A in both directions from the center of the strip along the width dimension, where $A < W/2$.

2. A delay line as set forth in claim 1 wherein said beam applying means includes a transducer poled in the longitudinal mode affixed to one end thereof and means for applying electrical signals to said transducer.

3. A delay line as set forth in claim 2 and further including

absorbing tape means wrapped around the minor surfaces of said strip and extending inwardly along said major surfaces toward the center of the strip a distance less than $W/2 - A$.

4. A delay line as set forth in claim 2

wherein A is a function of both the acoustical wavelength and the acoustical phase velocity such that its values throughout the frequency band of interest are smaller for the longitudinal mode M11 than for the mode M22; and

wherein the edges of said absorbing tape means are positioned so as to absorb acoustical wave propagation in the M22 mode and to allow acoustical wave propagation in the M11 mode.

5. A delay line as set forth in claim 4 wherein said contour is generally continuous.

6. A delay line as set forth in claim 4 wherein said contour includes a central section having a uniform thickness $h1$ and a pair of edge sections each of thickness $h2$; and

wherein the edges of said absorbing tape means are positioned along the edge sections.

7. A delay line as set forth in claim 4

wherein said contour has a central position of uniform thickness and width W1, where $W1<W$, and a pair of tapered edge sections.

8. A delay line as set forth in claim 4

wherein said contour includes a pair of tapered sections which have their maximum thickness at the center of the strip.

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