

June 17, 1958

H. J. McSKIMIN

2,839,731

MULTI-FACET ULTRASONIC DELAY LINE

Filed Jan. 14, 1953

4 Sheets-Sheet 1

FIG. 1

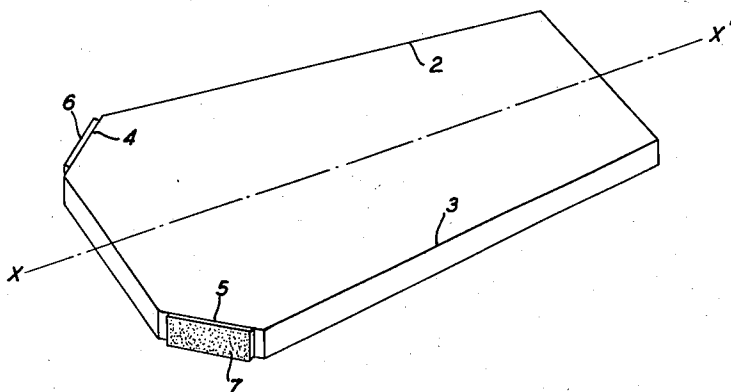
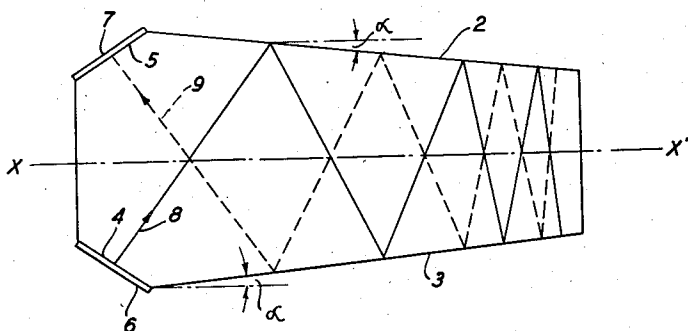


FIG. 2



INVENTOR
H. J. Mc SKIMIN
BY *Martha L. Hugh*

AGENT

June 17, 1958

H. J. McSKIMIN

2,839,731

MULTI-FACET ULTRASONIC DELAY LINE

Filed Jan. 14, 1953

4 Sheets-Sheet 2

FIG. 3

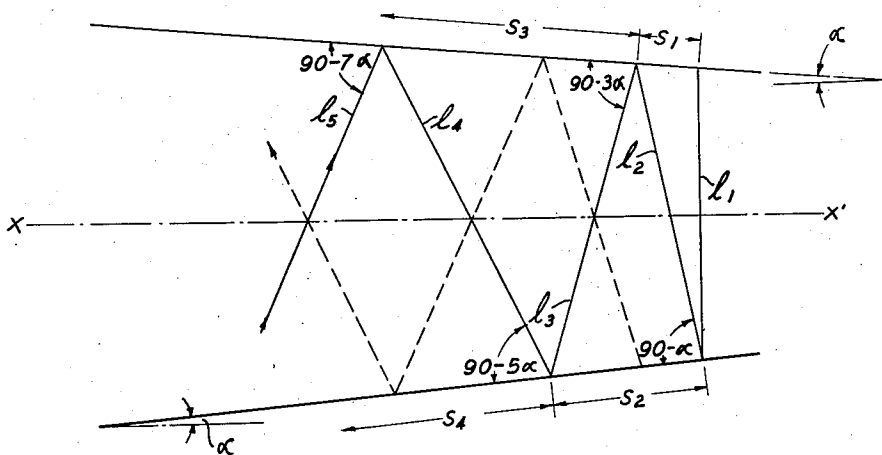


FIG. 4

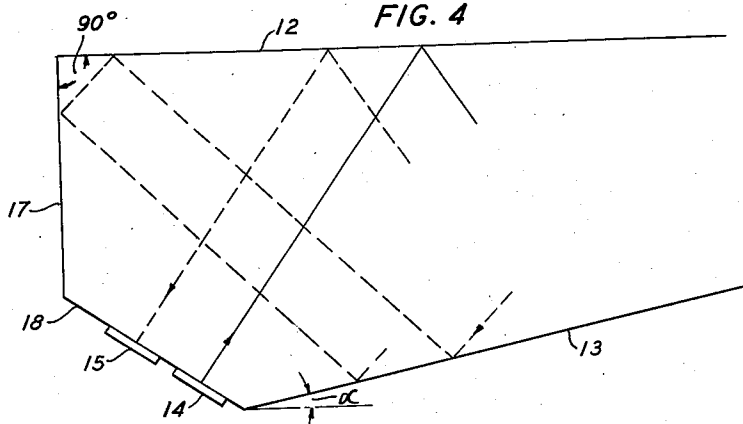
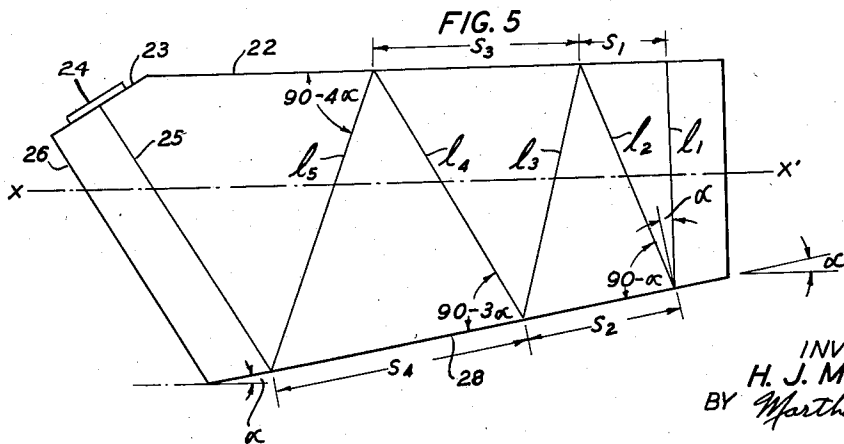


FIG. 5



INVENTOR
H. J. Mc SKIMIN
BY *Martha L. Lugh*

AGENT

June 17, 1958

H. J. McSKIMIN

2,839,731

MULTI-FACET ULTRASONIC DELAY LINE

Filed Jan. 14, 1953

4 Sheets-Sheet 3

FIG. 6

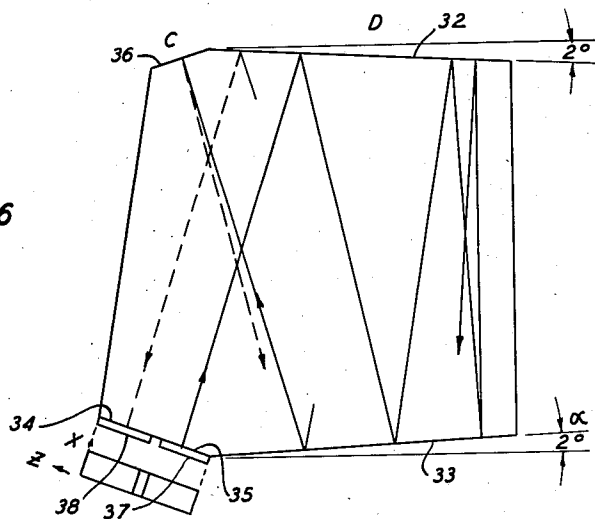


FIG. 8

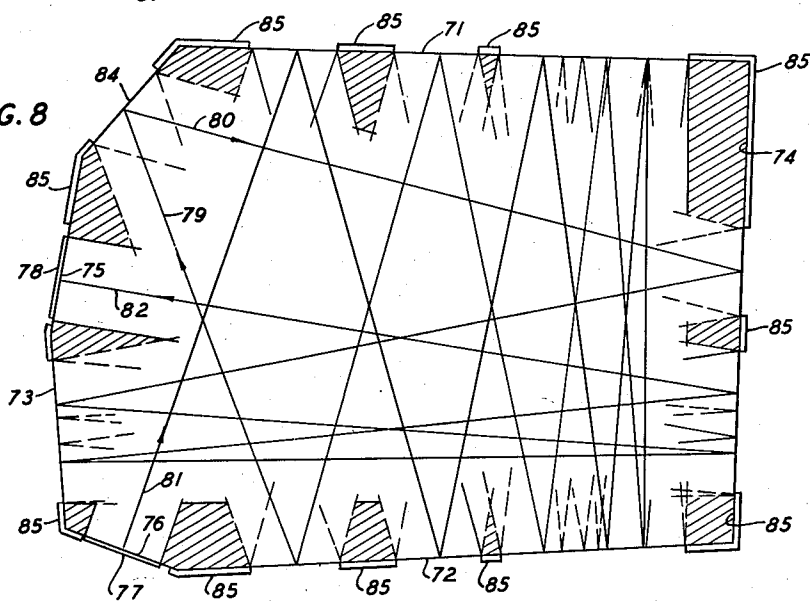
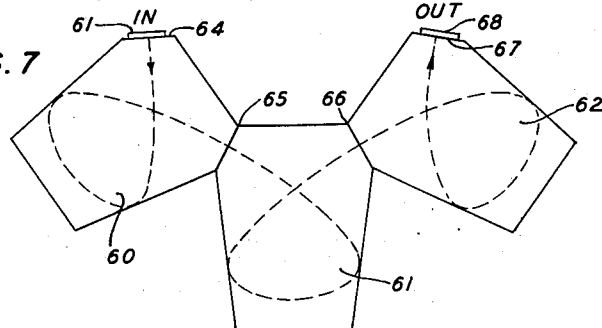


FIG. 7



INVENTOR
H. J. Mc SKIMIN
BY *Martha L. Pugh*

AGENT

June 17, 1958

H. J. McSKIMIN

2,839,731

MULTI-FACET ULTRASONIC DELAY LINE

Filed Jan. 14, 1953

4 Sheets-Sheet 4

FIG. 9

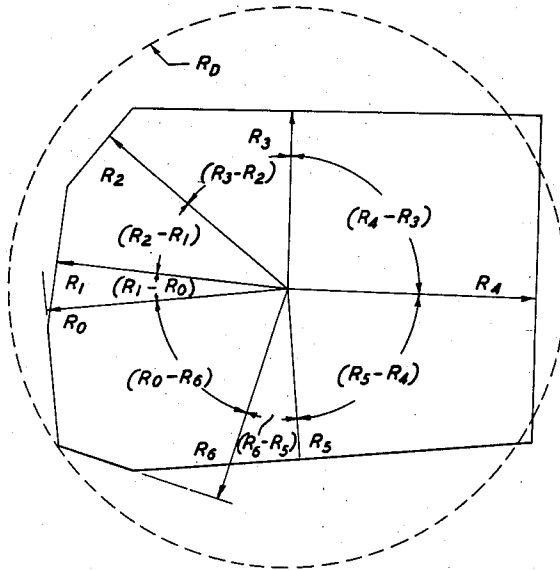


FIG. 10

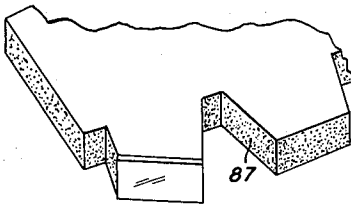


FIG. 11A

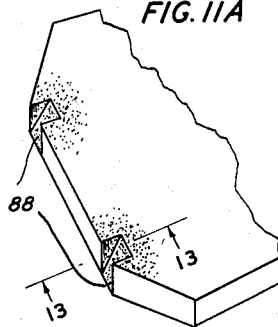


FIG. 11B

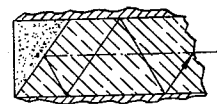


FIG. 12

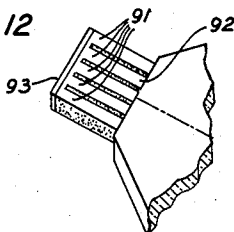


FIG. 13A

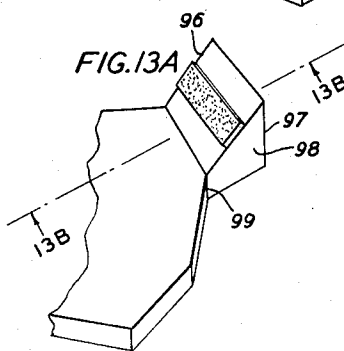
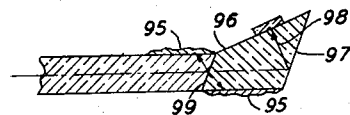


FIG. 13B



INVENTOR
H. J. Mc SKIMIN
BY *Martha E. Pugh*

AGENT

1

2,839,731

MULTI-FACET ULTRASONIC DELAY LINE

Herbert J. McSkimin, Basking Ridge, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application January 14, 1953, Serial No. 331,299

4 Claims. (Cl. 333—30)

The present invention relates to delay lines, and more particularly to delay lines comprising solid or liquid media for retarding the transmission of ultrasonic waves.

Ultrasonic delay lines using shear and longitudinal waves in rods or plates comprising acoustic delay media such as vitreous silica, have been found to operate over wide frequency bands and to have delay characteristics that are stable with time and temperature.

A principal disadvantage of the common types of ultrasonic delay lines used in prior practice has been their bulkiness. Although a design recently developed to utilize multiple reflections of the beam in the delay medium provides for considerably reduced bulk and greater compactness, this particular design has the disadvantage of many surfaces which require critical adjustment, accordingly increasing the cost of individual delay units.

A general object of the present invention is to provide certain improvements in ultrasonic delay lines.

A more specific object of the present invention is to provide economy of the delay media, in combination with facility of manufacture, by utilizing designs of compact geometrical shapes which include a minimum number of critical facets.

Another object of the invention is to provide delay lines in which the level of spurious reflections is substantially reduced.

These and other objects are attained in accordance with the present invention in an ultrasonic delay line, the reflecting surfaces of which form a wedge, such that a beam, preferably of shear or transverse waves, directed into the wedge obliquely from an ultrasonic transducer is reflected back and forth between the two surfaces forming the wedge at gradually decreasing angles of incidence which close in at the narrow end, from which reflections take place in a reverse direction, at gradually increasing angles of incidence to the broad end for reception. One advantage afforded by this design is that the cross-reflected beams are widely separated at the broad end of the line where the transmitting and receiving transducers are positioned, and are close together at the narrow end, thereby fully utilizing the delay space without introducing spurious reflections into the receiver. This advantage is to be stressed, since it is the deleterious effect of beam spreading which ultimately limits the usefulness of this and other "common volume" types of delay lines.

A particular feature of delay lines designed in accordance with the present invention, is that very few critical surfaces are required, making their manufacture relatively simple.

In the disclosure hereinafter, wedge-shaped designs in accordance with the present invention are applied to solid acoustic transmitting media, such as vitreous silica, the facets of which are ground to the desired angles. Alternatively, however, designs in accordance with the present invention may be applied to liquid delay lines, in accordance with one example of which the reflecting facets may comprise steel slightly roughened to prevent

2

intimate mechanical contact with the mercury or other liquid which serves as the acoustic transmitting medium.

A simple form of the disclosed invention is a wedge symmetrical about its longitudinal axis, and having only four critical faces in edgewise planes around the periphery. The wedge is formed between two elongated edge surfaces, which are inclined slightly towards each other symmetrically with respect to the longitudinal axis. The transmitting and receiving transducers are applied symmetrically with respect to the longitudinal axis to a pair of surfaces cut across the corners at the broad end of the wedge, so that the beam is directed from the transmitter obliquely onto one of the elongated surfaces, and is reflected back and forth between the two elongated surfaces to the narrow end of the wedge, from which it is returned along a symmetrical path, finally striking the separate receiving transducer. Because of the symmetrical wedge shape, the beam angle, as measured between the incident ray and the normal to the reflecting surface, is decreased at each reflection by twice the angle between the wedge reflecting surface and direction of the longitudinal axis of the line.

Numerous modifications of the wedge-shaped delay line of the present invention are disclosed hereinafter. These include a delay line having only three critical reflecting facets, so angularly related that the beam is reflected at gradually decreasing angles between the wedge surfaces from the wide to the narrow end, where it is reflected at normal incidence, retracing the same path back to the single transducer, which serves for both transmission and reception.

It is often desirable to obtain delay of greater length than is possible when the beam traverses a single wedge. One form of delay line which accomplishes this purpose is a composite, formed by the series connection of several symmetrical simple wedges, the receiving portion of the first coupled to the transmitting portion of the second, the receiving portion of the second coupled to the transmitting portion of the third, etc. Such a form is particularly adaptable to liquid delay lines, since the coupling between sections can be automatically obtained through the liquid medium.

Another type of wedge delay line designed to provide longer delays is the reentrant loop which makes repeated use of the volume of the transmitting medium.

One disclosed form of the wedge-shaped reentrant loop is so designed that the beam, after traversing the length of the wedge and back for a first trip, is reflected through two right angles, thereby reversing its direction so as to make a second trip through the wedge in slightly off-set position, with respect to the first path, finally returning to a receiving crystal positioned adjacent to and slightly off-set from the transmitting crystal.

In accordance with another disclosed reentrant wedge design, the beam, after a first trip the length of the wedge and back, is reflected from a beveled corner at the broad end so as to execute a second path of reflections down the wedge which is directed at a slight angle to the first path. The receiving transducer is placed adjacent and at a slight angle to the transmitting transducer at the broad end of the wedge.

Another practical adaptation of the wedge-shaped delay line is the "double wedge" which comprises two pairs of reflecting surfaces arranged so that the beam is reflected back and forth between the first pair, and is then deflected in a transverse direction to utilize a second pair of wedge surfaces.

Due to spreading of the ultrasonic beam and small discontinuities in the reflecting surfaces, a proportion of the beam energy is misdirected within the wedge, and reflected back and forth, masking or interfering with the

true signal in the output. These misdirected portions of the beam energy are known as "spurious" responses.

Since the proportion of spurious responses which reach the receiver imposes the chief limitation on any of the delay line designs, consideration is given herein to certain devices in accordance with the present invention for combination with the disclosed wedge shapes to significantly reduce the level of the spurious responses.

These include short rod lines the outer surfaces of which are coated with solder absorber, which are placed between the transducing crystals and the transmitting and receiving surfaces of the wedge. A further device for absorbing spurious responses at the output end of the line is a stub line, preferably rectangular, containing solder filled slots which divide the line into several channels extending in the direction of the true received beam. Striking the solder partitions obliquely, the spurious beam components are reflected back and forth between the solder partitions, and are thereby absorbed.

A further feature of the present invention is the use at locations where spurious reflection is expected of a combination including beveled end surfaces together with solder absorber on adjacent surfaces.

This same objective may also be accomplished in accordance with the present invention by notching or cutting out portions along the reflecting edges where spurious reflections are expected, and coating the cut-out portions with solder.

In solid delay lines comprising, for example, vitreous silica, in which reflection takes place at the solid-air interfaces, transverse or shear waves polarized to produce particle motion parallel to the reflecting surfaces provide certain advantages for operation in that they can be reflected through a wide range of angles within the delay line without shifts in mode from one reflection to the next, and without the presence of a series of "trailing" spurious waves, even at low frequencies. Certain transducer materials, such as barium titanate, which are useful for generating and receiving acoustic waves in the delay media, operate best in a longitudinal mode of vibration. Hence, if it is desired to utilize a longitudinal vibrator, but transverse or shear waves in the delay medium, it is necessary to provide a mode-converting unit between the transducers and the surface of the solid delay line to which it is applied. This mode-converter may take the form of a solid angular block which is designed so as to completely convert the longitudinal beam to a beam of shear waves. In accordance with the present invention, spurious reflections are reduced at the interface between the mode-converter and the surface of the delay line by providing a junction between the two which is at an oblique angle to the principal beam direction, so that reflections from the impedance discontinuity thereby presented are deflected away from the principal beam path, and onto solder absorbing surfaces.

Objects and features of the present invention, in addition to those pointed out in the foregoing paragraphs, will be apparent from a study of the specification hereinafter and the attached drawings in which:

Fig. 1 is a showing in perspective of a simple symmetrical wedge delay line in accordance with the present invention;

Fig. 2 is a plan view of the delay line of Fig. 1, indicating the beam path therethrough;

Fig. 3 is a diagram expository to the shaping of the simple wedge shown in Figs. 1 and 2;

Figs. 4, 5, and 6 are diagrams showing several forms of reentrant wedge lines in accordance with the present invention;

Fig. 7 is a diagrammatic showing of several simple wedge lines connected in series;

Fig. 8 is a plan view of one form of double-wedge delay line with the beam paths indicated;

Fig. 9 is a plan showing of the double-wedge delay

line of Fig. 8 with designations indicating critical dimensions;

Fig. 10 shows a portion of the double-wedge delay line notched to reduce spurious reflections;

Figs. 11A and 11B show in perspective and in cross section a portion of a wedge-shaped delay line including beveled stop surfaces to reduce spurious reflections;

Fig. 12 shows a solder channeled stub line attached to the wedge receiving surface for reducing spurious response; and

Figs. 13A and 13B show in perspective and in cross section a mode-converter attached to a portion of wedge delay line, through a beveled connecting junction.

This invention is concerned principally with delays effected by converting electrical waves to ultrasonic waves, passing the latter through a solid or liquid medium characterized by appreciable delay in the passage of these waves, and reconverting the same again to electrical waves.

The electrical signal to be delayed is impressed on a piezoelectric crystal transducer, frequently operating in the megacycle range because of band width requirements. This sets up ultrasonic vibrations in the crystal which are communicated to the transmitting medium. After passage through the transmitting medium, the ultrasonic vibrations are impressed on a receiving piezoelectric crystal for conversion back into electrical impulses corresponding to the original signal.

For use in the delay lines of the present invention, transverse or shear vibrations have been found to be advantageous, inasmuch as they can be reflected through a large range of angles without change in mode, thereby eliminating one source of spurious reflections.

A delay line in accordance with the present invention may assume, for example, the symmetrical wedge shape shown in Figs. 1, 2, and 3 of the drawings.

Referring to Fig. 1, a block 1 of fused silica is ground with its major faces accurately parallel and the peripheral surfaces perpendicular thereto. The surface roughness is preferably small compared to a wavelength (of the order of a tenth or twentieth). One suitable grinding means is a 600 diamond wheel. Alternatively, the surface may be ground with Carborundum and water used against a lapping plate. The peripheral edges of the block, which are ground symmetrically about the longitudinal axis, serve as reflecting surfaces for the ultrasonic beam. The wedge is formed by the elongated edge surfaces 2 and 3, which are inclined slightly in the direction of the longitudinal axis, $X-X'$, the angle of inclination to be precisely determined in a manner which will be described in detail with reference to Fig. 3. Surfaces 4 and 5 are ground across the corners of the broad end of the block, symmetrical with respect to the longitudinal axis, and assuming positions normal with respect to the plotted path of the beam. To these are attached a pair of electroacoustical transducers 6 and 7, which, for example, may be Y-cut quartz crystals resonant at a desired frequency.

Fig. 2 shows a plan view of the symmetrical wedge of Fig. 1, indicating the path of the beam 8, generated by the transmitting crystal 6, as it is reflected back and forth between the reflecting surfaces 2 and 3, at gradually decreasing angles, to the narrow end of the wedge 1, the return beam 9 being reflected back and forth at gradually increasing angles in a reverse direction for reception by the transducer 7. In the symmetrical wedge form indicated in Figs. 1 and 2 the paths of beams 8 and 9 cross each other symmetrically, gradually closing in at the small end of the wedge. In designing a specific unit, after the wedge angle has been chosen, and the two wedge surfaces laid out graphically, the beam is plotted with a protractor, starting at the small end of the wedge with a line perpendicular to the longitudinal axis of the wedge in the plane of the major faces. Using both ends of this line as projected incident beams, the angles of reflection are plotted with respect to the normals of the two wedge

5

surfaces. In each case the line representing the reflected beam is extended until it intercepts the opposing wedge surface. At this point, it is treated as a new incident beam, and the angle of reflection plotted with respect to the normal as before. This process is carried on until the projected reflections of the beam are sufficient in number to obtain the desired delay. Surfaces 4 and 5, for attachment of the transmitting and receiving transducers 6 or 7, respectively, are then ground perpendicular in each case to one of the oppositely directed lines representing the last reflected beams at the broad end of the wedge.

Fig. 3 of the drawings shows diagrammatically the relationships between the angle of wedge, and the angle of incidence of the beam in the symmetrical wedge form indicated in Figs. 1 and 2. Let α equal the angle between either of the inclined wedge surfaces 2 and 3 and the longitudinal axis X—X'. Let s_1, s_3 , etc. indicate the distances measured along the upper wedge surface between respective points of reflection from the narrow end of the wedge outwardly, and let s_2, s_4 , etc. represent the corresponding distances between reflecting points on the lower surface. Let l_1, l_2 , etc. indicate the distances measured obliquely across the wedge along the path of the beam between successive reflecting points on the upper and lower surfaces from the small end of the wedge, towards the large end. The following relationships obtain:

$$l_n = \frac{l_1 \cos^2 \alpha}{\cos (2n-3)\alpha \cos (2n-1)\alpha}$$

$$s_n = \frac{l_n \sin (4n-2)\alpha}{\cos (2n+1)\alpha}$$

where n represents any integer.

Certain modifications of the wedge-shaped design described make more efficient use of the volume of the transmitting medium by reflecting the beam down the length of the wedge and back for more than a single trip. One such design, as indicated in Fig. 4 of the drawings, is a modification of the simple wedge of Figs. 1-3 in accordance with which one reflecting edge 12, corresponding to edge 2 of the former, is extended to meet edge 17, making a right angle at one corner of the broad end of the wedge. Hence, a beam 19, reflected back and forth the length of the wedge through a path plotted as described with reference to Figs. 1-3, is incident upon reflecting facet 12, by which it is reflected across the rectangular corner to the reflecting facet 17 for a second reflection as beam 20, parallel to and slightly off-set with relation to the beam 19. The course of beam 20 for a second trip the length of the wedge and back, is plotted parallel to, and in off-set relation to beam 19. The second returned beam is picked up by the receiving crystal 15 which is positioned parallel to and slightly displaced from the crystal 14 on the surface 18, obliquely cut across the other corner at the broad end of the wedge, so as to be perpendicular to the beam emerging from the transmitting transducer 14, and the parallel beam received by receiving transducer 15.

Another modified form of the reentrant wedge indicated in Fig. 5 of the drawings, is shaped so that the beam 25 transmitted from the single transducer attached to the surface 23 traverses the length of the wedge comprising a pair of plane surfaces 22 and 23, to the small end, where it strikes the reflecting surface at normal incidence, and is thereby returned along the same path to the transducer 24 for reception. This shape is designed by plotting the path of the beam, as in previous cases, starting with a line perpendicular to one inclined wedge reflecting surface 22, and plotting the angles of incidence and reflection as the zig-zag paths progress to the broad end of the wedge, whereat surface 23 is ground perpendicular to the projected path of the transmitted and received beam. As with reference to Fig. 3, α represents the angle between the wedge surface 23 and the longitudinal axis X—X', s_1, s_3 , etc., the distances between re-

6

flecting points as measured along the upper surface, s_2, s_4 , etc. corresponding distances measured along the lower reflecting surface, and l_1, l_2 , etc. the distances between reflecting points as measured obliquely across the wedge from one reflecting point to the next succeeding one. Referring to this figure, the following relationships obtain:

$$l_n = \frac{l_1 \cos \alpha}{\cos (n-1)\alpha \cos n\alpha}$$

$$s_n = \frac{l_n \sin 2n\alpha}{\cos (n+1)\alpha}$$

Fig. 6 of the drawings shows another form of reentrant wedge delay line. The material used for this purpose, as in the previous embodiments, may take the form, for example, of a block of a strain-free, optical grade of vitreous silica having dimensions $3\frac{1}{16}'' \times 3\frac{3}{16}'' \times \frac{1}{4}''$ prior to grinding.

The wedge surfaces 32 and 33 are ground as precisely as possible using a shop protractor to specified angles of, for example, +2 degrees and -2 degrees with the transverse axis. The block is then placed in a grinding jig, so that it can be rotated. Front surface mirrors are then placed flush with and extending slightly above the wedge surfaces 32 and 33. A light beam directed through a pair of slits is incident immediately above surface 34, and the path traced by viewing the beam emerging at surface 36. Surface 34 is then ground perpendicular to the path established by the beam. An additional mirror is then placed on the grinding edges of the jig at surface 36, and the angular position of the block adjusted until the beam is reflected back from surface 36 emerging at surface 35. Finally, surface 35 is aligned in a manner similar to 34, making sure the beam emerging at surface 36 passes through the same point it did during the alignment of 34.

These angles could alternatively be directly ground to specified values, using precision grinding equipment of types well-known in the art.

In the illustrative embodiment under description the electroacoustic transducers 37 and 38, for example, take the form of Y-cut quartz crystals having the following dimensions: length, 12 millimeters; width (along the X-axis), 6.30 millimeters; and thickness, 0.15 millimeter. The crystals 37 and 38 are attached to the corresponding surfaces 35 and 34 by conventional silver-paste solder technique, which includes hand spraying with silver-paste and baking at 540° C. for about a half hour. Preferably, the silvered surfaces are then filed to remove high spots, burnished with steel wool, and tinned with lead-tin-bismuth eutectic solder, melting point, 95° C. A saturated solution of ammonium chloride in glycerine serves as a flux. The crystals 37 and 38 are then oriented with their X-axes respectively perpendicular to the major faces of the delay line, so that the shear particle motion takes place parallel to the reflecting facets 35 and 34. Crystals 37 and 38 are then soldered by means of any of the techniques well-known in the art, such as described, for example, in my application Serial No. 125,049, filed November 2, 1949, now Patent 2,727,214, of December 13, 1955.

For example, if crystals 37 and 38 have a resonant frequency in air of approximately 13 megacycles for the fundamental, and 39 megacycles for the third harmonic, they operate in a delay line to provide pass-bands near and including these respective frequencies. A fairly wide pass-band can be obtained at 39 megacycles by designing the solder seal to have a thickness of approximately a quarter-wavelength at the operating frequency, such as disclosed in application Serial No. 125,049, supra.

A piece of plastic tape, which may take the form of ordinary Scotch tape, pressed onto the surface 32 of the wedge can be used to minimize end-to-end and other spurious responses.

A delay line constructed in the manner described in

the preceding paragraphs gave a delay of 394 microseconds under test. It has been found that if greater delays are desired, all of the major dimensions should be increased in linear proportion. Thus, a 1000 microsecond delay line would require a stock blank having a dimension of about $8\frac{1}{2}$ " on a side, and thickness of the order of a quarter inch.

In order to increase the total delay obtainable over that obtainable with a single wedge-shaped line, a number of wedges can be connected in series in the manner indicated in Fig. 7 of the drawings. Fig. 7 shows three symmetrical wedges 60, 61, and 62, the individual shapes of which are similar to those described with reference to Figs. 1-3 of the drawings, wherein the receiving portion of the wedge 60 is coupled to the transmitting portion of the wedge 61; and the receiving portion of the wedge 61 is directly coupled to the transmitting portion of the wedge 62. Hence, a beam impressed on the wedge 60 normal to the transmitting surface 64 by the ultrasonic transducer 61 is reflected the length of wedge 60 and back, passing normally through receiving-transmitting junction 65 into the wedge 61, in which reflection takes place the length and back passing normally through the receiving-transmitting portion 66 of the wedges 61 and 62, after which it takes a similar course through wedge 62 and out through receiving surface 67 to which is attached the ultrasonic receiving transducer 68. Such an arrangement is particularly useful for liquid delay lines of the type disclosed in my Patent 2,505,364, issued April 25, 1950, wherein coupling between the sections is automatically obtained by continuity of the liquid. If mercury, for example, is the delay medium, vibrations in the longitudinal mode are utilized. Alternatively, if it is desired to utilize a solid delay medium in the multiple element form described, individual sections 60, 61, and 62 might be stacked and ground to dimensions as a unit, and then soldered together. The beam is preferably constricted at the junctions so that beam spreading is limited to the spread occurring in a single unit.

Fig. 8 of the drawings shows another modification of the wedge delay line in accordance with the present invention, in which the beam is reflected back and forth between two pairs of wedge surfaces, thereby providing increased delay and additional economy of the delay medium. In the design indicated in Fig. 8 of the drawings, the wedge action in one direction is provided by the reflecting surfaces 71 and 72; and in a transverse direction by the surfaces 73 and 74.

A beam 81 preferably of ultrasonic shear waves, is impressed normally on wedge surface 76, by the ultrasonic transducer 77, following which it is reflected several times internally at gradually decreasing angles of incidence between the wedge pair 71 and 72, returning from the smaller to the broader end of this wedge, where it strikes surface 84 and is deflected in a direction essentially transverse to the initial direction. The beam is then reflected back and forth between the second pair of wedge surfaces 73 and 74 and finally received at normal incidence by the ultrasonic receiving transducer 78 applied to the surface 75. As in the single-wedge shapes previously described, the double wedge shape may be simply designed by first selecting the angles of the two sets of wedge pairs, one in the direction of a longitudinal axis, and the other in the direction of a transverse axis. A line is then drawn perpendicular to the longitudinal axis at the narrow end of the first wedge pair, from the two ends of which a pair of lines are plotted representing the beam path reflected back and forth between the surfaces at gradually increasing angles. A second line is drawn perpendicular to the transverse axis at the narrow end of the second wedge pair, and from its two ends a pair of lines are plotted representing the beam path reflected back and forth between the

second pair of wedge surfaces. In that corner of the structure corresponding to the broad end of both wedge pairs, the last return-reflected beam path 79 in the longitudinal direction and the first transmitted beam path 80 in the transverse direction, intersect in an angle, the bisector of which is determined, and the surface 84 ground normal thereto. Surface 76 is ground perpendicular to the projected path of the transmitted beam 81, and surface 75 is ground perpendicular to the projected path of the received beam 82.

Fig. 9 of the drawings corresponds to Fig. 8, the letter designations R_1 , R_2 , etc. indicating the critical dimensions of the wedge. The wedge is preferably formed from a block of strain-free, optical grade, vitreous silica, five-eighths of an inch in thickness, ground in accordance with techniques well known in the art, so that the major faces of the block are parallel. Referring to the diagram shown in Fig. 9, the dimensions and angles for a specific disclosed embodiment are computed in accordance with the following table:

Radii		Inches
R_0	-----	2.6876
R_1	-----	2.5956
R_2	-----	2.5956
R_3	-----	1.9513
R_4	-----	2.6876
R_5	-----	1.8961
R_6	-----	2.4391
Angles		
$R_0-R_1=12^\circ 30'$		$R_5-R_4=85^\circ 30'$
$R_2-R_1=32^\circ 30'$		$R_6-R_5=22^\circ 0'$
$R_3-R_2=49^\circ 30'$		$R_0-R_6=67^\circ 30'$
$R_4-R_3=90^\circ 30'$		

The linear dimensions given are typical values for a line designed to give a delay of 500 milliseconds. For reducing or increasing the desired delay, the linear dimensions may be respectively increased or decreased, while retaining the angular relationships of the wedge.

It is apparent that while retaining the double wedge form, features of the design may be varied in order to vary the delays obtained. For example, instead of placing both transmitting and receiving transducers adjacent the same end of the line, the receiving transducer may be removed, for example, to surface 74 at the opposite end of the wedge as defined by the first pair of wedge surfaces, the only critical criterion being that the surface be ground perpendicular to the received beam. This would provide a somewhat increased delay, inasmuch as the beam would be reflected once more the length of the wedge.

The transmitting and receiving transducers applied to surfaces 76 and 75 normal to the projected beam, comprise in preferred form, a pair of transverse or shear wave vibrators comprising, for example, Y-cut quartz, applied in the manner described hereinafter with reference to Figs. 1-3 of the drawings.

As pointed out in the early part of the specification, the practical utility of any specific delay line is severely limited by the level of spurious responses intermingled with the signal responses received at the output of the line. In order to reduce these spurious reflections within the delay line, peripheral areas 85 in Fig. 8, between the selected reflecting points, are coated to a thickness of, for example, one-thirty-second of an inch with a material having an impedance approximating that of the delay medium. The width of the ultrasonic beam to be applied to the delay line is computed, and its projection plotted as indicated in Fig. 8. Areas not within the path of the projected beam are indicated by the shaded portions of Fig. 8, the peripheral surfaces of which, in each case, are coated with absorber.

As indicated in Fig. 10, still further reduction of spuri-

ous reflections has been achieved in accordance with the present invention by cutting slots or notches 87 in the periphery of the delay line at points from which such spurious reflections are likely to originate, and coating these notches with absorbing material such as for example lead-tin-bismuth eutectic solder. The outline of the slots is approximately indicated by the shaded areas of Fig. 8.

An additional means for the reduction of undesired spurious reflections from reflecting surfaces is the use of beveled stop surfaces 88 on the peripheral edges which are inclined inwardly as indicated in perspective and in cross section in Figs. 11A and 11B of the drawings. The upper and lower surfaces adjacent the beveled portions are coated with lead-tin-bismuth eutectic solder or other absorbent in the manner indicated with reference to Fig. 10, so that a beam striking the beveled surface is reflected to the upper or lower soldered surface and is absorbed.

A further feature of the present invention for reducing spurious reflections, indicated in Fig. 12 of the drawings, takes the form of a channeled or slotted rectangular stub line which may be applied to either the transmitting or receiving surfaces or both. This structure contains several parallel slots 91 extending through the stub in a direction normal to the broad surfaces of the wedge and also to the receiving surface 92. The slots are several wavelengths apart, and are filled with solder of sufficient thickness to be absorbing, for example, one-thirty-second of an inch. Thus, an ultrasonic beam striking this channel element attached to the receiving surface 92 is directed to impinge normally on the receiving crystal 93, whereas obliquely traveling waves are deflected and absorbed by the solder partitions.

In conjunction with delay lines of the type described, preferably designed for operation with transverse or shear waves, it is necessary, when using certain types of longitudinal vibrators, such as, for example, barium titanate elements, to insert a mode-converter between the line and the generator or receiver. A type of mode converter useful for this application is indicated in Figs. 13A and 13B of the drawings, which show the structure in perspective and in cross section. This takes the form of a block 98 of strain-free optical grade vitreous silica, prismatic in form, such that if the transmitting transducer is applied to the surface 96, the transmitted beam is deflected from the surface 97 at such an angle that the mode of vibration is converted from longitudinal to shear. In the prior art structures such a mode-converter is soldered to the interface of the delay line in a joint which is normal to the direction of the transmitted beam. However, in accordance with the present invention, spurious reflections are reduced by substituting a junction 99 between the surface of the delay line and the mode-converter, which junction is disposed obliquely to the direction of transmission of the acoustic beam. Hence, the undesirable reflections resulting from the waves striking the interface which presents an impedance discontinuity are deflected onto another surface of the delay line which is coated with solder absorber of a type described hereinbefore. This is indicated in the cross sectional showing in Fig. 13B. Solder absorbing layers 95 are positioned to receive the spurious beams.

It is apparent that the technique of reducing spurious

reflections described in detail in the foregoing paragraph, can be applied to other delay line structures comprising a junction which forms an impedance discontinuity, such as, for example, the junction with the slotted stub line indicated in Fig. 12, or the junctions between the tandem connected units indicated in Fig. 7.

The present invention is not limited to the specific forms disclosed. It is apparent that a liquid delay medium, such as disclosed in my Patent 2,505,364, supra, may be used to replace the solid delay medium disclosed herein whenever convenient. It is further apparent that other designs, not herein disclosed, using specific wedge shapes adapted to fulfill given delay requirements can be devised in accordance with the teachings of the present invention.

What is claimed is:

1. An ultrasonic delay line bounded by a plurality of edge surfaces normal to a common plane, a first pair of said surfaces disposed at a slight angle of inclination to each other with respect to a longitudinal axis of said line, a second pair of said surfaces disposed at a slight angle of inclination with respect to a transverse axis of said delay line, means for transmitting a beam of ultrasonic radiations for internal reflection the length of said first pair of surfaces and back, means comprising an obliquely disposed edge surface for deflecting said beam onto said second set of surfaces for internal reflection the length of said second pair of surfaces and back, and means for receiving the beam of ultrasonic radiation reflected the length and back of said second pair of surfaces, wherein said ultrasonic transmitting and receiving means are substantially normally disposed to the projected path of said beam.

2. An ultrasonic delay line comprising a plurality of peripheral reflecting surfaces, means for reducing spurious reflections in said line which comprises beveling said edges at positions of spurious reflection outside the plotted beam path in said line and placing solder absorbing surfaces adjacent said beveled surface.

3. In combination with an ultrasonic delay line a mode-converter, comprising a block of ultrasonic transmitting medium, an ultrasonic transmitting transducer for transmitting a beam of ultrasonic waves vibrating in the longitudinal mode connected to one surface of said block, a second surface of said block disposed at an oblique critical angle with respect to the surface of attachment of said ultrasonic transducer, whereby a beam from said transducer is converted from longitudinal to transverse mode, and a junction between said mode-converter and said ultrasonic delay line oblique with respect to the plane of travel of said beam.

4. A combination in accordance with claim 1 wherein said ultrasonic transmitting and receiving means are both disposed adjacent edge surfaces at the broad end of the wedge formed by one said pair of surfaces.

References Cited in the file of this patent

UNITED STATES PATENTS

2,199,843	Schmidt	May 7, 1940
2,540,720	Forbes et al.	Feb. 6, 1951
2,624,804	Arenberg	Jan. 6, 1953
2,624,852	Forbes et al.	Jan. 6, 1953
2,649,550	Hardic et al.	Aug. 8, 1953