March 13, 1962 J. M. WOLFSKILL 3,025,479

LONG ULTRASONIC DELAY LINE

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FIG_1

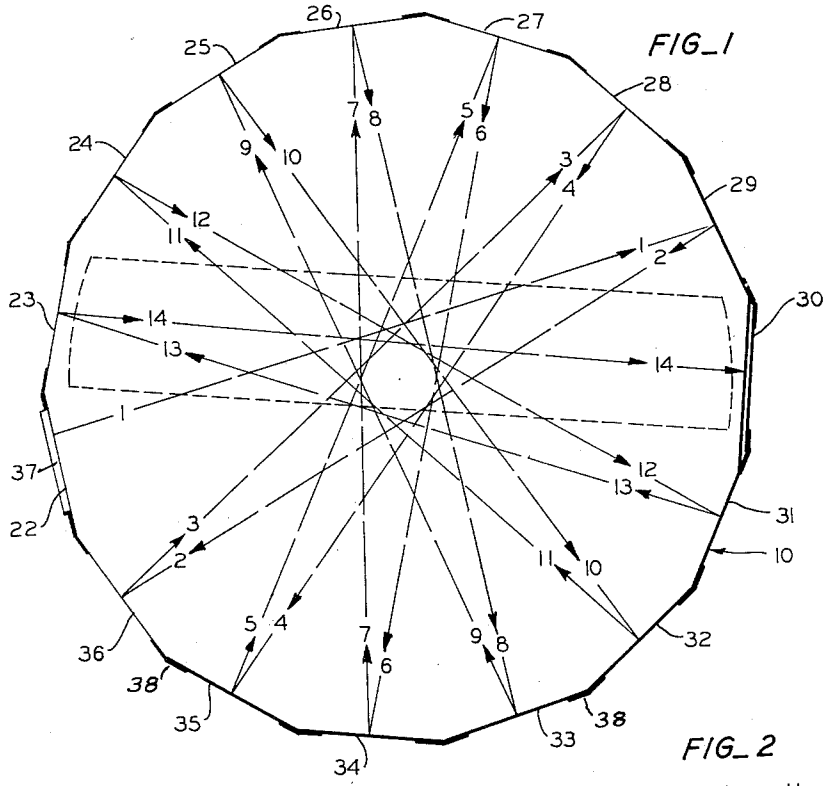
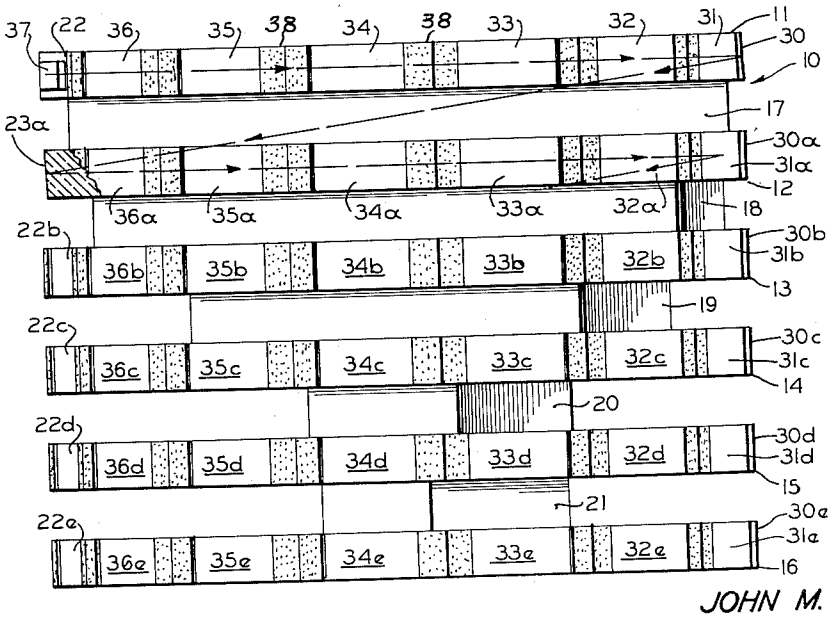


FIG_2



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FIG_3

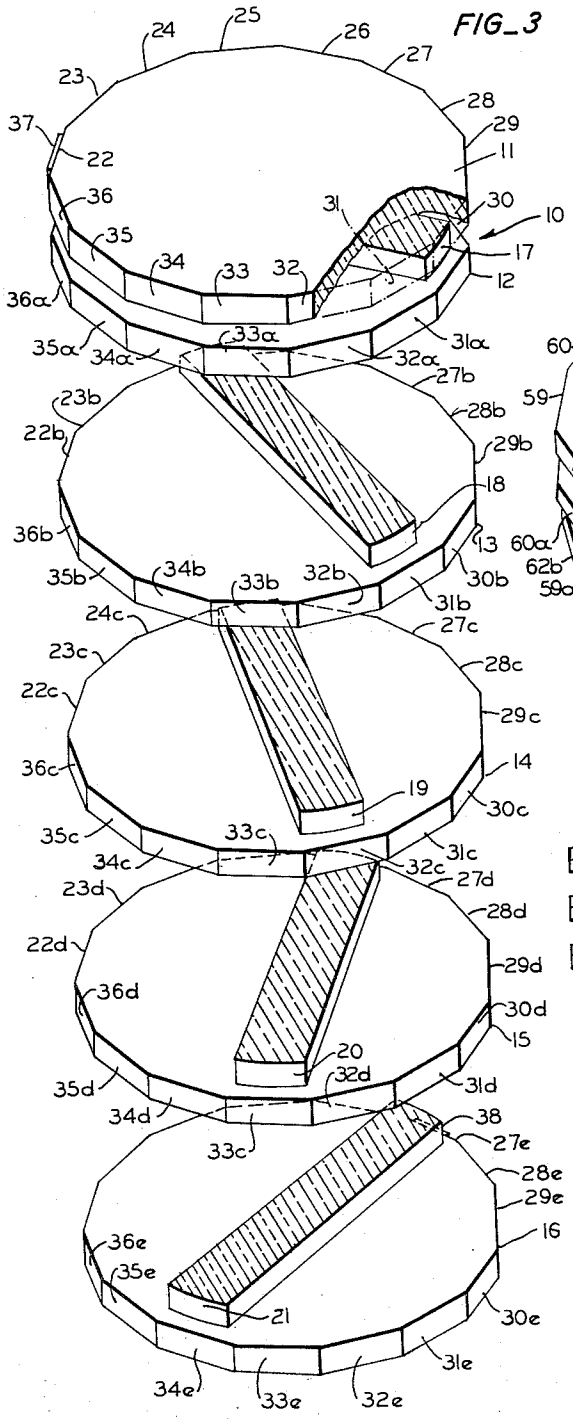


FIG_4

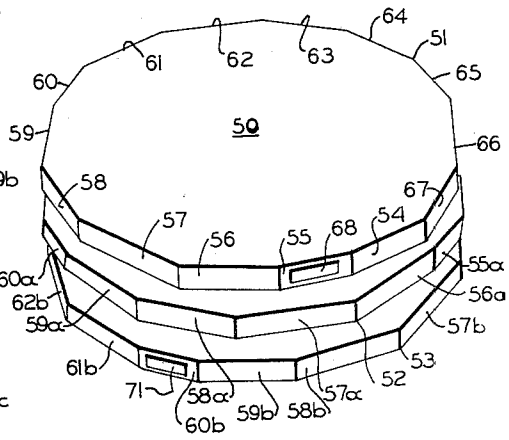
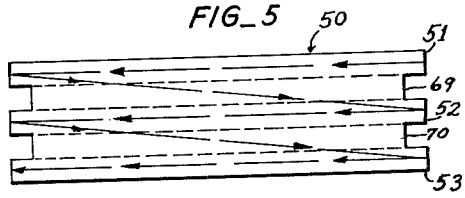


FIG_5



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LONG ULTRASONIC DELAY LINE

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FIG_6

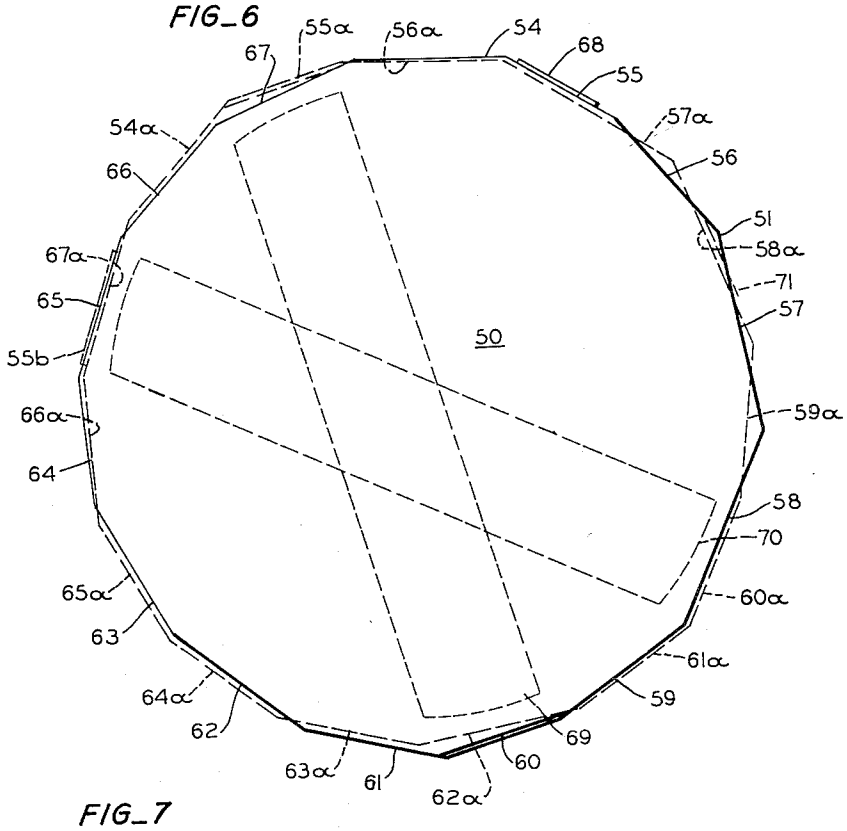
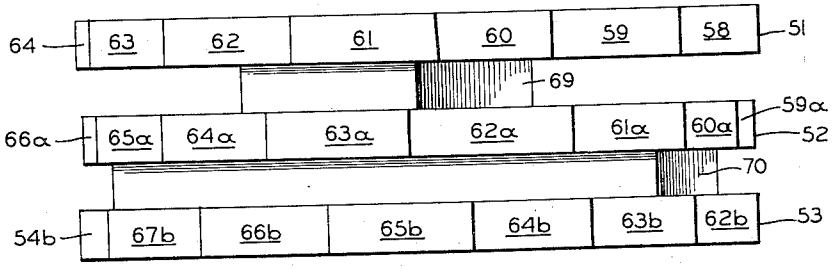


FIG_7



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United States Patent Office 3,025,479 Patented Mar. 13, 1962

3,025,479

LONG ULTRASONIC DELAY LINE

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Filed June 1, 1959, Ser. No. 817,198
8 Claims. (Cl. 333—30)

This invention relates to solid ultrasonic delay lines in general. More particularly this invention relates to delay lines of the multi-facet type in which a plurality of these elements is arranged in a stack such that the ultrasonic energy does not leave the transmission medium until it is picked up by the final output transducer.

In the prior art relating to solid ultrasonic delay lines it has been the general practice to construct the multi-facet delay element as a single layer polygonal disc. Where long delay times are involved, the transmission medium designed to be constructed in this fashion becomes too large in diameter for practical procurement, and furthermore it is impractical from an economic standpoint. Fused quartz of the homogeneity required for delay line media increases in price approximately as the square of the diameter and there is presently with current production techniques a limit of 19½" on the diameter.

To secure long delays therefore, it is necessary to resort to other schemes, one of which is to make two delay lines and put them in tandem. Usually because the major portion of the loss takes place at the transducers, an amplifier is necessary in between the two lines to restore the signal level to a normal value before transmitting it to the second line. This arrangement would also hold true for two or three or more lines in tandem.

Other schemes have been used in the prior art for increasing the practical delay line values such as joining two or more discs together by means of prisms so that when the signal ends up at the end of the traveled path in one disc, it is reflected into a second disc by a prism that is bonded to one of the facets of each disc. Such an arrangement in addition to being difficult to make also introduces losses in the path. It also becomes increasingly difficult to maintain two discs in the exact juxtaposition under adverse environmental conditions such as vibration and shock. This frequently has a tendency to break or otherwise to destroy the bond. Such arrangements at best are quite fragile and in addition they suffer an increased loss from passing through two or more interfaces at the cemented joints.

It is an object of this invention to provide a means of obtaining long delay times in an ultrasonic medium such as fused quartz in relatively small diameters without having the ultrasonic beam leave the fused quartz until it arrives at the output transducer.

It is another object of this invention to provide an improved delay line having a long delay time and giving greatly improved performance substantially free from the spurious signals heretofore frequently encountered in lines having long delay times.

Still another object of this invention is to provide an improved delay line having a long delay time, said delay line being constructed out of one piece of material so that additional undesirable reflections such as would be generated at the interfaces between the prism facets disc joining prisms, are eliminated.

Still another object of this invention is to provide a delay line of long delay time which is a solid integral piece of fused quartz, which is rugged and capable of withstanding stringent environmental shock and vibration without deleterious effects.

Another object of this invention is to provide a multiple layer delay line of long delay time in which the loss in signal intensity is held at a minimum such that the loss

levels therein are no greater than those which would be experienced if the same length line were made in a single layer.

It is another object of this invention to provide a multiple layer delay line in which the ultrasonic energy is transferred from one layer into the next layer in a manner such that the angles of incidence and reflection of the ultrasonic energy beam in the transfer path do not exceed 10° and usually are more of the order of 3° to 5°.

A further object of this invention is to provide an improved multi-layer delay line in which the ultrasonic energy is transferred from one layer to the next through small angles of incidence and reflection, said small angles of incidence and reflection in the transfer path produce low losses in ultrasonic energy and also tend to inhibit production of spurious and other unwanted reflections.

Other and further objects of this invention will be apparent to those skilled in the art to which it relates from the following specification, claims and drawing in which briefly:

FIGURE 1 is a plan view of an embodiment of this invention in which the path of the sonic energy is indicated by broken lines in the top layer of the delay line;

FIGURE 2 is a side view of the multiple layer delay line;

FIGURE 3 is an exploded view of the delay line shown in FIGURE 2;

FIGURE 4 is a perspective view of another embodiment of this invention;

FIGURE 5 is a side view of a multiple layer delay line such as shown in FIGURE 4 and this view illustrates the direction of the sonic energy between the layers thereof;

FIGURE 6 is a plan view of the delay line shown in FIGURE 4; and

FIGURE 7 is a side view of the delay line shown in FIGURE 6.

Referring to FIGURES 1, 2 and 3 in detail, there is shown an embodiment of this invention employing a plurality of multi-faceted layers **11**, **12**, **13**, **14**, **15** and **16** arranged in a stack so that the layer **11** forms the top delay element of this stack and the layer **16** forms the bottom delay element thereof. While the stack **10** is shown with six layers different numbers of layers either more or less than six may be provided depending upon the signal delay time desired.

The adjacent layers are joined by means of integral ribs which hold the adjacent layers in spaced relation and which function to provide connecting paths for the transmission of sonic energy between the adjacent layers. Thus layers **11** and **12** are joined by the integral rib **17**; layers **12** and **13** are joined by the integral rib **18**; layers **13** and **14** are joined by the integral rib **19**; layers **14** and **15** are joined by the integral rib **20** and layers **15** and **16** are joined by the integral rib **21**.

In practice the stack **10** may be made of one piece of fused quartz such as Hereaus optical grade No. 1 fused quartz and suitable slots may be cut therein by means of a diamond impregnated saw or similar tool so that the fused quartz body **10** is divided into a plurality of layers **11**, **12**, **13**, **14**, **15** and **16** which are spaced by the integral ribs **17**, **18**, **19**, **20** and **21**, respectively. On the other hand the fused quartz body **10** may be cast or molded with the slots between the layers formed during the casting or molding operation.

Each of the delay line layers is provided with a plurality of facets such as the facets **22** to **36** inclusive to form a substantially regular polyhedron. Thus the top layer **11** is provided with facets **22** to **36** inclusive; layer **12** is provided with corresponding facets **22*a*** to **36*a*** inclusive; layer **13** is provided with corresponding facets

22*b* to 36*b* inclusive; layer **14** with facets 22*c* to 36*c* inclusive; layer **15** with facets 22*d* to 36*d* inclusive and layer **16** with facets 22*e* to 36*e* inclusive. In the case of the top layer of the stack **10** the facet **22** is provided with a transducer **37** which may be a piezoelectric crystal that is bonded to the facet **22** by means of suitable material such as indium, epoxy resin or any other suitable cements or solders. This transducer **37** supplies sonic energy to the layer **11** and this sonic energy is reflected between the facets so that it makes a total of fourteen passes in the layer, as shown by the arrows and broken lines, before it impinges the slightly tilted output facet **30** which is positioned in line with the rib **17**.

The facet **30** is tilted so that the plane thereof is disposed at a small angle between 3° to 5° with respect to the axis of the stack **10**. As a result this facet does not reflect sonic energy into the layer **11** but reflects this energy to the input facet **23***a* of layer **12** through the integral rib **17** which is aligned between the facets **30** and **23***a*. The input facet **23***a* of layer **12** is below the facet **23** of the layer **11** and the plane of the input facet **23***a* is also disposed at a small angle of 3° to 5° with respect to the axis of the stock **10** whereby this facet **23***a* reflects the sonic energy received thereby into the layer **12**. The sonic energy is then reflected between the multiple facets of layer **12** and makes a total of fourteen passes in this layer before it impinges the output facet **31***a* thereof. This output facet **31***a* is also disposed with the plane thereof at a small angle of 3 to 5 degrees with respect to the axis of the stack **10** and it is aligned with the rib **18** so that it reflects sonic energy through this rib into the next adjacent layer **13**. The energy reflected by the output facet **31***a* of layer **12** impinges the facet **24***b* of layer **13** which is also positioned with the plane thereof disposed at a small angle of 3 to 5 degrees with respect to the axis of the stack.

In each case the integral rib between the adjacent layers is in alignment with the output facet of the uppermost layer and the input facet of the lower layer. Thus the rib **17** is in alignment with the output facet **30** of the layer **11** and the input facet **23***a* of layer **12**; rib **18** is in alignment with the output facet **31***a* of layer **12** and input facet **24***b* of layer **13**; rib **19** is in alignment with the output facet **32***b* of layer **13** and input facet **25***c* of layer **14**; rib **20** is in alignment with the output facet **33***c* of layer **14** and input facet **26***d* of layer **15** and rib **21** is in alignment with output facet **34***d* of layer **15** and input facet **27***e* of layer **16**.

In the form of this invention illustrated in FIGURES 1, 2 and 3, each of the multifacet layers is constructed so that the sonic energy supplied to the top layer **11** by the transducer **37** is reflected from each of the facets only once, in accordance with the pattern of reflections illustrated in FIGURE 1. A similar pattern of reflections takes place in each of the layers **11** to **16** inclusive of the multilayer stack. Each of the fourteen facets of these layers is disposed around the circumference of the layer in such fashion as to form a substantially regular polyhedron, however, if some of the facets of the layer are made of slightly different lengths as illustrated in the plan view FIGURE 6, then multiple reflections may take place from selected ones of the facets. In other words, the sonic energy beam supplied to the multifacet layer may be reflected two or three different times from selected ones of these facets. Thus, the sonic energy beam instead of making fourteen passes between the facets of the layer as shown in FIGURE 1, may make as many as thirty-one or more passes between the facets of the layer illustrated in FIGURE 6 before it impinges upon the tilted facet which directs it through the integral rib into the next lower layer.

The stack **50** illustrated in FIGURE 4 is provided with three layers **51**, **52** and **53** although a greater number of layers may be provided thereto, if it is desired to construct a delay line having a greater time delay. Each of these layers **51**, **52** and **53** is provided with fourteen facets such as the facets **54** to **67** inclusive, shown on the layer **51** in FIGURE 6. The facets of layer **52** are shown in FIGURE 6 in broken lines in order to distinguish them more readily from the facets of layer **51** and it will be noted that similar facets of layer **52** are displaced by a certain angle with respect to the corresponding facets of layer **51**. The facets of layer **52** are designated by reference numerals **54***a* to **67***a* inclusive and these correspond to the facets **54** to **67** inclusive of layer **51**; however from FIGURE 6 it will be noted that facet **54***a*, for example, of layer **52** is not aligned with facet **54** of layer **51** but is displaced by an angle of between 45 and 50 degrees. The other corresponding facets of layer **52** are likewise displaced by a similar angle. Also the facets of layer **53** are displaced by a similar angle with respect to corresponding facets of layer **52**. Other angular displacements may be employed if desired to suit the particular facet configurations of the delay line layers.

A transducer **68** which may be a piezoelectric crystal, for supplying sonic energy to the top layer **51** is attached to the facet **55** and the sonic energy supplied thereby is reflected between the various facets of this layer making a total of thirty-one passes therebetween before impinging facet **60** which is tilted with respect to the axis of the stack by an angle of 3 to 5 degrees so that sonic energy impinging on it is reflected through the rib **69** to the input facet **55***a* of layer **52**. Facet **55***a* and facet **60** are of course aligned with rib **69** and facet **55***a* is also tilted with respect to the axis of the stack by an angle of 3 to 5 degrees whereby sonic energy impinging this latter facet **55***a* is reflected into the layer **52** at the proper angle so that it makes a multiplicity of passes between the various facets of this layer in order to produce the desired signal delay in this layer before impinging the facet **60***a*. Facet **60***a* is also tilted at an angle of 3 to 5 degrees with respect to the axis of the stack so that the sonic signal impinging on it is reflected by it through the rib **70** to the facet **55***b* of layer **53** which is also tilted with respect to the axis of the stack at an angle of 3 to 5 degrees so that the sonic signal impinging on this latter facet is reflected by it into layer **53** at the proper angle so that it makes a multiplicity of passes between the various facets of this layer. After the sonic signal is reflected between the facets of the layer **53** in accordance with a predetermined pattern it impinges the output facet **60***b* and the output transducer **71** which is cemented or bonded to facet **60***b* by solder, indium, epoxy resin or other suitable bonding agents. Accordingly the electrical signal supplied to the input transducer **68** which is converted into a sonic signal by this transducer is converted into an electrical signal by the transducer **71** after it is delayed a predetermined time interval in the delay line.

All of the forms of this invention may have sonic energy absorbers such as the absorbers **38** which are made up of solder or similar material suitable for this purpose attached, bonded or cemented to the corner portions between the facets as is illustrated in FIGURES 1 and 2, to reduce interference and undesirable signal reflections from these areas.

This invention may be employed for making delay lines of various lengths by using a cylinder of fused quartz of relatively small size and providing it with a suitable number of layers required to produce the desired delay. Thus it is not necessary to employ a fused quartz element of the maximum obtainable diameter or of a diameter approaching this maximum but smaller diameters may be employed and cut or formed into a plurality of layers of sufficient number to provide the required signal delay.

Furthermore, it is not necessary to cut out a substantial thickness of the fused quartz between the adjacent layers up to the rib connecting these layers because all that is necessary is to provide a narrow cut in the fused quartz body up to the rib. In other words, while each of

the spacings between the layers **11** to **16** inclusive shown in FIGURE 2 is commensurate with the thickness of these individual layers, these spacings actually do not have to be any thicker than the width of a diamond saw cut if desired. However where the stack of layers is to be roughly shaped by a casting or molding operation it is desirable to make the spacings wider, that is commensurate with the thickness of the layers to facilitate the casting or molding thereof. Such cast or molded units may be of rough outline and they may be finished to accurate dimensions by grinding and lapping.

The transducers **37** and **38** shown in FIGURE 3 and those shown in FIGURE 4 are piezoelectric crystals lapped to a frequency that is considerably higher than the center frequency of the delay line because the loading effect produced by bonding the transducers to the fused quartz reduces the frequency of the transducers to the center frequency of the delay line. The information to be delayed whether pulsed or continuous wave is modulated on this center frequency. These crystals are adapted to vibrate in the shear mode to produce transverse vibrations which have a velocity of 3.76×10^5 centimeters per second in fused quartz which results in a delay of the acoustic wave of 2.66 microseconds per centimeter travel in the fused quartz. On the other hand the velocity of propagation of longitudinal or compression waves in a fused quartz solid delay line is 5.95×10^5 centimeters per second and this results in a delay of the acoustic wave of 1.68 microseconds per centimeter of travel in the delay line. Whether shear or longitudinal type crystals are employed as transducers depends on the desired performance characteristics of the delay line such as delay time signal bandwidth, midband attenuation and spurious response limitations.

In the form of this invention shown in FIGS. 1–3 where only single reflections are employed for each facet spurious responses produced by unwanted reflections and dispersion of the acoustic signal are held to a minimum. Also in this embodiment of the invention the angle between the incident signal and the reflected signal on each of the peripheral facets is less than 12° and in the cases of the facets reflecting the signal into a rib and receiving the signal from the rib the angle of the incident signal beam and the angle of the reflected signal beam with respect to the normal of the facet are each between 3° and 5°. This results in an extremely low signal loss and also the signal is free from spurious reflections even in a delay line made up of twelve layers producing a delay time of 12,000 microseconds.

While I have shown a preferred embodiment of the invention it will be understood that the invention is capable of variation and modification from the form shown so that its scope should be limited only by the scope of the claims appended hereto.

What I claim is:

1. In a solid multiple layer ultrasonic signal delay line for producing relatively long ultrasonic signal delays the combination of a homogeneous solid body of ultrasonic signal conducting material, said body having a plurality of ultrasonic signal delay layers separated by slots formed in said body, integral means connecting adjacent ones of said plurality of layers together, said integral means comprising ribs that are integral with adjacent ones of said layers and extend substantially diametrically across said body, input and output transducers attached to selected ones of said layers, the rib between any two adjacent ones of said layers being of elongated shape arranged in line with the output facet of one of said adjacent layers and the input facet of the other of said adjacent layers so that sonic energy reflected from this output facet is directed through said rib to this input facet whereby said sonic energy is passed from layer to layer until it reaches the one of said layers that is provided with said output transducer.

2. In a solid ultrasonic signal delay line for producing relatively long ultrasonic signal delays the combination of a homogeneous solid body of ultrasonic signal conducting material, said body having a plurality of multi-facet ultrasonic signal delay layers separated by slots formed in said body, integral means connecting adjacent ones of said plurality of layers together, said integral means comprising ribs that are integral with adjacent ones of said layers and extend substantially diametrically across said body, input and output transducers attached to selected ones of said layers, and means for directing sonic energy from one of said layers to the next layer through the rib between these layers whereby said sonic energy is passed from layer to layer until it reaches the one of said layers that is provided with said output transducer.

3. In a solid ultrasonic signal delay line for producing relatively long ultrasonic signal delays the combination of a homogeneous solid body of ultrasonic signal conducting material, said body having a plurality of multi-facet ultrasonic signal delay layers separated by slots formed in said body, integral means connecting adjacent ones of said plurality of layers together, said integral means comprising ribs that are integral with adjacent ones of said layers and extend substantially diametrically across said body, an input transducer and output transducer, each of said transducers being attached to a selected facet of one of the end layers of said body, and means for directing sonic energy serially through said layers from said layer provided with said input transducer to said layer provided with said output transducer.

4. A compact delay line comprising a plurality of substantially flat multi-facet elements forming a stack and having a first end element and a second end element, integral means comprising a rib for connecting adjacent ones of said elements, said rib being confined entirely between said adjacent elements with which it is integral, each of said elements having a plurality of facets positioned around the periphery thereof, a transducer attached to a facet of said first end element for supplying mechanical energy to said stack, a second transducer attached to a facet of said second end element for receiving mechanical energy from said stack, each of said elements except the element provided with said output transducer being provided with means for directing said mechanical energy after it is reflected therein, from a selected facet thereof to the next adjacent one of said elements through said integral rib to the input facet of this next adjacent element.

5. A compact delay line comprising a plurality of substantially flat multi-facet elements forming a stack and having a first end element and a second end element, adjacent ones of said elements being connected by a rib integral therewith, each of said elements having a plurality of facets positioned around the periphery thereof, a transducer attached to a facet of said first end element for supplying mechanical energy to said stack, a second transducer attached to a facet of said second end element for receiving mechanical energy from said stack, each of said elements except the element provided with said output transducer being provided with a facet that is tilted with respect to the axis of said stack at an angle of not more than 10° for directing said mechanical energy after it is reflected in the element, to the next adjacent one of said elements through said integral rib to the input facet of this next adjacent element.

6. A compact signal delay line comprising a plurality of substantially flat multi-facet delay elements arranged side by side in spaced relation to form a stack, said stack having a plurality of integral ribs, adjacent ones of said elements being connected by one of said ribs integral therewith, said stack having a first end element with an input transducer attached to one of the facets thereof, said stack also having a second end element with an output transducer attached to an output facet thereof, the ones of said elements positioned between said first and

said second end elements each being provided with an input facet and an output facet, each of said input and said output facets being tilted at a predetermined angle with respect to the medial plane of the respective element so that the angle of incidence of sonic energy impinging thereon and the angle of reflectance of the sonic energy reflected therefrom do not exceed 10°, said input facets each being positioned so that sonic energy impinged thereon from the next adjacent element through one of said ribs is reflected therefrom into the respective delay element associated therewith, each of said output facets being aligned with one of said ribs so that sonic energy reflected thereto from one of the other facets of the re-respective multi-facet element is reflected by it through the aligned one of said ribs to the one of said delay elements next adjacent to said last mentioned element.

7. A compact delay line comprising a plurality of substantially flat multi-facet delay elements forming a stack, said stack having a plurality of ribs, adjacent ones of said elements being joined by one of said ribs which is integral therewith and which holds said adjacent elements in substantially parallel spaced relation, said stack having a first end element and a second end element, said first end element having an input transducer positioned on a facet thereof, said second end element having an output transducer positioned on a facet thereof, said input transducer being adapted to transmit mechanical energy into said first end element and said output transducer being adapted to receive mechanical energy from said second end element, each of said elements having a plurality of facets positioned on the periphery thereof for reflecting mechanical energy in the respective element substantially parallel to the medial plane thereof and ultimately to an output facet thereof, said first end element having an output facet and said second end element having an input facet, each of said elements positioned between said first and said second end elements having an input facet and an output facet, each of said input and output facets being disposed at a predetermined angle with respect to the medial plane of the respective one

of said elements whereby the mechanical pulse energy impinging said output facets is directed by the respective output facet to the next adjacent one of said elements through the one of said ribs joining this element to this next adjacent element to impinge the input facet of this next adjacent element.

8. A compact signal delay line comprising a plurality of multi-facet delay elements forming a stack having a first end element and a second end element, said stack having a plurality ribs, adjacent ones of said elements being connected by one of said ribs which is integral therewith, an input transducer positioned on one of the facets of said first end element and an output transducer positioned on one of the facets of said second end element, said first end element also having an output facet the reflecting surface of which is tilted with respect to the medial plane of said first mentioned element at a predetermined angle so that acoustic wave energy impinging said tilted output facet is reflected through the one of said ribs joining this element to the next adjacent multi-facet element, said elements disposed between said end elements each being provided with an input facet and an output facet each disposed at a predetermined angle whereby acoustic energy may be supplied to said elements of said stack serially, said acoustic energy being transmitted from element to element through said ribs, said second end element having an input facet also disposed at a predetermined angle with respect to the medial plane of said second end element, said input facet of said second end element being adapted to reflect acoustic energy impinging thereon into said second end element.

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