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TAPPED ULTRASONIC DELAY LINE

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FIG. 1

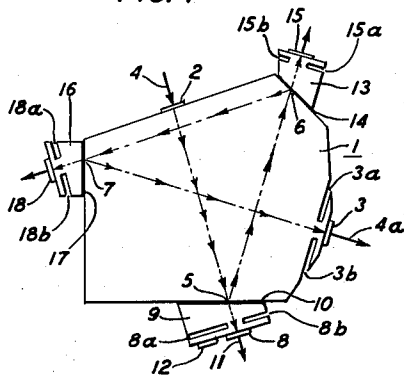


FIG. 3

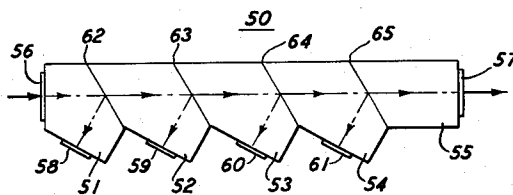


FIG. 2

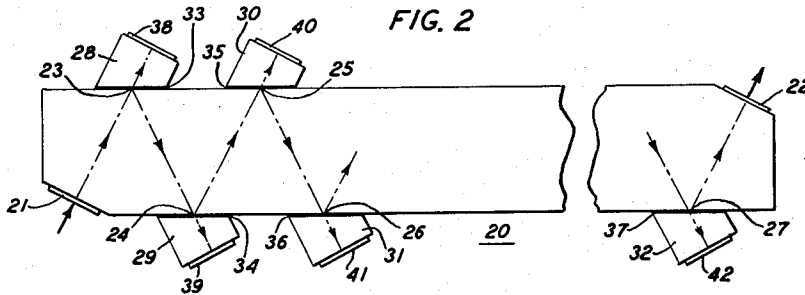


FIG. 4

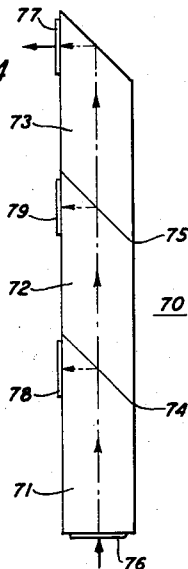
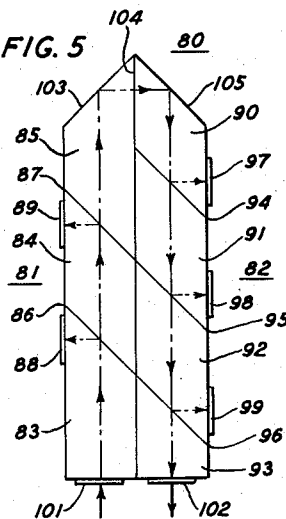


FIG. 5



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TAPPED ULTRASONIC DELAY LINE

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1 Claim. (Cl. 333—30)

This invention relates to ultrasonic delay lines and, more particularly, to a tapped ultrasonic delay line for providing acoustically and electrically a number of independent output pulses.

Heretofore, tapped ultrasonic delay lines have employed tap transducers mounted in series with and in the line. It has been found that, in a delay line of this type, reflections from either side of the tap transducer propagate along the direction of the main ultrasonic beam thereby producing undesired responses at the tap transducer as well as at both the input and output transducers. A tap transducer mounted in this manner also produces a loss or diminution of the energy proceeding toward the output transducer because the external electrical components which are coupled to the tap termination have an adverse influence on the amount of energy proceeding past the tap point.

Accordingly, it is an object of this invention to provide an improved tapped ultrasonic delay line.

Another object of the invention is to provide an ultrasonic delay line with improved means for externally coupling a tap transducer to the line at a reflection point thereof.

An additional object of the invention is to provide an ultrasonic delay line with improved means for mounting a plurality of tap outputs on partially reflecting interfaces at points on the external surface of the line.

Still another object of the invention is to provide improved means for supplying a tap output of an ultrasonic delay line with wave energy refracted from the line as distinguished from energy reflected from the line.

These and other objects of the invention are attained by selecting an energy reflection point of an ultrasonic delay line and by forming at this point an interface having a tap transducer mounted thereon, the interface being partially reflecting and partially refracting. The tap transducer is located externally with respect to the line and is so disposed and oriented in relation to the reflection point as to receive therefrom wave energy at normal incidence. In one embodiment of the invention, the tap transducer is mounted on a wedge-shaped block of fused quartz having one of its surfaces parallel to an outside surface of the delay line and having another surface normal to wave energy traveling through the line to the reflection point at which the block is located.

These and other features of the invention are discussed more fully in connection with the following detailed description of the drawing in which:

Fig. 1 illustrates the application of the invention to an ultrasonic solid delay line in the shape of a polyhedron and having secured thereto a plurality of angular blocks with tap transducers mounted thereon;

Fig. 2 shows the invention applied to an ultrasonic delay line in the shape of a solid bar and having a plurality of tap transducers mounted thereon for receiving wave energy refracted thereto through interfaces located at reflection points on the line;

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Fig. 3 shows an ultrasonic delay line in the form of a series of angular blocks joined together with a plurality of interfaces for reflecting to a plurality of tap transducers portions of the wave energy refracted through the line;

Fig. 4 represents an ultrasonic delay line formed by a series of angular blocks and having a plurality of parallel interfaces for reflecting portions of the wave energy to a plurality of tap transducers which are all mounted on the same side of the delay line; and

Fig. 5 shows a tapped ultrasonic solid delay line of a type somewhat similar to that shown in Fig. 4 but having a folded construction for increasing the length of the wave transmission path and having a larger number of tap transducers.

In Fig. 1, a solid ultrasonic delay line 1 is shown in the shape of a polyhedron of suitable acoustical wave transmitting material, such as fused quartz. The line 1 is provided with an energy-receiving input in the form of a transducer 2 and an energy extracting output in the form of another transducer 3. The input and output transducers 2 and 3 may be of any suitable piezoelectric material, such as crystalline quartz, and may be secured to the sides of the line 1 in any suitable manner. An input connection 4 to the input transducer 2 provides means for applying an electrical signal which is to be delayed.

When electrical wave energy is applied to the input transducer 2 in any suitable manner known to those skilled in the art, the input transducer 2 converts the electrical wave energy into acoustical wave energy and applies it to the delay line 1. Here it travels along the multiple reflection paths indicated in Fig. 1, being reflected from the reflection points 5, 6 and 7, and finally arrives at the output transducer 3. The output transducer 3 converts this acoustical wave energy back into the form of electrical wave energy which can be extracted therefrom at the output connection 4a in any suitable manner known to those skilled in the art.

For the purpose of deriving electrical wave energy from a point intermediate the input and output transducers 2 and 3, one of the energy reflection points, such as the reflection point 5, is selected. An intermediate tap transducer 8, which may be of the same material as the input and output transducers 2 and 3, is so positioned, in a manner described hereinafter, as to receive some of the acoustical wave energy which arrives at the reflection point 5. The acoustical wave energy so received will be converted by the tap transducer 8 into electrical wave energy which can be extracted therefrom in any suitable manner known to those skilled in the art.

Since it is desirable that the wave-shape of the electrical energy derived from the tap transducer 8 be the same as the wave-shape of the electrical energy applied to the input transducer 2, it is necessary for the tap transducer 8 to be so positioned as to receive the acoustical wave energy at normal incidence. If the tap transducer 8 is located in such a manner that the acoustical wave energy impinges upon it at other than normal incidence, the electrical wave-shape will not be correctly reproduced but, instead, will be distorted.

Accordingly, in one embodiment of the invention, the tap transducer 8 is mounted on a wedge-shaped block 9 of suitable material, such as fused quartz. The block 9 is so shaped and is so disposed that one of its surfaces is parallel to that one of the outside surfaces of the delay line 1 on which the reflection point 5 is located. Another surface of the block 9 carries the tap transducer 8 and is so oriented that acoustical wave energy traveling from the reflection point 5 through the block 9 will impinge upon the tap transducer 8 at normal incidence.

In order to cause acoustical wave energy arriving at the reflection point 5 to divide with part of it being

reflected so as to continue to travel along the indicated delay path in the delay line 1 while another part of it is refracted toward the tap transducer 8, it is necessary to create an impedance discontinuity at this point in the delay medium. This may be produced firstly by employing a bonding agent between the adjacent surfaces of the delay line 1 and the block 9. Any suitable bonding material may be used for this purpose, such as evaporated indium. Secondly, the impedance discontinuity may be produced by forming the block 9 from material having an acoustical impedance which is different from the acoustical impedance of the material used to form the delay line 1. Thirdly, the impedance discontinuity can be constituted by the joint use of both of the above methods.

The creation of such an impedance discontinuity forms an interface 10 which is partially reflecting and partially refracting thereby permitting part of the applied energy to pass through it while, at the same time, reflecting some of the applied energy. Since the energy refracted through the interface 10 is utilized by the tap transducer 8 and the energy reflected from the interface 10 travels through the delay line 1 to the output transducer 3, there is substantially no appreciable loss or waste of the wave energy. The ratio of the reflected wave energy to the refracted wave energy is determined by the relations between the acoustical impedances of the delay line medium 1, the bonding medium at the interface 10, and the wedge medium 9. All of these factors can be selectively controlled to produce a particular desired ratio.

It should be noted that the efficiency of this construction is enhanced by the fact that the top transducer 8 is mounted on the block 9 and not directly on the reflecting surface of the delay line 1 nor in the direct path of the acoustical beam which is being transmitted to one or more subsequent outputs of the delay line 1. In these latter cases, the ratio would be affected by the electrical output termination 11 of the tap transducer 8 and would consequently not be so easily controlled. This is because the termination of a transducer in its characteristic impedance for the purpose of obtaining minimum loss would theoretically absorb all the incident energy so that none would proceed to the output transducer 3. However, by utilizing a separate interface 10, as shown in Fig. 1, the reflection properties can be predetermined as explained above. This permits the termination 11 of the tap transducer 8 to be chosen as desired for producing optimum loss or bandwidth characteristic without influencing the reflecting properties of the interface 10.

Another important feature of the organization shown in Fig. 1 is that the wedge 9 serves to isolate the tap transducer 8 from the delay line 1 so that the acoustical wave energy which is reflected from the point 5 to the next reflection point 6 is not attenuated by traversing the interface 10, or the wedge 9, or the tap transducer 8. This results in efficient conservation and utilization of the acoustical wave energy with substantially no unnecessary loss by attenuation.

Still another desirable feature of the construction shown in Fig. 1 is that, if any wave energy should be reflected from the tap transducer 8, it would not reach the output transducer 3. It would, instead, be propagated toward the input transducer 2 and some would be reflected at the interface 10 toward the outer side of the wedge 9 where it could be absorbed in a manner well known to those skilled in the art by means of a coating 12 of any suitable material, such as solder. It is to be understood that the absorbing coating 12 may, if desired, be extended over a wider area of the block 9 than is indicated in the drawing.

Various changes in the organization shown in Fig. 1 may be made by those skilled in the art without exceeding the scope of the invention. For example, it would be possible to construct both the delay line 1 and the wedge 9 as an integral unit from a single piece of mate-

rial. The desired partially reflecting interface 10 could then be created by drilling holes in the delay medium along the line 10 and by filling them with material having an acoustical impedance different from that of the delay line 1.

The invention is not limited to a delay line having only one tap transducer. If it is desired to derive from a single delay line a plurality of individual electrical outputs separated in time, additional tap transducers may be applied in the manner illustrated in Fig. 1. For example, at the reflection point 6 on the delay line 1, a wedge-shaped block 13 may be mounted in a manner similar to that described above so as to form a second partially reflecting and partially refracting interface 14. A tap transducer 15 is secured to the top surface of the block 13, this top surface being so oriented that acoustical wave energy from the delay line 1 will impinge upon the tap transducer 15 at normal incidence.

A third wedge-shaped block 16 may be mounted in a similar manner on an outside face of the delay line 1 at the reflection point 7 so as to form a third partially reflecting and partially refracting interface 17. A third tap transducer 18 is secured to the top surface of the block 16, this top surface being so oriented that acoustical wave energy from the delay line 1 will impinge upon the tap transducer 18 at normal incidence. If desired, absorbing coatings, similar to the coating 12, may be mounted on the blocks 13 and 16 for absorbing any unwanted reflections.

The use of this plurality of tap transducers 8, 15 and 18 permits a plurality of separate electrical outputs to be derived or extracted from the delay line 1 with each output being separated in time from the other outputs. Thus, the voltage output from the tap transducer 8 is delayed A microseconds with respect to the input transducer 2, this being the time interval required for the acoustical wave energy to travel from the input transducer 2 to the tap transducer 8. The voltage output from the tap transducer 15 will be delayed B microseconds with respect to the output from the tap transducer 8, the output from the tap transducer 18 will be delayed C microseconds with respect to the output from the tap transducer 15, and the voltage output from the output transducer 3 will be delayed D microseconds with respect to the output from the tap transducer 18.

The organization shown in Fig. 1 can be so designed and constructed that the voltage outputs therefrom will be equally spaced apart in time so as to provide a plurality of equal delay periods. This can be accomplished in a number of different ways. One method for achieving this result comprises forming the interfaces 10, 14 and 17 in such a manner that they are all identical; employing the same material for each of the blocks 9, 13 and 16; shaping the blocks 9, 13 and 16 in such a manner that their refraction paths are of equal lengths; and shaping the delay line 1 so that its paths are of proper lengths.

In performing this last step, several requirements should be met. In defining these requirements, it should first be stated that it can be calculated that a path length of M units in the delay line 1 would require the same amount of time for the acoustical wave energy to traverse as the amount of time required for the wave energy to traverse the refraction path from the reflection point 5 to the tap transducer 8. If it be now assumed that the reflection path 5—6 has a length of R units, then the path 2—5 should have a length of R minus M units, the path 6—7 should be equal to R units, and the path 7—3 should have a length of R plus M units.

When the organization shown in Fig. 1 is constructed in the manner described above, the values A, B, C and D of the delay periods identified above will all be equal. In other words, the voltage outputs from the tap transducers 8, 15 and 18 and from the output transducer 3 will all be equally spaced apart in time.

It is to be understood that, instead of being equally

spaced apart in time, the above-mentioned voltage outputs may be separated from each other by respectively different time intervals. This can be accomplished by selecting appropriate lengths for the wave paths described above. For example, if it should be desired to have the voltage outputs separated in time by progressively larger intervals, this could be accomplished by suitably shaping the delay line 1 so as to cause the above-mentioned wave paths to be of progressively longer lengths.

The organization shown in Fig. 1 can also be so designed and constructed that the voltage outputs therefrom will not only be equally spaced apart in time but will also have equal voltages. This can be accomplished in several different ways. One method for attaining this result is based on the fact, known to those skilled in the art, that the voltage output from a transducer is proportional to the average incident wave intensity over its whole area. Accordingly, the voltage outputs from the tap transducers 8, 15 and 18 and from the output transducer 3 can be equalized by adjusting the effective area of the acoustical beams that are incident thereon. This can be done conveniently in the case of the tap transducers 8, 15 and 18 by creating suitable apertures between them and their respectively associated interfaces 10, 14 and 17, such as by sawing slots in their respectively associated blocks 9, 13 and 16. In the case of the output transducer 3, the apertures or slots could be incorporated in the medium of the delay line 1. In both cases, the slots should be perpendicular to the direction of propagation of the wave energy.

This feature of the invention is illustrated in Fig. 1 in which the block 9 is shown to be provided with slots 8a and 8b which are so cut as to be perpendicular to acoustical wave energy traveling to the tap transducer 8. Similar slots 15a and 15b are cut in the block 13 so as to be perpendicular to wave energy traveling to the tap transducer 15. The block 16 is similarly provided with slots 18a and 18b which are cut in such a manner as to be perpendicular to wave energy traveling to the tap transducer 18. Two slots 3a and 3b are shown to be incorporated in that side of the delay line 1 upon which the output transducer 3 is mounted. These slots 3a and 3b are formed so as to be perpendicular to wave energy traveling to the output transducer 3. The individual slots associated with any one of the transducers 3, 8, 15 and 18 should lie in the same plane as is indicated in Fig. 1. If desired, an absorbing coating, similar to the coating 12 described above, may be applied to the interior of any or all of the slots for the purpose of absorbing undesired wave energy. Thus, by properly designing all of these slots, the effective area of the wave energy that is incident on each of the transducers 3, 8, 15 and 18 can be so adjusted that the individual voltage outputs from these transducers will all be equal.

The invention is not restricted to use with a solid delay line in the form of a polyhedron, but may be used with delay lines having other shapes. In Fig. 2, the invention is shown to be applied to a bar-shaped ultrasonic solid delay line 20 which may be of the same material as the delay line 1. This delay line 20 is provided with an input transducer 21 and an output transducer 22 similar to the input and output transducers 2 and 3. At various points along the delay path indicated in Fig. 2, a number of reflection points 23, 24, 25, 26 and 27 are selected and wedge-shaped tap blocks 28, 29, 30, 31 and 32, which may be of the same material as the delay line 20, are mounted thereat in the manner described above so as to create respectively associated partially reflecting and partially refracting interfaces 33, 34, 35, 36 and 37. It is to be noted that the interfaces 33 to 37, inclusive, are, as is shown in Fig. 2, all disposed parallel to each other. Each of the wedges 28, 29, 30, 31 and 32 has mounted upon its outer face a respectively associated one of a plurality of tap transducers 38, 39, 40, 41 and 42.

As was the case with the wedge 9 of Fig. 1, each of the wedges 28 to 32, inclusive, is so shaped and so disposed that one of its surfaces is parallel to an outside face of the delay line 20 while another of its surfaces is so oriented that acoustical wave energy from its respectively associated one of the reflection points 23 to 27, inclusive, will be refracted through it and will impinge upon its respectively associated one of the tap transducers 38 to 42, inclusive, at normal incidence.

It is to be understood that by selecting proper dimensions for the delay line 20 and the wedges 28 to 32, inclusive, and by utilizing identical interfaces 33 to 37, inclusive, uniform, or equally spaced time delay periods may be obtained from the individual tap transducers 38 to 42, inclusive. In addition, the organization shown in Fig. 2 may be constructed in accordance with the principles described above with respect to the tapped delay line shown in Fig. 1, so that the individual voltage outputs from the tap transducers 38 to 42, inclusive, and from the output transducer 22 will all be of equal magnitude.

It is to be noted that the main beam of acoustical wave energy travels along the delay line 20 by the process of reflection from the reflection points 23 to 27, inclusive, and that the tap transducers 38 to 42, inclusive, are each supplied with refracted acoustical wave energy.

A delay line which is somewhat the converse of this is the tapped ultrasonic delay line 50 shown in Fig. 3. The delay line 50 comprises a series of contiguous angular blocks 51, 52, 53, 54 and 55 of the same material as that described above. The block 51 has an input transducer 56 secured thereto, and an output transducer 57 is fastened to the block 55. Each of the blocks 51, 52, 53 and 54 has a tap transducer 58, 59, 60 and 61, respectively, mounted thereon as is indicated in Fig. 3. The adjacent surfaces of the blocks 51 to 55, inclusive, are fastened to each other with a suitable bonding agent which may be a thermosetting resin, such as an epoxy resin, which also serves to create a series of impedance discontinuities which function as reflecting-refracting interfaces 62, 63, 64 and 65.

In this delay line 50, acoustical wave energy from the input transducer 56 travels first to the interface 62. Here, some of the energy is reflected to the tap transducer 58 and some is refracted into the next block 52. The acoustical wave energy entering the block 52 meets the second interface 63 which reflects some of the energy to the second tap transducer 59 and refracts some into the third wedge 53. This process is repeated until the last interface 65 refracts energy into the last block 55. This energy travels through the block 55 and impinges upon the output transducer 57. It is to be noted that the shape of each of the blocks 51, 52, 53 and 54 is so selected as to enable its respectively associated one of the tap transducers 58 to 61, inclusive, to receive the reflected energy at normal incidence. Accurately spaced delay periods may be obtained from the tap transducers 58 to 61, inclusive, by appropriate selection of the dimensions and proportions of the individual blocks 51 to 54, inclusive.

Fig. 4 illustrates another type of ultrasonic delay line having a plurality of parallel interfaces somewhat like those shown in Fig. 3. In Fig. 4, a delay line 70 is represented as comprising a plurality of angular blocks 71, 72 and 73 of suitable acoustical wave transmitting material, such as that used for the delay line 1. These blocks 71, 72 and 73 do not have projecting areas like the blocks 51 to 54, inclusive, shown in Fig. 3, but, instead, are so shaped as to form a line 70 having smooth sides. Adjacent surfaces of the blocks 71, 72 and 73 are joined by means of a suitable bonding material which may be the same as that used in the line 50 shown in Fig. 3. These joints, therefore, present impedance discontinuities to acoustical wave energy in the line 50 so that they form refracting-reflecting interfaces 74 and 75.

An input transducer 76 is mounted on the front face

of the wedge-shaped block 71 and an output transducer 77 is fastened to a side surface of the angular block 73. Tap transducers 78 and 79 are secured to side surfaces of the blocks 71 and 72, respectively. It is to be noted that the adjacent surfaces of the blocks 71, 72 and 73 are cut at such an angle that acoustical wave energy which is reflected from the interfaces 74 and 75 impinge upon the tap transducers 78 and 79 at normal incidence. The end face of the block 73 is cut at a similar angle so as to cause acoustical wave energy reflected therefrom to impinge upon the output transducer 77 at normal incidence.

Thus, when electrical wave energy is applied to the input transducer 76, it becomes transformed into acoustical wave energy which travels through the wedge-shaped block 71 until it meets the first interface 74. At this point, a portion of the wave energy is reflected to the first tap transducer 78. Another portion of the wave energy is refracted through the interface 74 into the adjacent angular block 72 and arrives at the second interface 75. This interface 75 reflects a portion of the wave energy to the second tap transducer 79 and refracts another portion into the next angular block 73. As was stated above, the end face of the block 73 reflects the incident wave energy to the output transducer 77.

Fig. 5 shows a tapped ultrasonic solid delay line 80 which is somewhat similar to the delay line 70 shown in Fig. 4 except that it employs a folded construction. Thus, the line 80 comprises two parallel sections 81 and 82. The first line section 81 includes a first plurality of angular blocks 83, 84 and 85 having parallel interfaces 86 and 87 similar to the interfaces 74 and 75 shown in Fig. 4. A first plurality of tap transducers 88 and 89 are secured to side surfaces of the blocks 83 and 84 in such a manner as to receive at normal incidence wave energy reflected from the interfaces 86 and 87, respectively.

The second line section 82 includes a second plurality of angular blocks 90, 91, 92 and 93 having parallel interfaces 94, 95 and 96. A second plurality of tap transducers 97, 98 and 99 are secured to side surfaces of the blocks 90, 91 and 92, respectively, so as to receive at normal incidence acoustical wave energy reflected from the respectively associated interfaces 94, 95 and 96.

An input transducer 101 is mounted on the front face of the first wedge-shaped block 83 and an output transducer 102 is fastened to the terminating face of the last wedge-shaped block 93. It is to be noted that the end face 103 of the angular block 85 is cut at the proper angle so that acoustical wave energy in the block 85 will be reflected by the end face 103 in such a direction as to impinge at normal incidence upon the side wall 104. The wave energy is refracted through the side wall 104 into the angular block 90 which has its end face 105 cut at the proper angle for causing the wave energy to be reflected therefrom in a direction corresponding to the main longitudinal axis of the line section 82. Except for this difference, the tapped delay line 80 functions in a manner

similar to that of the tapped delay line 70 shown in Fig. 4 with the further exception that the wave energy in the last wedge-shaped block 93 travels directly along the main longitudinal axis of the line section 82 so as to impinge upon the output transducer 102 at normal incidence as is the case with the tapped delay line 50 shown in Fig. 3.

What is claimed is:

An ultrasonic delay line of the multiple reflection type having a plurality of reflection points, said line comprising in combination input means for applying acoustical wave energy to said line, a plurality of partially reflecting and partially refracting interfaces, each of said interfaces being formed at a respectively different one of said reflection points for presenting an impedance discontinuity to acoustical wave energy arriving thereat, a plurality of transducers, each of said transducers being so disposed as to receive wave energy from a respectively different one of said plurality of interfaces, and means for isolating each of said transducers from said line, said means including a plurality of blocks of acoustical wave transmitting material, each of said blocks having a first surface secured to a respectively different one of said interfaces and having a second surface fastened to a respectively different one of said transducers, and said second surface of each of said blocks being so oriented in relation to its respectively associated interface that wave energy therefrom impinges upon its respectively associated transducer at normal incidence, said ultrasonic delay line further comprising an output transducer secured to said delay line and means for producing voltage outputs at said transducers which are equally spaced apart in time, said last-mentioned means including a plurality of wave paths each having a length of R units where R is the length of the wave path from the first of said reflection points to the next successive reflection point, each of said wave paths extending from a respectively different one of said reflection points to the next successive reflection point, said last-mentioned means further comprising a wave path extending from said input means to said first reflection point and having a length of R minus M units where M is the length of a wave path in said delay line which requires the same amount of time for acoustical wave energy to traverse as the amount of time required for the acoustical wave energy to traverse the wave path from said first reflection point to its respectively associated tap transducer, and a wave path extending from the last of said reflection points to said output transducer and having a length of R plus M units.

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