

July 27, 1954

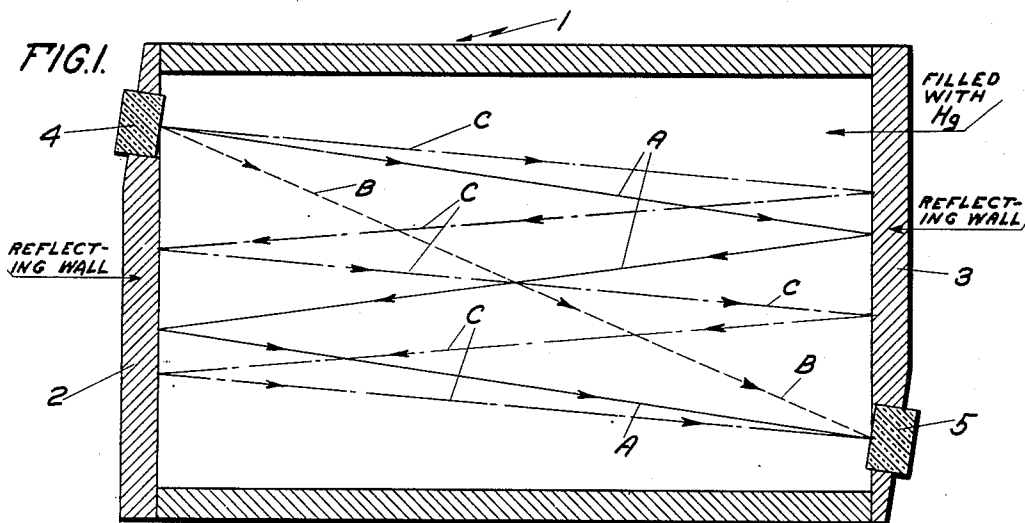
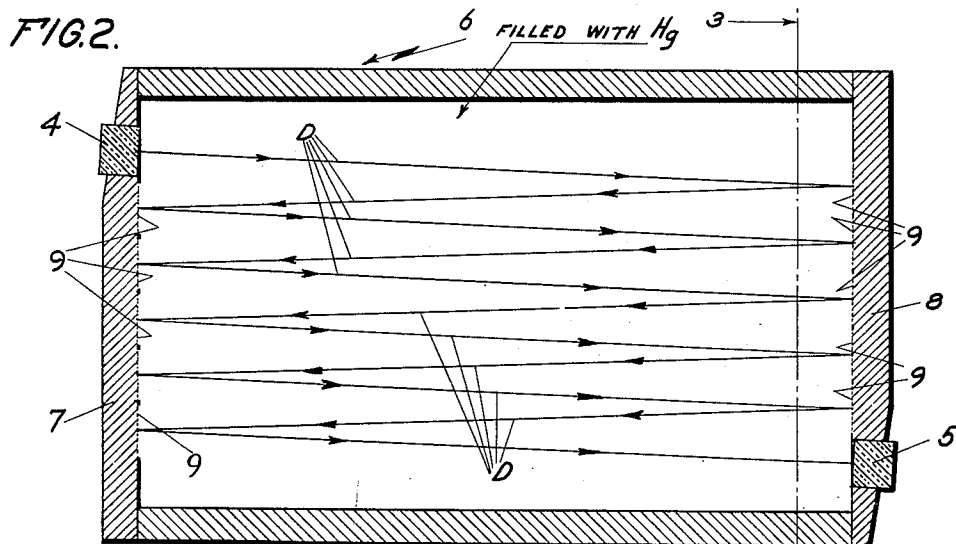
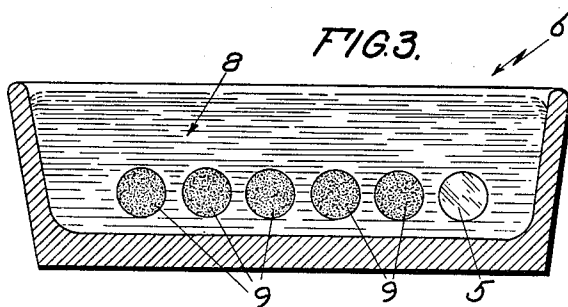
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2,685,067

MEANS FOR DELAYING ELECTRICAL SIGNALS

Filed March 12, 1948

4 Sheets-Sheet 1



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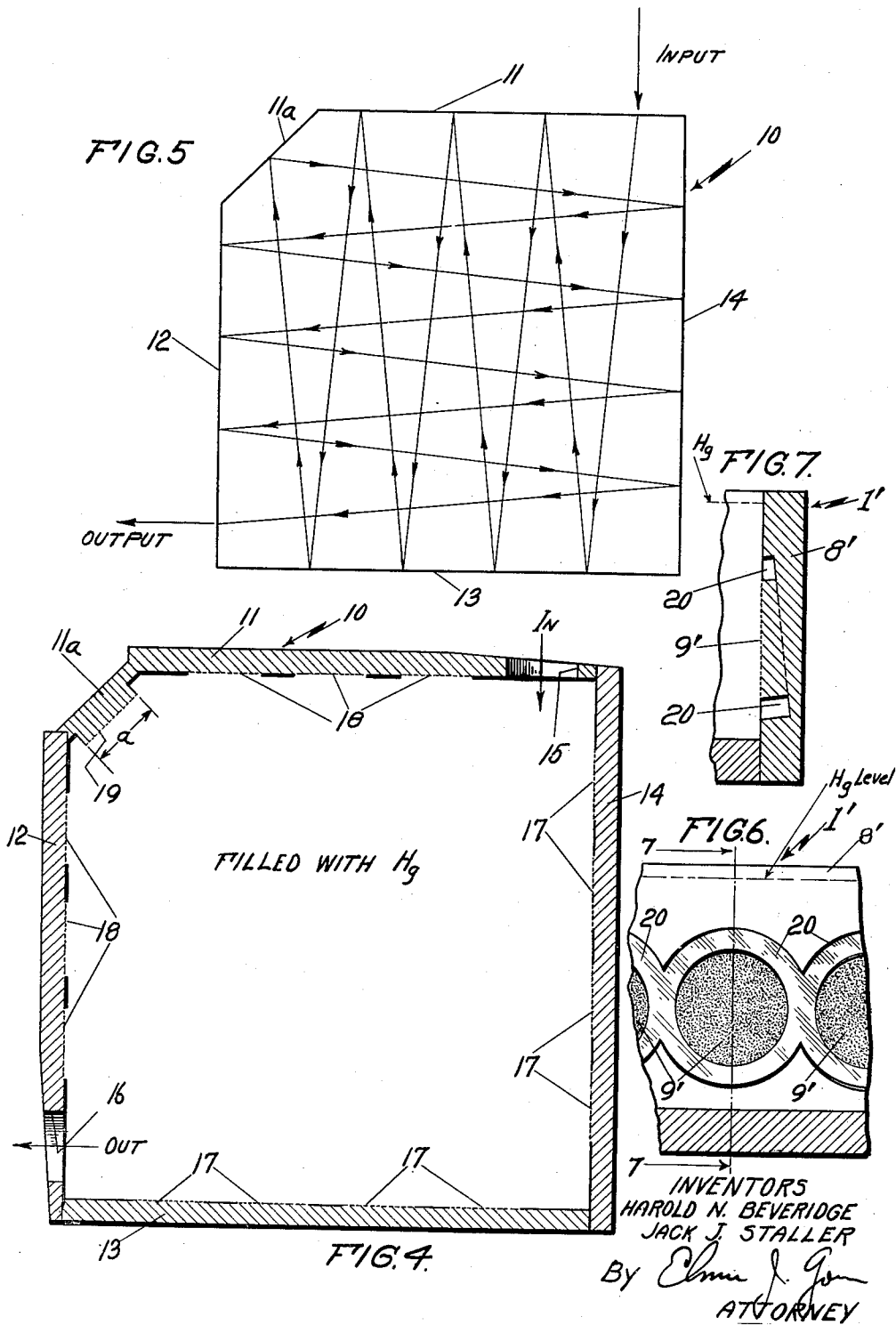
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MEANS FOR DELAYING ELECTRICAL SIGNALS

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4 Sheets-Sheet 3

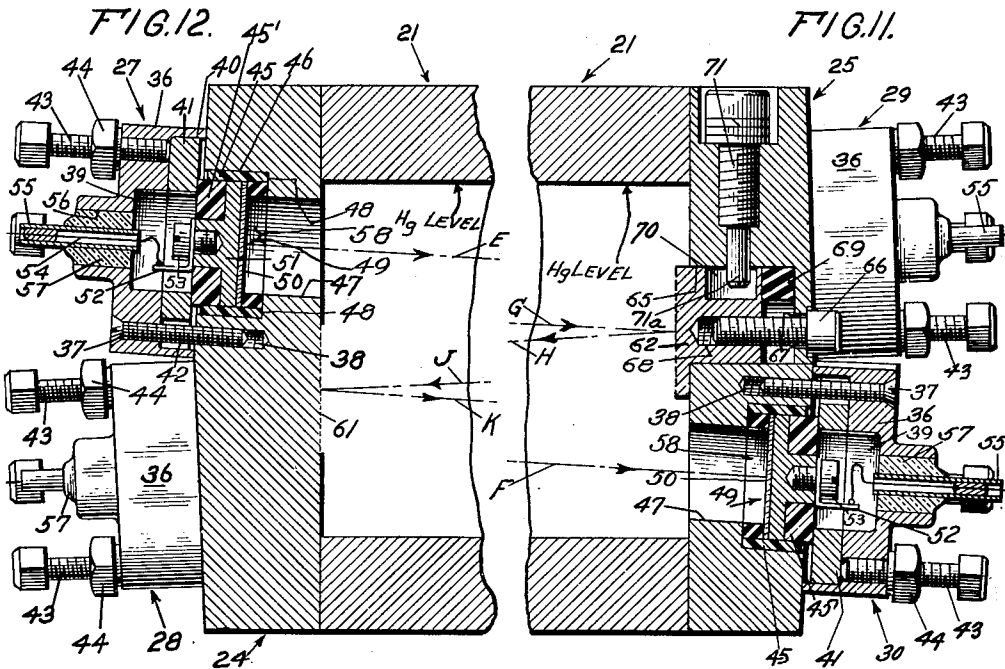
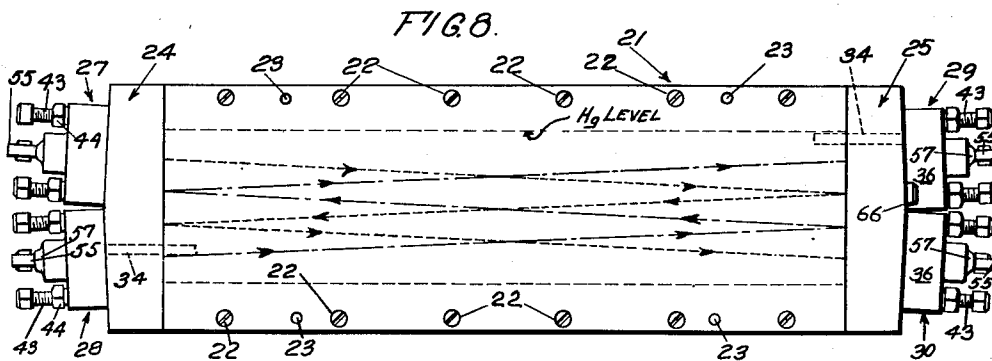
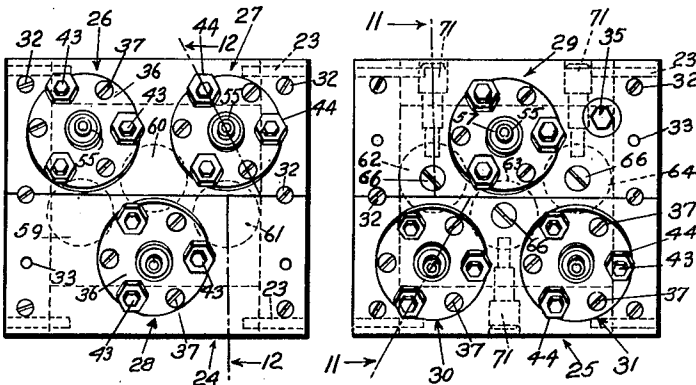


FIG. 10.

FIG. 9.

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MEANS FOR DELAYING ELECTRICAL SIGNALS

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17 Claims. (Cl. 333—30)

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This invention relates to means for delaying electrical signals, and more particularly to an ultrasonic mercury delay line of the tank type.

An object of this invention is to devise an ultrasonic delay line which is of small size, is rather simple in construction, and yet in which delays of a relatively long time may be obtained.

Another object is to provide a multiple-path mercury delay line in which all of the paths traverse a single pool or body of mercury.

A further object is to devise a construction in which a plurality of ultrasonic mercury delay lines utilize the same pool of mercury, thereby providing uniform velocities of travel of the compressional waves in each of such lines.

A still further object is to devise means for independently adjusting the time delays of each of a plurality of delay lines, in order to compensate for manufacturing tolerances and circuit dissimilarities, to thereby enable such delays to be brought into equality with each other.

An additional object is to devise an ultrasonic mercury delay line wherein spurious or undesired paths of travel of the energy, which could result from spreading of the ultrasonic beam, are substantially eliminated.

Still another object is to provide substantially perfect reflecting surfaces in the metallic tank of a mercury delay line, which surfaces may be very readily and inexpensively produced.

Yet another object is to devise a multiple-reflection ultrasonic mercury delay line construction which utilizes the mercury very efficiently, thereby reducing the overall dimensions and total weight of such line without at the same time reducing the delay time of such line.

A further object is to devise an ultrasonic delay line construction in which the side edges of the slightly diverging ultrasonic beam are in effect clipped off and diverted away from the main beam so as not to interfere therewith.

The foregoing and other objects of the invention will be best understood from the following description of some exemplifications thereof, reference being had to the accompanying drawings, wherein:

Fig. 1 is a horizontal cross-section through a mercury ultrasonic tank with reflecting walls, showing possible paths of compressional waves therein;

Fig. 2 is a horizontal section through a tank or delay line according to this invention, showing the path of travel of compressional waves therein;

Fig. 3 is a vertical section through the device of Fig. 2, taken along the line 3—3 thereof but on a larger scale;

Fig. 4 is a horizontal section through a modified construction according to this invention;

Fig. 5 is a schematic diagram corresponding to Fig. 4 showing the compressional wave path therein;

Fig. 6 is a partial vertical sectional view similar to Fig. 3 of a modified construction;

Fig. 7 is a section taken along line 7—7 of Fig. 6;

Fig. 8 is an elevation of another type of delay line according to this invention;

Fig. 9 is an end view of the device of Fig. 8;

Fig. 10 is an opposite end view of the device of Fig. 8;

Fig. 11 is a section taken along line 11—11 of Fig. 9;

Fig. 12 is a section taken along line 12—12 of Fig. 10;

Fig. 13 is a block diagram of a portion of a radar system utilizing a delay line according to this invention; and

Fig. 14 is a block diagram of a portion of a computer system utilizing the delay line of Figs. 8—12.

In general, this invention relates to a mercury delay line, which functions to delay broad band intelligence or electrical signals from a few microseconds up to several milliseconds. Such a mercury delay line consists of a body of mercury having a pair of spaced electromechanical transducers acoustically coupled thereto, one being a transmitting transducer and the other a receiving transducer. Since the mercury line exhibits not a long pass but a band pass characteristic, it is necessary first to modulate the incoming electrical intelligence on a carrier wave. This modulated electrical energy causes the quartz transmitting transducer to vibrate in a piston-like manner, sending an ultrasonic compressional wave (one having a frequency on the order of 5–30 megacycles, for example) down the mercury column. Upon striking the quartz receiving transducer, the acoustic or compressional wave energy is converted back into an electrical carrier wave signal like the original, which electrical signal is amplified and demodulated to give back the original intelligence delayed in time. In some cases, it is entirely feasible to operate the mercury delay line without utilizing a carrier wave, the line operating also in this case to delay the electrical signals impressed thereon.

In general, delays of anywhere from 25 to 10,000 microseconds might be wanted. The velocity of compressional waves in mercury is approximately 145,000 centimeters per second, so that five feet of mercury corresponds approximately to a delay of 1,000 microseconds or one millisecond. There-

fore, the range of time delays stated corresponds to a range of lengths of travel in the mercury of the compressional wave of from approximately 0.125 foot to approximately 50 feet.

Now referring to Fig. 1, in order to provide for longer time delays with delay tanks of reasonable dimensions, or in order to decrease the overall length of the delay devices, a box or tank 1 containing mercury is used, this box being more or less rectangular in outline and having opposite reflecting upstanding side walls 2 and 3. A quartz transmitting or input transducer is shown schematically at 4 and is mounted near one end of side wall 2, with the vibrating or inner portion thereof lying in a plane which makes a small angle with the inner face of wall 2. Such an angle may be conveniently provided by beveling a portion of the outer face of wall 2. Fig. 1 is a horizontal section through a mercury tank which might be used. A quartz receiving or output transducer is shown schematically at 5 and is mounted near the opposite end of side wall 3, with its vibrating portion lying in a plane which is substantially parallel to that of the aforesaid portion of transducer 4. The active or inner faces of transducers 4 and 5 are both acoustically coupled to the mercury in tank 1.

Fig. 1 indicates several possible patterns of travel of the compressional wave energy between input transducer 4 and output transducer 5. The desired path of travel is indicated by solid lines A and employs three traverses of the tank 1. The beam starts out substantially perpendicular to the transmitting face of transducer 4 and is reflected back and forth between the side walls 2 and 3, with the respective angles of incidence being equal to the corresponding angles of reflection, the beam of compressional wave energy after three traverses of the tank impinging on the receiving transducer 5. A possible spurious or undesired path between transducers 4 and 5 is that indicated by the dotted line B, which is the direct path between said transducers and employs only one traverse of the tank. This path B is possible because of undesired and unavoidable spreading of the beam of compressional wave energy. Still another possible spurious or undesired path of travel of the compressional wave energy is indicated by the dot-dash lines C, which path, similarly to path A, is reflected back and forth between the side walls 2 and 3 with the respective angles of incidence being equal to the corresponding angles of reflection, this path employing five traverses of the tank. Path C is a result of spreading or divergence of the beam. There are other spurious paths as well, employing seven, nine, eleven and so on traverses. The paths A, B and C illustrated are all substantially horizontal.

It may be seen that there is only a rather small angle between the original directions of paths A and C, the original directions here referring to their directions as they emanate from input transducer 4. In the example illustrated in Fig. 1, the tank has been designed for a time delay, or time of travel of the compressional wave therein, corresponding to three traverses of the tank. It should be apparent that spurious patterns such as C, which involves five traverses of the tank, give an improper time delay and are therefore undesired; such spurious patterns are quite serious since they diverge from the desired path direction by only very small angles. Moreover, as one goes to designs involving a greater number of traverses of the tank, these spurious paths be-

come more serious since they diverge or differ from the original desired path direction by still smaller angles.

It has been found, according to this invention, that over relatively great distances between two compressional wave transducers, most of the transmitted energy is contained within a circle equal in diameter to the transmitting transducer. However, at distances on the order of 100 inches and with customarily used circular transducers at ultrasonic frequencies, even though the diameter of the transducer is quite large as compared to the wavelength of the energy, the radiation pattern of a plane wave front of uniform energy emanating from such transmitting transducers has very noticeable minor lobes at the sides of the main beam, these lobes having high enough relative amplitudes to be noticed. If this pattern were allowed to develop in a design employing say eleven traverses of the tank, a number of spurious paths would be produced due to the divergence or spreading of the beam (or to the presence of minor lobes), such spurious paths involving nine and thirteen traverses, seven and fifteen, five and seventeen, etc., due to the symmetry of the minor lobes about the main beam. Thus, it may be seen that, in the design of Fig. 1, one problem which exists is the beam spreading or divergence and the consequent development of spurious or undesired paths. As will hereinafter appear, this problem has been satisfactorily solved according to the present invention.

Another problem which has been solved according to this invention is the development of satisfactory reflecting surfaces for the tank. The proportion of compressional wave energy reflected at the interface between two different acoustic media depends on the relative acoustic impedances of the two media, being small when the difference between the two impedances is rather small and large when the difference between the two acoustic impedances is rather large.

It has been found that quartz crystals function very effectively as transducers for devices of the type under discussion. For the longitudinal mode, quartz has an acoustic impedance of 15.2×10^5 in C. G. S. units. For the same mode, mercury has an acoustic impedance of approximately 19.6×10^5 , which is rather close to that of quartz, so that mercury can be acoustically coupled to quartz in a quite effective manner with a minimum of reflection at the quartz-mercury interface; since mercury is a liquid, it may be very advantageously used as the transmitting medium in an ultrasonic delay line. As the term "acoustic impedance" is commonly used in the art, this quantity is the product of the compressional wave velocity in a substance and the density of that substance.

Since substantially perfect reflection of compressional wave energy is desired at the walls 2 and 3 of the tank, in order to minimize the overall attenuation of the tank from input transducer 4 to output transducer 5, it is very important that a substantial impedance mismatch occur at the tank side wall-mercury interface. In other words, it is necessary that the side walls 2 and 3 be highly reflecting, to allow a plurality of traverses of the tank to be made without appreciable attenuation of the compressional wave energy. Another characteristic which the side walls of the tank, as well as the rest of the tank, must have is that they must be able to contain the mercury and must not chemically react or combine therewith. Steel and stainless steel have

been found to be suitable materials for the walls of a tank containing mercury, from the points of view of necessary strength and chemical inertness with respect to mercury. Steel has an acoustic impedance of approximately 39×10^5 , while stainless steel has an acoustic impedance of approximately 43.0×10^5 . Considering the relative acoustic impedances of mercury and steel, however, it appears from calculations that about $\frac{1}{10}$ of the compressional wave energy striking a mercury-steel interface would pass into the steel and only $\frac{1}{10}$ of the incident energy would be reflected. Experiments utilizing steel with its surface ground very smooth or very fine bear out these calculations; steel with a very fine ground surface forms a reasonably good acoustic impedance match to mercury, the reflected energy being down 10 db on the incident energy. Therefore, if the walls 2 and 3 of the tank 1 in Fig. 1 are to be utilized as reflecting surfaces as in said figure, steel with a fine ground surface cannot be used for such walls, since such material forms a reasonably good acoustic impedance match to mercury and not a substantial impedance mismatch as is necessary for good reflection of compressional wave energy.

It has been found, according to this invention, that, if the steel face is lightly sandblasted or etched, 100 per cent. reflection of compressional wave energy results at the mercury-steel interface. Thus, as one passes from a fine ground surface to a rough surface, the transmission of energy changes from the $\frac{1}{10}$ transmission predicted in theory, and found in practice, to no transmission or total reflection.

Although we do not wish to be limited to any particular theory as to why an etched or sandblasted steel surface provides 100 per cent. reflection, as contrasted to only approximately 10 per cent. reflection with a finely ground steel surface, the following is our present understanding of the theory behind this phenomenon. Mercury does not wet steel. Hence, at a sandblasted or etched steel surface, the mercury touches the steel only at the high spots of such roughened surface, leaving a cushion of air between the mercury and the steel at all the low points of such surface. Air has an acoustic impedance of 41.3, which is vastly different from that of mercury, so that, at the mercury-air interface provided by the roughened surface, there is a substantial acoustic impedance mismatch, which provides the totally reflecting characteristic desired. It should be clearly understood that this invention operates as described above without regard to the truth or falsity of any theory explaining or tending to explain the operation of the same.

From the above, it may be seen that it is possible to have a mercury-steel interface which can be made totally reflecting (when rough) or absorbing to the extent of 10 db (when smooth). Moreover, this change in reflection characteristics can be accomplished in a rather simple and inexpensive manner. Thus, the problem of providing satisfactory reflecting surfaces for the tank has been solved according to this invention.

Figs. 2 and 3 show a construction of mercury ultrasonic delay line according to the principles just discussed. The tank 6 is substantially rectangular in outline or configuration, is filled with mercury, as indicated, and has the input and output quartz electromechanical transducers 4 and 5, respectively, located in the pair of upstanding side walls 7 and 8 in the same way as such

transducers are located in Fig. 1. The active or inner faces of transducers 4 and 5 are both acoustically coupled to the mercury in tank 6. Each of the walls 7 and 8, in addition to being provided with apertures for the corresponding transducers 4 and 5, is provided with five equally-spaced circular sandblasted areas 9, the centers of which on both walls all lie in a common horizontal plane, so that the circles on each wall are in horizontal alignment with the other circles on that same wall. The diameter of each of the sandblasted circles 9 is substantially equal to the diameter of transmitting transducer 4 and the receiving transducer 5. The interior surfaces of walls 7 and 8 are fine ground throughout their areas, except for the sandblasted circular reflectors or areas 9, so that smooth ground steel surfaces are provided in between such reflectors.

The circular reflectors 9 on wall 8 are staggered or displaced with respect to those on wall 7, in a direction from top to bottom of Fig. 2, which figure is a horizontal section through the tank, by an amount which depends on the angle between the active or inner face of transducer 4 and the inner face of wall 7, and also on the distance between walls 7 and 8. This amount of displacement is made such that the center line D of the cylindrical beam of compressional wave energy emanating from transducer 4 will strike the center of the uppermost (in Fig. 2) reflector 9 of wall 8, and so that the center line of such beam reflected from said uppermost reflector on wall 8 will strike the uppermost reflector 9 of wall 7.

The tank 6 has five sandblasted reflectors on each of the walls 7 and 8 and, as indicated by the lines D in Fig. 2, which indicate the center line of the cylindrical beam of compressional wave energy in the travel of such energy through the tank, is designed for eleven traverses through said tank. The circular reflectors are provided on the walls in areas where reflection is wanted. The energy from transducer 4 falls almost totally on the upper most reflector 9 of wall 8, since the distance across the tank is rather short and since the diameter of the reflector is equal to the diameter of the transducer 4. Some very small amounts of energy, which has spread beyond the original diameter of the beam, fall outside of said uppermost reflector 9, impinge on the smooth steel surrounding this reflector, and are substantially all absorbed, since such smooth steel is highly absorbing.

The energy reflected from this uppermost reflector 9 is projected toward the second reflector, which is the uppermost reflector 9 on wall 7, since the angle of incidence on the first reflector is equal to the angle of reflection therefrom. The energy from the first reflector falls primarily on the second reflector, which is also of the same diameter as transducer 4, with the spread falling outside of the second reflector and again being substantially all absorbed by the smooth steel surrounding this reflector.

The same thing happens to the energy reflected from the second reflector toward and to the third reflector, which is the second reflector from the top on wall 2, and also for each and every reflection throughout the eleven traverses of the tank by the compressional wave beam, since all of the reflectors 9 have diameters equal to the diameter of the transmitting and receiving transducers and since all of the reflectors are surrounded by substantially non-reflecting or absorbing smooth steel surfaces.

Thus, it should be apparent that, throughout its path of travel in the tank, the compressional wave beam is continuously and successively clipped or limited in diameter to one equal to that of the transmitting transducer. Since most of the transmitted energy is contained within a circle equal in diameter to the transmitting transducer, at least out to relatively great intertransducer spacings, no appreciable amount of energy is lost by this beam clipping technique. On the other hand, by this continuous and successive beam clipping technique, the divergent or side energy of the beam, corresponding to the minor lobes thereof, is progressively eliminated at each reflector, thus preventing such energy from adding up cumulatively. The energy therefore arrives at the output or receiving transducer 5, never having had a chance to spread out and develop a radiation pattern in which there are any appreciable minor lobes. By this technique, the energy path is uniquely defined, spurious paths which could be produced by divergence or spreading of the beam being effectively prevented or eliminated, so that the proper and desired time delay is positively obtained. Thus, it will be seen that we have effectively solved the problem of spurious or undesired paths of compressional wave energy by eliminating the same.

It should be seen that the tank of Figs. 2 and 3 is of rather simple design and may be readily constructed. Each of the steel side walls 7 and 8, which may be of stainless steel if desired, is first fine ground, after which a mask with holes therein where reflectors 9 are wanted is placed over the wall and sandblasting is applied. If the tank 6 is entirely filled with mercury and sealed, an air-filled expansion tank (not shown) of conventional design is provided, this tank having a flexible diaphragm contacting the mercury; such a tank allows for expansion and contraction of the mercury resulting from changes in temperature.

In the tank design shown in Figs. 2 and 3, much of the mercury is used doubly by the cylindrical beam, as should be seen from a consideration of the location of the center line D of the beam and of the diameter of reflectors 9, which have a diameter equal to that of the cylindrical beam. Thus, the mercury pool or body is used rather efficiently, minimizing the amount of mercury required for the tank.

Figs. 4 and 5 show a modified design according to this invention, in which the mercury is used still more efficiently. Fig. 4 is a horizontal section through the tank, with the input and output electromechanical transducers omitted, while Fig. 5 is a diagrammatic illustration of the path of the compressional wave energy in the tank of Fig. 4. The tank 10 is substantially square in outline and has four steel side walls 11, 12, 13 and 14. Each of these walls has a planar inner face, with the exception that, at one end, wall 11 has a small portion 11a which angles inwardly at an angle of approximately 45° with respect to the plane of the remainder of wall 11. Therefore, walls 11 and 12 intersect at an angle of approximately 45°, instead of 90°, as do the other pairs of intersecting walls. Wall 11 has an aperture 15 therein adjacent one end thereof, in which an input transducer (not shown) may be mounted. As in the modification of Figs. 2 and 3, the transducer is adapted to be mounted with its active face lying at a small acute angle to the inner face of wall 11, this angle being conven-

iently provided by bevelling a portion of the outer face of said wall.

Wall 12 has a similar aperture 16 therein in which may be mounted an output transducer (not shown). Aperture 16 has a diameter equal to the diameter of aperture 15, and the output transducer is adapted to be mounted therein with its responsive face at a similar small angle to the inner face of wall 12.

The inner face of walls 13 and 14 are each provided with four spaced aligned sandblasted circular reflectors 17, each of these reflectors having a diameter equal to the diameter of transducer apertures 15 and 16, all of the inner surfaces of these walls except for the reflectors being smooth ground or fine ground. The inner faces of walls 11 and 12 are each provided with three spaced aligned sandblasted circular reflectors 18, each of which has a diameter equal to the diameter of transducer apertures 15 and 16, all of the inner surfaces of these walls except for the reflectors being smooth ground or fine ground. Also, the angular portion 11a of wall 11 has a sandblasted inner surface 19, the width a of this surface being equal to the diameter of apertures 15 and 16, although the height of this surface does not necessarily need to be limited to the dimension a, but may if desired cover the full height of tank 10; this reflector 19 may therefore be rectangular rather than circular.

Tank 10 is filled with mercury. The reflectors 17, 18 and 19 are located with respect to each other to produce a compressional wave beam path as indicated by the lines and arrows in Fig. 5. This may be done by taking into account the angle between the input transducer and wall 11, the internal dimensions of the tank, and the fact that the angles of incidence are equal to the corresponding angles of reflection. As may be seen in Fig. 5, this design employs sixteen traverses of the tank, with the beam first bouncing back and forth between walls 11 and 13 in a substantially vertical direction in Fig. 5, and then bouncing back and forth between walls 12 and 14 in a substantially horizontal direction in said figure, the change in direction being effected by the angular wall portion 11a. Thus, in this modification there is travel of the energy in two separate directions through the mercury, utilizing the mercury still more efficiently than the modification of Figs. 2 and 3 and resulting in substantially a twofold improvement over the previous embodiment. For the same time delay, the quantity of mercury necessary is substantially less in the embodiment of Figs. 4 and 5 than in the embodiment of Figs. 2 and 3.

In the embodiment of Figs. 4-5, as in the previous embodiment described, the energy path is uniquely defined (thus substantially preventing spurious paths) by the beam clipping action, because the diameters of the reflectors 17 and 18 are the same as the diameter of the transmitting transducer and because the reflectors 17 and 18 are all surrounded by highly absorbing and substantially non-reflecting smooth ground steel areas.

The beam clipping or beam control technique of this invention is equally applicable to solid delay lines. Thus, if a block of fused quartz having the configuration shown in Fig. 5 is used, it is possible to solder a metal having an acoustic impedance rather close to that of quartz, such as lead, for example, onto the sides of the quartz in areas where absorption is wanted (that is, where the beam spreads beyond its original diam-

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eter), leaving the quartz-air interface (at which there is a large mismatch in acoustic impedances) in areas where reflection is desired.

It has been stated above that there is some reflection of energy by the smooth steel areas, though this is very small indeed as compared to the amount of energy reflected by the sandblasted areas. It has been found that energy falling outside of the reflectors on the fine ground steel suffers a 10 db loss on reflection from such areas. Figs. 6 and 7 illustrate a modification whereby such loss may in effect be increased.

Tank 1' is similar to tank 1 and has a pair of similar opposite side walls, only one of which is shown at 8'. A plurality of spaced sandblasted circular reflectors 9' is provided on the inner surface of side wall 8', these reflectors being similar to those of Figs. 2 and 3. An annular recess or trough 20, which may be termed a "moat," is cut around each sandblasted reflector 9' into the body of wall 8' from the inner face thereof, the bottom of each trough being smooth. As shown more particularly in Fig. 7, the bottom of each trough is inclined with respect to its corresponding reflector 9' or with respect to the inner surface of wall 8', since in this, as in all previous modifications, the sandblasted reflectors are coplanar with the inner faces of their corresponding walls. Each trough 20 is inclined in such a direction that a line perpendicular to the plane of the bottom of the trough points toward the bottom end of wall 8' or toward the bottom of tank 1'.

The unwanted spread or divergent energy impinges on these troughs which surround each reflector. Due to the fact that troughs 20 are inclined as above described, the small portion of this spread energy which is reflected therefrom (which portion is approximately $\frac{1}{16}$ of the total energy impinging thereon, since the troughs have smooth steel bottoms) is reflected from the bottom of the trough toward the bottom of the tank 1'. This energy which is diverted toward the bottom of the tank is effectively eliminated as far as the signal-responsive path between the input and output transducers is concerned, since such energy is diverted entirely beyond the effective range of the output transducer. When a construction in accordance with that just described, with inclined troughs 20, was tested, it was found that the spurious path energies were more than 50 db down. The unwanted spread energy which is diverted toward the bottom of the tank is dispersed thereat by multiple travels through and attenuation by the mercury and the walls and, at any rate, is effectively prevented from interfering with the desired energy flowing between the two transducers in the tank.

It has been stated previously that this invention is applicable equally well to liquid and solid delay lines. It is desired to be made clear, at this juncture, that the "moat" construction of Figs. 6-7 may be utilized in such solid lines, as well as in liquid lines.

Figs. 8-12 illustrate a modified construction according to this invention, in which a plurality, here shown as three, of separate or independent delay lines are operative in a single common pool of mercury, and in which, also, the effective lengths of each of the delay lines are independently adjustable within a certain range, from outside the tank.

A hollow prismoidal stainless steel tank 21, of rectangular outer configuration, is formed by fastening together four planar sides to form the

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body thereof, as by means of bolts 22 and dowel pins 23. The sides are finished to a tolerance sufficient to provide leak-proof joints therebetween, and sufficient to make the two ends of the resulting open-ended elongated hollow rectangular prismoid substantially parallel. The opposite ends of the aforesaid hollow prismoid are closed by means of opposite stainless steel end plates 24 and 25, which are fastened to the open ends of the body in a leak-proof manner. Plates 24 and 25 will be described more fully hereinafter. When the end plates have been secured to the body of the tank, a leak-proof tank is provided, and for use this tank is filled with mercury.

End plate or end wall 24 may be termed the input end of the device, since it has mounted thereon a plurality of input electromechanical transducers 26, 27 and 28, while end plate or end wall 25 may be termed the output end of the device, since it has mounted thereon a plurality of output electromechanical transducers 29, 30 and 31. It is to be understood, however, that all of the transducers are exactly alike and may be used interchangeably as receiving or transmitting transducers, or as input and output transducers.

Fig. 10 is a face or front view of one end of the tank. End wall 24 may be fastened to the body of the tank in a leak-proof manner by means of bolts 32 which pass through spaced apertures provided in said end wall and thread into corresponding aligned tapped holes provided in the corresponding end of the tank body, and also by means of dowel pins 34 secured to the tank body and passing through suitable apertures 33 provided in end wall 24.

Fig. 9 is a face or front view of the opposite end of the tank. Similarly, end wall 25 is fastened to the body of the tank in a leak-proof manner by means of bolts 32 which pass through spaced apertures provided in said end wall and thread into corresponding aligned tapped holes provided in the corresponding end of the tank body, and also by means of dowel pins 34 secured to the tank body and passing through suitable apertures 33 provided in end wall 25.

A counterbored tapped filler and drain hole 35 is provided in each of the end walls 24 and 25, the one in wall 24 being omitted in order to simplify the drawing. These holes are provided in order to fill and drain the mercury tank. When the tank 21 is filled with mercury, these holes are closed by bolts which thread into said tapped holes.

The outer faces of the rectangular end walls 24 and 25 are not parallel to their inner faces, but as shown in Fig. 8 are both somewhat roof-shaped with respect to the horizontal center lines which are parallel to their longer sides. In other words, the outer faces of these walls are beveled inwardly a few degrees from each side of their horizontal center lines, thus making their maximum thickness at their center lines and their minimum thickness at their upper and lower ends, their thickness at their upper ends being equal to their thickness at their lower ends. The reason for this beveling will appear hereinafter.

Transducer assemblies 26 and 27 are mounted on end wall 24 above the horizontal center line of said wall and are equally spaced from the vertical center line of said wall on opposite sides of said vertical center line. Transducer assembly 28 is mounted on end wall 24 below the horizontal center line of said wall with its center on the

vertical center line of said end wall. Transducer assemblies 29, 30 and 31 are mounted on end wall 25 oppositely with respect to those on end wall 24, transducer assemblies 30 and 31 being mounted below the horizontal center line of wall 25 equally spaced from the vertical center line of said wall on opposite sides of said vertical center line, and transducer assembly 29 being mounted above the horizontal center line of wall 25 with its center on the vertical center line of said wall.

Transducer assemblies 26—31 are all exactly the same and are mounted on the corresponding end walls 24 and 25 in exactly the same manner; therefore only one of such assemblies will be described in detail.

Transducer assembly 27 includes a substantially cup-shaped housing 36 which is secured to the outer surface of end wall 24 by means of three circularly-arranged equally-spaced mounting bolts 37 which pass through suitable holes provided in housing 36 and thread into corresponding tapped holes 38 which are provided in plate 24 and which extend into the material of said plate a suitable distance from the outer face thereof. Housing 36 has a central circular opening 39 therein and also a larger central coaxial circular opening 40 therein at the inner or right-hand end thereof which provides a substantially vertical annular shoulder at the outer end of aperture 40.

An annular metallic spacer 41 is seated inside aperture 40 and is free to move therein with respect to housing 36, the outward or leftward movement of this spacer being limited by the contact of the outer face of said spacer with the aforesaid annular shoulder and the inward or rightward movement of this spacer being limited by the contact of the inner face of said spacer with the outer face of the metallic end wall or plate 24. In order to permit free movement of spacer 41 with respect to bolts 37, three equally-spaced arcuate grooves 42 are cut from the outer edge of spacer 41 toward the central opening thereof, these grooves being of sufficient size to allow free movement of spacer 41 past the corresponding bolts 37. Spacer 41 is adjustable from outside the tank to move the same inwardly or outwardly with respect to housing 36 and to tilt the vertical faces of said spacer with respect to the aforementioned vertical annular shoulder, to thereby correspondingly move and tilt the part of the transducer assembly, to be hereinafter described, that bears against spacer 41. This adjustment is made possible by means of three circularly-arranged equally-spaced adjusting bolts 43 which thread into corresponding tapped apertures in housing 36 and the inner ends of which bear against the spacer 41. Each of the bolts 43 is preferably spaced half-way between the two adjacent mounting bolts 37. The tapped apertures for bolts 43 in housing 36 open at the outer face of said housing, so that bolts 43 are manipulable from the outside of wall 24; the desired movements and tilting of spacer 41 may be had by turning each of the three bolts 43 as may be desired. A lock nut 44 is provided on each of the adjusting bolts 43.

A sleeve 45 of insulating material is fixedly secured in a circular bore 46 in wall 24 which extends inwardly from the outer surface of said wall. A somewhat smaller circular bore 47 is coaxial with bore 46 and extends entirely through wall 24, providing a substantially vertical annular shoulder 48 at the inner end of bore 46. The

inner end of sleeve 45 abuts said shoulder, and said sleeve has a length such that its outer end is located slightly inwardly from the outer face of wall 24.

An annular disk 45' of insulating material has an outer diameter such that it is freely movable within sleeve 45, and disk 45' is mounted for sliding movement within said sleeve. A crystal unit 49, consisting of a thin quartz crystal disk 50 which abuts the inner face of a metallic base member 51, is secured to the inner face of disk 45' by any suitable means, such as a stud 53 which threads into member 51 and a portion of which engages disk 45'; crystal unit 49 is also mounted for sliding movement in sleeve 45. Base member 51 consists of a disk-like body having a central outwardly-extending boss thereon. The disk portion of member 51 bears against the inner face of disk 45' as aforesaid, and the boss portion of said member extends through the central circular hole of disk 45'. The outer face of disk 45' engages the inner face of spacer 41 and moves with said spacer, thereby to cause members 45', 50 and 51 to slide in sleeve 45. In order to provide electrical connection to the outer electrode of crystal 50, a conducting clip 52 is maintained in electrical contact with metal member 51 by means of a stud 53 which passes through a hole provided in said clip and is threaded into a tapped opening provided in the boss part of member 51. The inner end of a flexible lead wire 54 is electrically connected as by soldering to clip 52, this lead wire being coaxial with and soldered in a metal tube 55 which passes out of housing 36 through a suitable central aperture 56 provided in the outer or base portion of said housing, aperture 56 having a larger diameter than tube 55. In order to hold tube 55 in position with respect to housing 36 and to electrically insulate the same therefrom, a sleeve 57 of insulating material surrounds and is sealed to tube 55 and in aperture 56 of housing 36. Tube 55 extends outside of housing 36 and serves as one electrical connection to crystal 50. The thin quartz disk 50 has its inner face directly exposed to and in acoustic and electrical contact with the mercury in tank 21 by means of bore 47 which extends entirely through wall 24, since the crystal unit 49 is positioned in sleeve 45 in bore 46, which bore is coaxial with bore 47. A second electrical connection to crystal 50 may therefore be made through metallic tank 21 and the mercury therein which is in contact with the tank and with the crystal.

A narrow resilient washer 58 is also positioned within sleeve 45 and is free to move with respect thereto. The outer face of this washer engages the inner face of crystal 50 and the inner face of said washer bears against the shoulder 48. This washer, when the transducer is assembled in end wall 24 as shown, is normally under compression, so that it tends to expand to its original shape and it exerts a force which tends to urge the crystal unit 49 outwardly or to the left in Fig. 12.

As shown, normally the inner face of spacer 41 is spaced somewhat from the outer face of wall or plate 24. When adjusting bolts 43 are tightened, the inner ends of such bolts, bearing as they do on spacer 41, force spacer 41, disk 45', and crystal unit 49 inwardly or to the right in Fig. 12 against the yielding force of resilient washer 58, disk 45' and unit 49 sliding in sleeve 45. As bolts 43 are tightened more and more, eventually the inner face of metallic spacer 41

comes into contact with the outer face of metallic wall 24, thus positively stopping any further inward movement of spacer 41 by the metal-to-metal contact of members 41 and 24. In this manner, possible damage to the crystal 50 is prevented, which damage could be produced if sufficient inward pressure were applied to said crystal to cause it to come into contact with shoulder 43 or to cause it to be forced with too large a pressure against washer 53.

Since washer 53 at all times tends to urge the crystal unit 49 outwardly or to the left, when adjusting bolts 43 are loosened washer 53 is permitted to expand, pushing crystal unit 49, disk 45', and spacer 41 outwardly or to the left in Fig. 12. Thus, by manipulation of bolts 43, crystal unit 49 may be moved outwardly or inwardly; by means of the three-point pressure on spacer 41, the crystal unit 49 may also be tilted with respect to housing 36 or end wall 24.

Because of the beveled outer surface of end plate 24, the inner face of housing 36, which bears thereagainst, is tilted at a small angle to the inner face of end wall 24. This means that the inner surface of spacer 41, the inner surface of disk 45', and the quartz disk 50 are similarly tilted at a small angle to the inner surface of wall 24. As a result, the line E, which is normal to the active face of crystal 50 and which indicates the direction of travel of the compressional wave beam emanating from transducer 27, is directed downwardly at a small angle with respect to the horizontal or with respect to the upper and lower sides of tank 21.

Transducer assemblies 26 and 29-31 are all exactly similar to transducer assembly 27 described above. The transducers 26 and 29 are both directed downwardly at a small angle with respect to the horizontal, while the transducers 28, 30 and 31 are all directed upwardly at a small angle with respect to the horizontal, due to the mounting of these transducers on the end walls as previously described and to the beveled outer surfaces of the end walls. For example, the receiving transducer 30 responds to energy received from the direction indicated by F in Fig. 11.

Three sandblasted circular areas or reflectors 59, 60 and 61, similar to the reflectors 9 of Fig. 2, are provided on the inner surface of end plate 24. Each of these reflectors may if desired have the same diameter as the bores 47, in accordance with the principles underlying, and for carrying out, the beam clipping technique described in connection with Fig. 2. However, we have found that, in the three-traverse design of Figs. 8-12, in which, moreover, the total length of the compressional wave path is somewhat limited, it is not absolutely necessary to limit the diameter of the reflectors to the original diameter of the beam, since for lengths of beam travel on this order the beam does not diverge sufficiently to establish spurious paths which appreciably interfere with the desired operation of the device. For this reason, the diameter of each of the reflector areas 59, 60 and 61 is illustrated as being somewhat greater than the diameter of bores 47.

The center of reflector 59 is located somewhat below the horizontal center line of end plate 24 and in the same vertical plane as the center of transducer 26, the center of reflector 60 is located somewhat above the horizontal center line of end plate 24 and in the same vertical plane as the center of transducer 28, and the center of reflector 61 is located somewhat below the horizontal center line of end plate 24 and in the same

vertical plane as the center of transducer 27. How the spacings of reflectors 59, 60 and 61 with respect to the horizontal center line of end plate 24 are determined will be explained subsequently. Except for the bores 47 and 35 and for the sandblasted areas 59-61, the entire inner face of end plate 24 is uninterrupted and is fine ground or ground very smooth, to provide a highly polished steel surface.

Three adjustable reflectors 62, 63 and 64, which are cylindrical stainless steel plugs having their inner ends sandblasted to provide reflecting surfaces, are mounted in output end plate 25. The circular inner face of each of the plugs 62-64 is parallel to the inner face of plate 25. The diameter of each of these plugs is equal to the diameter of reflectors 59-61. The center of plug 62 is located somewhat above the horizontal center line of end plate 25 and in the same vertical plane as the center of transducer 30, the center of plug 63 is located somewhat below the horizontal center line of said end plate and in the same vertical plane as the center of transducer 29, and the center of plug 64 is located somewhat above the horizontal center line of said end plate and in the same vertical plane as the center of transducer 31.

The plugs 62-64 are all alike so only one of them will be described in detail. Plug 62 is mounted for longitudinal sliding movement in a corresponding circular bore 65 which extends outwardly from the inner face of plate 25 and has a depth which is a substantial portion of the thickness of said plate. A cap screw 66 extends through a suitable aperture 67 in plate 25, aperture 67 being smaller in diameter than bore 65, being coaxial therewith, and being in communication therewith. The inner end of screw 66 is threaded into a centrally-located tapped aperture 68 which extends for a suitable distance into plug 62 from the outer end thereof. The inner face of the cap of screw 66 is adapted to bear on a counterbored shoulder provided at the outer end of aperture 67. In this way, when screw 66 is tightened, the cap of said screw bears against end plate 25 and plug 62 is moved outwardly or to the right in Fig. 11. A resilient washer 69 is positioned between the outer end of plug 62 and the vertical shoulder provided at the outer end of bore 65, this washer being normally under compression so that it tends to expand to its original shape and to thereby exert a force which tends to urge the plug 62 inwardly or to the left in Fig. 11. When screw 66 is tightened, plug 62 is moved to the right or outwardly against the yielding force of washer 69, plug 62 sliding in bore 65. When screw 66 is loosened, washer 69 is permitted to expand, pushing plug 62 inwardly or to the left in Fig. 11. The compressional wave beam emanating from the input end 24 of the tank is adapted to impinge on the reflecting surface of plug 62 and be reflected thereby, as indicated by lines G and H, respectively. It may be seen that, by moving plug 62 in and out with respect to end plate 25 or toward and away from end plate 24, the length of the path traversed by the compressional wave energy in the tank 21 is correspondingly decreased or increased, thereby decreasing or increasing the time delay of the portion of the tank involving plug 62.

Means are provided both for limiting the range of movement of plug 62 and also for preventing rotation of said plug when screw 66 is rotated. A substantially rectangular slot 70 is cut into the

cylindrical wall of plug 62, this slot having a desired depth and a length equal to the desired range of movement of said plug; this slot is closed at both ends by the material of the plug. A vertical hole is drilled downwardly from the upper end face of end plate 25 into communication with bore 65, and a portion of the length of this hole is threaded. A stud 71 is threaded into this hole, said stud having a shank portion 71a which extends down into bore 65 and which is of such diameter as to fit nicely into bore 70 of plug 62. The inward and outward movements of plug 62 are limited by engagement of shank portion 71a with the outer and inner end wall surfaces of slot 70. At the same time, as adjusting screw 66 is turned, the plug 62 is effectively prevented from rotating also by the engagement of shank portion 71a with the side edges of slot 70.

Plugs 63 and 64 are both adjustable, have exactly the same construction as plug 62, and are mounted in end plate 25 in exactly the same way as plug 62, except that the hole for the stud 71 which coacts with plug 63 is drilled upwardly from the lower end face of plate 25, since plug 63 is below transducer 29, while plugs 62 and 64 are above the respective transducers 30 and 31.

Except for apertures 47 and 35 and plugs 62-64, the inner face of plate 25 is uninterrupted and is ground smooth.

The tank 21 has three separate delay lines utilizing the same body or pool of mercury, and each line employs three traverses lengthwise of the tank. Input transducer 27 cooperates with output transducer 30 to provide one delay line, input transducer 28 cooperates with output transducer 29 to provide a second delay line, while input transducer 26 cooperates with output transducer 31 to provide a third delay line. The circular reflectors 59-64 are so located on their corresponding end plates 24 and 25 that, taking into account the angle of bevel of the outer surfaces of such plates and the consequent tilt of transducers 26-31, the length of the tank 21, and the fact that the angle of incidence of the compressional wave beam on a reflecting surface is equal to the angle of reflection from such surface, reflectors 62-64 will each receive a beam from a corresponding transmitting transducer 26-28 and will reflect the beam to a corresponding reflector 59-61, while reflectors 59-61 will each receive a beam from a corresponding reflector 62-64 and will reflect the beam to a corresponding receiving transducer 29-31.

Now referring to Figs. 11-12, the beam of compressional wave energy for one of the delay lines emanates from the crystal 50 of transmitting transducer 27 along the line E, which is inclined downwardly at a small angle to the horizontal, travels to the opposite end 25 of the tank, impinges on reflector plug 62 along line G, is reflected therefrom along line H, travels to end 24 of the tank, impinges on integral reflector 61 along line J, is reflected therefrom along line K, travels to end 25 of the tank, and impinges on the crystal 50 of output or receiving transducer 30 along line F. It will thus be noted that this beam from transducer 27 travels back and forth three times across the tank and downwardly from transducer 27 to transducer 30. The path between transducers 27 and 30 is indicated by dotted lines in Fig. 8.

Similarly, the third delay line path includes

input transducer 26, plug reflector 64, integral reflector 59, and output transducer 31, this beam also traveling back and forth three times across the tank and downwardly from transducer 26 to transducer 30.

The second delay line path includes input transducer 28 (which is inclined upwardly at a small angle with respect to the horizontal), plug reflector 63, integral reflector 60, and output transducer 29, this beam traveling back and forth three times across the tank and upwardly from transducer 28 to transducer 29. The path between transducers 28 and 29 is indicated by dot-dash lines in Fig. 8.

From the above, it may be seen that, in the structure of Figs. 8-12, three separate or independent delay lines are provided in a single tank of rectangular prismoidal shape, this tank containing a single pool or body of mercury which is common to all three lines. All of the mercury in the tank is maintained at the same temperature by normal convection currents. Therefore, the velocity of travel of the compressional waves in the mercury is exactly the same for all three lines, thus compensating for differences in the lines due to thermal effects; such differences in velocity could easily arise due to slight differences in temperatures of the separate mercury pools if separate pools or tanks were used for each of the three lines.

By manipulation of any of the separate screws 66, the corresponding plug reflectors 62-64 may be moved inwardly or outwardly as desired, to thereby vary the length of the corresponding delay line or the amount of delay of the corresponding line. In this way, differences between the three lines due to natural manufacturing tolerances or to circuit dissimilarities may be compensated for. Also, since the crystal units of each of the transducers 26-31 are adjustable inwardly and outwardly and also for tilt, the input transducers of each delay line may be properly aligned with their corresponding output transducers.

If tank 21 is entirely filled with mercury and sealed, an air-filled expansion tank (not shown) is preferably provided thereon, to allow for contraction and expansion of the mercury induced by temperature variations.

Fig. 13 is a block diagram of a portion of a moving-target-indicator (MTI) radar system utilizing a mercury delay line according to this invention. Incoming video intelligence, such as the output of a radar receiver, is applied to a modulator 72, to which is also applied a carrier wave from an oscillator 73 in order to produce a modulated carrier signal in line 74. As previously stated, it is not absolutely necessary to use the oscillator 73 or the modulator 72; if these circuit components are omitted, the incoming video intelligence may be applied directly to point 75. At point 75, the modulated carrier is split and applied to two separate channels, one consisting of a mercury delay line 76, an amplifier 77, a detector 78, and an output resistor 79, and the other consisting of an attenuator 80, an amplifier 81, a detector 82, and an output resistor 83 which is connected in series opposition to resistor 79.

Delay line 76 is constructed according to this invention and functions to delay the intelligence for a time corresponding to the periodicity of the radar transmitter, producing at its output delayed video intelligence which is amplified, detected, and applied to resistor 79. Attenuator 80

has an attenuation equal to that inherent in delay line 76 but provides no delay, so that undelayed video intelligence is provided at the output thereof, this intelligence being amplified, detected, and applied to resistor 83. When there are no moving targets within the field of search of the radar equipment, successive echo signal patterns are exactly alike and the undelayed and the delayed video intelligence are exactly the same so that they cancel each other, producing zero signal output at point 84 between resistors 79 and 83. On the other hand, when there are moving targets within the field of search, successive echo signal patterns are not alike and the undelayed and the delayed video intelligence are dissimilar so that they no longer cancel each other, producing an output signal at point 84, which signal is applied to a suitable indicator (not shown).

Fig. 14 illustrates the application of the delay line construction of Figs. 8-12 to the storage or memory portion of a computing system. In Fig. 14, parts the same as those of Figs. 8-12 are referred to by the same reference numerals. The tank 21 of Fig. 14 is in effect reversed with respect to that described previously, in that in the Fig. 14 circuit transducers 30, 29 and 31 are transmitting or input transducers while transducers 27, 28 and 23 are receiving or output transducers. However, as previously stated, transducers 26-31 are all exactly alike and may be used for either transmitting or receiving ultrasonic compressional wave energy. The first delay line path through tank 21 is from input transducer 30, to fixed reflector 61, to adjustable reflector 62, to output transducer 27. The second delay line path is from input transducer 29, to fixed reflector 60, to adjustable reflector 63, to output transducer 28. The third delay line path is from input transducer 31, to fixed reflector 59, to adjustable reflector 64, to output transducer 26.

The first delay line channel between transducers 30 and 27 is used as a control channel, and for this purpose a reference signal is supplied to input transducer 30 through a modulator and driver circuit 85, and is also supplied to one input connection 86 of a phase detecting circuit 87. The delayed reference signal picked up by output transducer 27 is applied through an amplifier 88 to the second input connection 89 of circuit 87. Circuit 87 produces at its output connection 90 a signal dependent on the phase relation between the two inputs 86 and 89, and this relation depends in turn on the time delay between transducers 30 and 27 in the mercury tank 21. The output connection may be applied to a temperature control for the mercury in tank 21, or it may be applied to a frequency control for the drivers 85, 91 and 103.

The second delay line channel between transducers 29 and 28 may be used for storing a series of electrical impulses representing digits, the time duration of the entire series being equal to the time delay provided in the tank between said transducers and the series of impulses being repetitively transmitted and retransmitted through said channel. For this purpose, the signal output of a modulator and driver circuit 91 is applied to input transducer 29. The delayed signal picked up by output transducer 28 is applied through an amplifier 92 to a reshaping gate 93, to which clock pulses from a suitable source are also applied. The output of the reshaping gate 93 is applied through an erase gate 94,

which is actuated by means of suitable control signals, to the input connection of driver circuit 91, so that the series of impulses is transmitted again and again through the second delay line channel by means of the loop just described. When the erase gate 94 is properly actuated by the control signals applied thereto, this loop is in effect broken and a certain impulse or certain impulses are effectively erased from this channel. The signals stored in this channel may be utilized by means of a read gate 95 connected to the output of reshaping gate 93 and actuated by suitable control signals applied thereto at 96; the signals appear in the output connection 97 of read gate 95, which connection is connected to point 98.

In order to "write" signals into this memory or storage system, a write gate 99 has its output connected to point 100 between gate 94 and driver 91. Gate 99 is supplied from a memory write-in lead 101 and is actuated by suitable control signals supplied through connection 102.

An arrangement similar to that described for the second delay line channel is provided for the third delay line channel between transducers 31 and 26. The output of modulator and driver circuit 103 is applied to input transducer 31, the delayed signal picked up by output transducer 26 being applied through an amplifier 104 to a reshaping gate 105 supplied with suitable clock pulses. The output of gate 105 is applied through erase gate 106 to the input connection of driver circuit 103, gate 106 being actuated by suitable control signals. Read gate 107 is connected to the output of gate 105 and is actuated by control signals applied thereto at 108. The output connection 109 of gate 107 is connected to point 98. Write gate 110 has its output connected to point 111 between gate 106 and driver 103. Gate 110 is supplied from memory write-in lead 101 and is actuated by control signals supplied through connection 112.

In the system of Fig. 14, two memory or signal storage channels are provided, along with one control channel, these three delay line channels utilizing a single common pool or body of mercury in accordance with the construction illustrated in Figs. 8-12.

Of course, it is to be understood that this invention is not limited to the particular details as described above, as many equivalents will suggest themselves to those skilled in the art. For example, although this invention has been described in connection with compressional waves in the longitudinal mode in liquids, it is equally applicable to solid delay lines, and, when such solid lines are used, transverse or shear mode waves may be utilized if desired, according to the principles set forth herein. Various other variations will suggest themselves. It is accordingly desired that the appended claims be given a broad interpretation commensurate with the scope of this invention within the art.

What is claimed is:

1. A delay line, comprising a metallic tank having at least one smooth internal wall, a compressional wave transmitting medium in said tank, an input transducer acoustically coupled to said medium, through a wall of said tank, the portion of said transducer which is coupled to said medium having a limited area and being arranged to project a beam of compressional wave energy having a cross section commensurate with said area toward said smooth wall, a rough metallic surface of limited area, com-

parable to the area of said portion, mounted on said smooth wall to serve as a reflecting surface for compressional waves, said rough surface being so located that a compressional wave beam emanating from said input transducer and traveling in said medium impinges on said surface and is reflected toward a region closely adjacent said input transducer, and an output transducer acoustically coupled to said medium, said smooth wall providing a reasonably good acoustic match to said medium and said rough surface providing substantially a mismatch to said medium.

2. A delay line, comprising a tank having first and second opposing parallel walls, a compressional wave transmitting medium in said tank, an input transducer acoustically coupled to said medium through said first wall and adapted to provide a beam of compressional wave energy directed toward said second wall, the portion of said transducer which is coupled to said medium having a limited area, a first reflecting surface of limited area, comparable to the area of said portion, mounted on said second wall of said tank and so located that a compressional wave beam emanating from said transducer and traveling in said medium impinges on said surface, the material of said wall surrounding said surface having an acoustic impedance which provides a reasonably good acoustic match to said medium, a second reflecting surface of limited area, comparable to the area of said portion, mounted on said first wall of said tank closely adjacent said input transducer and so located that the beam reflected from said second surface impinges on said second wall in a region closely adjacent said first surface, the material of said first wall surrounding said second surface having an acoustic impedance which provides a reasonably good acoustic match to said medium, and an output transducer acoustically coupled to said medium at said region in said second wall, said tank being devoid of interior partitions within the body of said medium.

3. In combination, a single body of homogeneous uninterrupted compressional wave transmitting medium totally devoid of any internal partitioning members, a plurality of directional input transducers acoustically coupled to said medium, each of said input transducers adapted when energized to project a beam of compressional wave energy of limited cross-sectional extent into said medium, an equal number of directional output transducers acoustically coupled to said medium, each one of said input transducers being directed to transmit compressional wave energy to a corresponding one of said output transducers, and a reflector located to reflect the beam from each input transducer to its corresponding output transducer, said reflector being of substantially the same shape and area as the cross section of said beam, whereby a plurality of separate and independent delay lines are provided which utilize in common said single medium.

4. In combination, a tank devoid of interior partition members and containing a single body of homogeneous uninterrupted compressional wave transmitting fluid, a plurality of directional input transducers mounted in said tank and acoustically coupled to said body, each of said transducers adapted when energized to project a beam of compressional wave energy of limited cross-sectional extent into said body, an equal number of directional output trans-

ducers mounted in said tank and acoustically coupled to said body, each one of said input transducers being directed to transmit compressional wave energy to a corresponding one of said output transducers, and a reflector located to reflect the beam from each input transducer to its corresponding output transducer, said reflector being of substantially the same shape and area as the cross section of said beam, whereby a plurality of separate and independent delay lines are provided which utilize in common said single body.

5. In combination, a tank containing a body of compressional wave transmitting fluid, a plurality of directional input transducers mounted in said tank and acoustically coupled to said body, an equal number of directional output transducers mounted in said tank and acoustically coupled to said body, each one of said input transducers being directed to transmit compressional wave energy to a corresponding one of said output transducers, whereby a plurality of separate delay lines are provided, a separate movable reflector for each of said lines mounted in said tank, each reflector being so located that a compressional wave beam traveling in said body between its corresponding input and output transducers impinges on such reflector, and separate means for independently moving each of said reflectors at will toward or away from one of its corresponding transducers.

6. In combination, a tank having a pair of opposite walls, a body of compressional wave transmitting fluid in said tank, a plurality of directional input transducers acoustically coupled to said body, an equal number of first reflecting surfaces associated with one of said walls, each of said surfaces being so located that a compressional wave beam emanating from its corresponding input transducer and traveling in said body impinges on such surface, an equal number of second reflecting surfaces associated with the other of said walls, each of said second surfaces being so located that the beam reflected from its corresponding first surface impinges on such second surface, an equal number of directional output transducers acoustically coupled to said medium to receive the energy which has been reflected by its corresponding second surface, whereby a plurality of separate delay lines are provided, the reflecting surfaces constituting one group each being separately movable with respect to the corresponding wall, and separate means for independently moving each of said movable reflectors at will toward or away from one of its corresponding transducers.

7. A delay line comprising a compressional wave transmitting medium having boundaries, means at a first boundary for introducing a substantially directive beam of compressional waves into said medium propagating in a first direction toward a second boundary, said beam having initially a prescribed cross-section, said boundaries being of a character such that said waves arriving at either boundary through said medium are substantially not reflected thereby, a first compressional wave reflective means at said second boundary in the path of said beam disposed to reflect said beam in a second direction toward a location at said first boundary other than the location of the wave introducing means, and a second compressional wave reflective means at said first boundary in the path of said beam disposed to reflect said beam in a third direction toward a location at said second boundary other than the location of said first

reflective means, said reflective means each having a reflective area substantially commensurate with said prescribed cross-section of said beam.

8. A delay line according to claim 7 in which said medium is continuous and completely devoid of partition members of any kind within said boundaries.

9. A delay line comprising a compressional wave transmitting medium having boundaries, means at a first boundary for introducing a substantially directive beam of compressional waves into said medium propagating toward a second boundary in a first direction making a nearly-normal angle with said second boundary, said beam having initially a prescribed cross-section, a first compressional wave reflective means at said second boundary in the path of said beam disposed to reflect said beam in a second direction toward a location at said first boundary closely adjacent to the location of the wave introducing means, a second compressional wave reflective means at said first boundary in the path of said beam disposed to reflect said beam in a third direction parallel to said first direction toward a location at said second boundary closely adjacent the location of said first reflective means, said reflective means each having a reflecting area substantially commensurate with said prescribed cross-section of said beam, and means surrounding each reflecting area for removing wave energy of the incident beam falling outside the reflecting area.

10. A delay line comprising a homogeneous continuous body of a compressional wave transmitting medium, means at a first location in said medium for introducing a substantially directive beam of compressional waves into said medium propagating in a first direction toward a second location, said beam having initially a prescribed cross-section, a first compressional wave reflective means located at said second location disposed to reflect said beam in a second direction toward a third location closely adjacent said first location, a second compressional wave reflective means located at said third location disposed to reflect said beam in a third direction parallel to said first direction toward a fourth location closely adjacent said second location, said reflective means each having a reflecting area substantially commensurate with said prescribed cross-section of said beam, and means surrounding each reflecting area for removing wave energy of the incident beam falling outside the reflecting area.

11. A delay line comprising a homogeneous continuous body of a compressional wave transmitting medium, means at a first location in said medium for introducing a substantially directive beam of compressional waves into said medium propagating in a first direction toward a second location, said beam having initially a prescribed cross-section, a first compressional wave reflective means at said second location disposed to reflect said beam with a single reflection in a second direction toward a third location closely adjacent said first location, said second direction thereby making an acute angle with said first direction at said first reflective means, a second compressional wave reflective means at said third location disposed to reflect said beam with a single reflection in a third direction parallel to said first direction toward a fourth location closely adjacent said second location, said third direction thereby making an acute angle with said second direction at said second reflective means, said reflective means

each having a reflective area substantially commensurate with said prescribed cross-section of said beam, and means surrounding each reflecting area for removing wave energy of the incident beam falling outside the reflecting area, said beam in traversing said medium in said second direction employing in part a portion of the medium traversed by said beam in said first direction and in part a portion of the medium to be traversed by said beam in said third direction, whereby plural use of said medium is made to propagate said beam therethrough.

12. A delay line, comprising a body of compressional wave-transmitting material having four rectangularly disposed parallel boundaries, the first and second of which constitute one pair of parallel opposite boundaries and the third and fourth of which constitute a second pair of parallel opposite boundaries, and a fifth boundary connecting two adjacent rectangularly-disposed boundaries and making an angle of forty-five degrees approximately with each, an input electro-acoustic transducer coupled to said medium through a boundary of said one pair and adapted to project a beam of compressional waves toward its opposite boundary, means in said opposite boundaries to reflect said beam back and forth therebetween, said means being constituted by reflectors of area limited in extent to approximately the same size and shape as the cross section of said beam, a similar reflector in said fifth boundary disposed to change the direction of said beam by approximately ninety degrees so that said beam is thereafter reflected back and forth between the boundaries of a second pair of opposite walls, similar reflectors disposed in said second pair of opposite walls in positions to effect reflection back and forth of said beam therebetween and an output electro-acoustic transducer in one of the walls of said second pair of opposite walls positioned to receive said beam after a series of reflections between said one pair and said second pair of opposite walls.

13. A delay line, comprising a metallic tank having a pair of first and second opposite substantially parallel walls, a compressional wave transmissive medium filling said tank and being devoid of interior partition members, an electroacoustic transducer mounted in said first wall and adapted to project a beam of compressional waves into said medium toward said second wall, said beam having a cross section of fixed area and shape, a reflector in said second wall of substantially similar area and shape disposed in the path of said beam to reflect said beam toward said first wall closely adjacent said input transducer, the material of said second wall surrounding said reflector being undercut to provide a reflecting surface in a plane different from the surface of said reflector, whereby compressional wave energy falling outside said reflector is reflected in a direction different from the energy falling upon said reflector, similar reflector means in said first wall adjacent said input transducer and an output electro-acoustic transducer disposed in one of said walls to receive said beam after repeated reflection between said walls.

14. A delay line comprising a plurality of spaced surfaces bounding a compressional wave transmitting body, one of said surfaces having an output transducer associated therewith, and predetermined areas integrated with other of said surfaces having a substantially greater coefficient of reflection than the portions of said

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surfaces surrounding said areas for causing a substantially directive beam of compressional waves to traverse said body a predetermined plurality number of times along substantially parallel paths and then emerge therefrom by way of said output transducer.

15. A delay line comprising a plurality of spaced surfaces bounding a compressional wave transmitting medium, a first surface portion of said surfaces having a signal input transducer coupled thereto for introducing a substantially directive beam of compressional wave energy propagating toward and reflecting successively from a plurality of areas of said spaced surfaces, said areas having a substantially greater coefficient of reflection than the portions of said surfaces surrounding said areas, and a signal output transducer coupled to a second surface portion of said surfaces and intercepting said beam successively reflected from said plurality of areas.

16. A delay line comprising a plurality of spaced surfaces bounding a compressional wave transmitting homogeneous body substantially devoid of intruding wave reflecting discontinuities throughout the entire internal volume thereof, one of said surfaces having an output transducer associated therewith, and predetermined areas integrated with other of said surfaces having a substantially greater coefficient of reflection than the portions of said surfaces surrounding said areas for causing a substantially directive beam of compressional waves to traverse said body a predetermined plurality number of times along substantially parallel paths and then emerge therefrom by way of said output transducers.

17. A delay line comprising a plurality of spaced surfaces bounding a compressional wave

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transmitting medium, a first surface portion of said surfaces having a signal input transducer coupled thereto for introducing a substantially directive beam of compressional wave energy propagating toward and reflecting successively from a plurality of areas of said spaced surfaces, said areas having a substantially greater coefficient of reflection than the portions of said surfaces surrounding said areas and said portions of said surfaces surrounding said areas having compressional wave energy absorbing means coupled thereto for absorbing energy at a substantially greater rate than said medium, and a signal output transducer coupled to a second surface portion of said surfaces and intercepting said beam successively reflected from said plurality of areas.

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