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ULTRASONIC DELAY LINE

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2 Sheets-Sheet 1

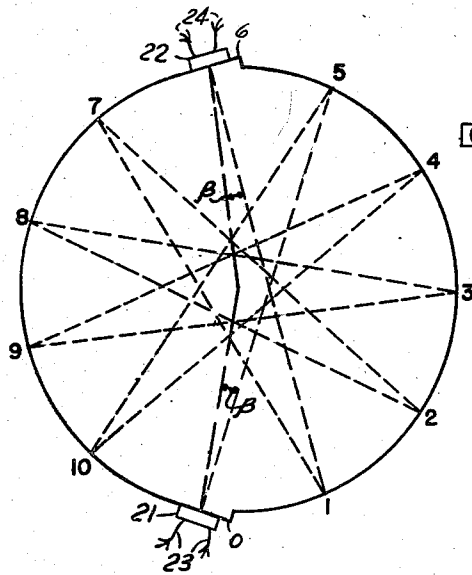


FIG. 1

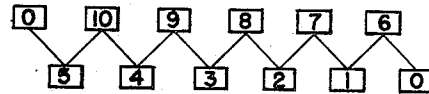


FIG. 2

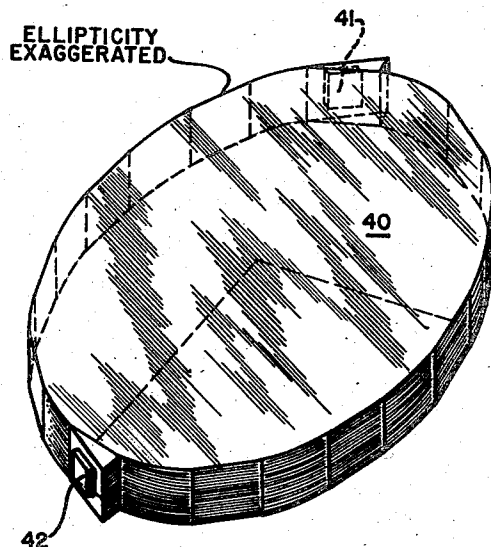


FIG. 6

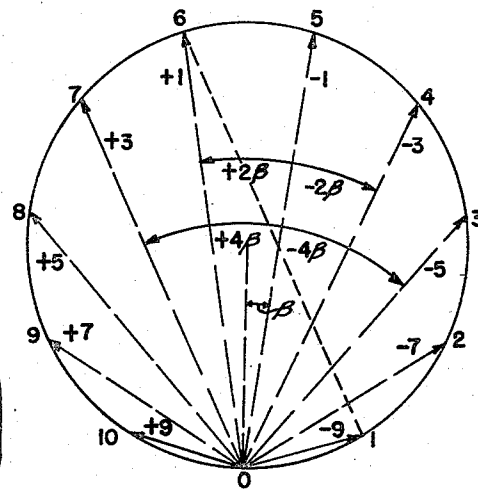


FIG. 5

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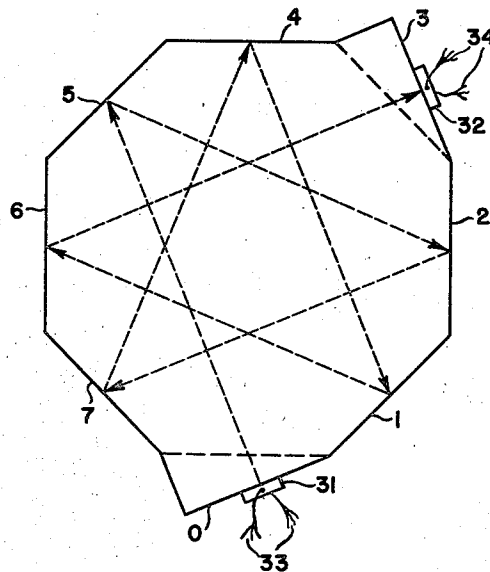


FIG. 3

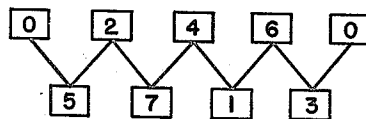


FIG. 4

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ULTRASONIC DELAY LINE

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This invention relates in general to the art of delaying in time, electrical signal transmission, and more particularly to improved ultrasonic delay lines employing multiple reflections of a directive acoustical beam.

In the electronics art, it is frequently desirable to delay signal transmission for periods of time ranging up to several milliseconds in duration. It is usually not feasible to employ electromagnetic delay lines for delays of these magnitudes. To attain a longer delay time than is possible with electromagnetic delay lines, various types of ultrasonic delay lines have come into general use. These ultrasonic delay lines operate as follows: The signals to be delayed a small, finite time are caused to modulate a high frequency signal. The frequency of the latter signal may be of the order of several megacycles per second. This modulated high frequency signal is converted to an acoustical (sound) signal which is made to traverse a given path as ultrasonic energy. At the end of this path, some or all of the acoustical energy is reconverted to electrical energy, amplified and detected to yield the original signal. The relatively low velocity of propagation of sound within the delay line results in longer delay times in this type than is possible with electromagnetic delay lines. The delay time in such an ultrasonic delay line is proportional to the total path length from the input to the output of the device. Even with the relatively low velocity of the propagation of sound, it frequently happens that the path length required is so great that it is difficult or impractical to construct a delay line having a single straight path from the input to the output. To reduce the over-all length of ultrasonic delay lines, for the longer delay times, tubes containing a liquid propagation medium have been arranged in various patterns with reflectors placed at the junctions of the tubes to direct the energy from one tube to another. Delay lines of this type have a relatively large size, are relatively difficult to construct, and are subject to leakage of the propagation medium. A second type of delay line using multiple reflection paths consists of a tank containing a liquid propagation medium with reflectors placed at certain points in the tank and in the path of the ultrasonic beam. These reflectors cause the ultrasonic beam to traverse the length and width of the tank a number of times before arriving at the output of the delay line. Delay lines of this type are also difficult to construct, are frequently unstable in their operation, and are apt to produce unwanted signals due to the fact that multiple reflections in the medium present alternative paths for the reflected beam. A third type of delay line using multiple reflection paths consists of either rectangular solids or rectangular forms containing liquid propagation mediums wherein a beam of energy is introduced at one corner of the rectangle and is directed at a point on the rectangle wall close to the corner opposite the point of introduction. Reflection of the beam takes place and a path is traced across the last-mentioned corner to another wall of the rectangle. A second reflection takes place at

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this point and the beam is reflected back to a point on a wall of the rectangle close to the corner where the beam originated. Successive reflections continue until the path traced by the beam comprises two series of parallel lines diagonally disposed across the rectangle, with one series of lines being perpendicular to the other series, the path terminating at a corner adjacent to the original corner in a suitable receiver. Delay lines of this type are said to have rectangular symmetry. The primary disadvantage of a rectangularly symmetrical design is that reflection must take place several times from any given wall of the structure to provide sufficient path length. For efficient use of the delaying medium, successive points of reflection on each wall must necessarily be closely spaced. Since the energy is not usually confinable to a beam of small diameter, dispersion often takes place, and the desired energy path is not followed by all of the energy. Those dispersed portions of the energy follow paths of greater and shorter length than the desired path. The ultimate result is that the major signal reaching the receiver is accompanied by several supernumerary signals caused by the energy which has traced paths other than the desired normal path.

A device which avoids the above-mentioned objections and difficulties has the reflecting points arranged in a circle. In one embodiment of this device a circular disk constructed of a suitable solid supersonic propagation medium is used. The circular disk has a number of facets ground on its periphery, the top and bottom surfaces being left flat. In general, the number of facets is uneven or a multiple of four.

Except for the first and last facets, on which generating and receiving transducers are mounted, all of the facets are alike and normal to the top and bottom disk surfaces and to radii of the structure. The first and last facets are maintained normal to the top and bottom surfaces of the disk but are slightly tilted from the normal to the radii of the disk. Thus, when energy is introduced to the transmitting crystal transducer, it is directed across the disk to a reflecting facet and subsequently reflected several times from other facets across the disk until it impinges on the receiving crystal transducer. Although the above-described device represents an improvement over the rectangular or square reflecting types of delay lines, secondary signals are still present which cause interference which becomes of importance when these signals arrive in phase at the receiver crystal and add vectorially. Such addition occurs because radiation from any facet, including the facet on which the transmitter crystal is mounted, can reach any other facet due to diffraction effects which are present because the energy beam does not obey purely geometric propagation. Thus, the possible paths of equal length are numerous and result in equally spaced secondary signals which are troublesome when they add to a level higher than that of the primary signal.

Therefore, it is an object of the present invention to prevent harmful interference in radially symmetrical delay lines.

A further object of the invention is to reduce the level of secondary signals in radial symmetrical delay lines.

An additional object is to inhibit vectorial addition of secondary signals.

In general, the present invention consists in the modification of a radially symmetrical delay line by the adjustment of the radii to the facets of the circular disk. Successive legs of the energy path are adjusted in such a manner as to effect a cancellation of secondary signals. For a better understanding of the invention, together with other and further objects, features, and advantages, reference should be made to the following description which

is to be read in connection with the accompanying drawings in which:

Fig. 1 is a schematic section view of a simple radially symmetrical delay line having an odd number of facets;

Fig. 2 is a block diagram useful in explaining the path of an energy beam propagated in the embodiment of Fig. 1;

Fig. 3 is a schematic sectional view of a radially symmetrical delay line having n sides, where n equals a multiple of 4;

Fig. 4 is a block diagram useful in explaining the path of an energy beam propagated in the embodiment of Fig. 3;

Fig. 5 is a diagrammatic representation of the diffraction pattern of an energy beam from a single facet of a radially symmetrical delay line of the type shown in Fig. 1;

Fig. 6 is a schematic perspective view of a preferred embodiment of the invention in which the ellipticity has been exaggerated for purposes of illustration.

Referring particularly to Fig. 1, there is schematically illustrated a radially symmetrical delay line consisting of a thin quartz disk ground flat on its top and bottom surfaces and having 11 facets cut on its periphery in series. In order to better illustrate its radial symmetry, the delay line is represented as a circular disk 20, and the facets which total an odd integer are represented by the numbers 0 through 10. In actual construction, of course, the delay line has a cross-sectional view similar to the view in Fig. 3, differing only in the number of facets cut on the periphery. Facet 0 has a crystal transducer 21 mounted thereon and is normal to the top and bottom disk surfaces but is cut at an angle β , which is equal to $90/n^\circ$, from the normal to the radius of disk 20, where n represents the total number of facets. Facet 6 is cut similarly to facet 0 and has a corresponding transducer 22 mounted thereon. The remaining facets 1 through 5 and 7 through 10 are ground normal to the top and bottom surfaces of disk 20 and normal to the radii of disk 20 extending thereto. Signals are applied to and received from transducers 21 and 22 by means of lead wires 23 and 24.

Thus, it may be seen that when energy is introduced to the crystal transducer 21 mounted on facet 0, an acoustical wave will be set up which will trace a path to facet 5 because of the tilting of facet 0. The energy impinging on facet 5 will be incident at an angle β , also equal to $90/n^\circ$, to a radius to facet 5, and will be reflected at an angle which is equal to the incident angle. The result is that a path will then be traced to facet 10. Another reflection similar to the first will occur at this facet and a path will be traced to facet 4. The process continues and a path is traced successively to facets 9, 3, 8, 2, 7, 1, and 6, as shown by the dashed lines of Fig. 1. Since facet 6 is tilted, as noted hereinabove, energy incident on that facet will be normal thereto and will be absorbed in exciting the transducer mounted on facet 6.

With particular reference to Fig. 2, the block diagram there illustrated constitutes a key to the terminology employed in describing the various possible modes of transmission in a radially symmetrical delay line. It may be seen that the striking sequence of the beam as illustrated in Fig. 1 follows the blocks from left to right and this mode of transmission is referred to as the -1 mode. If the block diagram were read from right to left with block 0 to the right of block 6 being considered the facet on which the transmitter is mounted, and an energy beam is directed at facet 6, eventually to reach facet 5, the receiver mounting facet, the mode of transmission would be referred to as the $+1$ mode. As noted herein-after similar terminology is used to identify all possible modes.

Fig. 3 schematically shows a radially symmetrical delay line 30 similar to the delay illustrated in Fig. 1 but having n equally spaced facets 0 through 7 ground on its periphery, n being a multiple of 4. All of the facets are

normal to the top and bottom disk surfaces, and all facets except 0 and 3 are ground normal to the radii of the disk. The facets 0 and 3 are cut at an angle equal to $90/n^\circ$ from the normal to the radius of disk 30, where n represents the total number of facets. Transducers 31 and 32 are mounted on facets 0 and 3, respectively. Signals are applied to and received from transducers 31 and 32 by means of lead wires 33 and 34. Thus it may be seen that if energy is introduced to crystal transducer 31 mounted on facet 0, an acoustical wave will be set up which will trace a path to facet 5 and will be reflected therefrom at an angle equal to the incident angle. The result is that a path will be traced to facet 2. Another reflection similar to the first will occur at this facet and a path will be traced to facet 7. The process continues and a path is traced successively to facets 4, 1, 6 and 3. Energy incident to facet 3 will be normal thereto and will be absorbed in exciting the transducer mounted on facet 3.

The block diagram of Fig. 4 is similar to the block diagram of Fig. 2 and shows the striking sequence of the beam as illustrated in Fig. 3. The striking sequence follows the blocks from left to right and this mode of transmission is referred to as the -1 mode. The last leg shown in Fig. 4, from facet 3 to 0, represents the path the beam would travel if facet 3 was not cut at an angle equal to $90/n^\circ$ from the normal to the radius.

Referring now to Fig. 5, the disadvantage of the delay line of Fig. 1 is graphically illustrated. Due to diffraction effects, radiation from any facet can reach any other facet; i. e., the beam does not obey purely geometrical propagation. The graphical analysis of the energy paths created by these diffraction effects discloses several interesting phenomena. Since the angle between the desired -1 mode and the diffracted beam proceeding in either the $+1$ or -3 modes is the same, these latter modes are equally intense and equally probable. A similar diffraction phenomenon can exist at any of the reflecting facets with the same probability. Fig. 5, for purposes of simplicity of illustration, indicates the effects at only one of the reflecting facets. To explain the illustration, consider that at first radiation from facet 0 goes in the $+1$ mode instead of the desired -1 mode and reaches facet 6. At facet 6 it may be reflected back to facet 1 and proceed in the $+1$ mode or be diffracted back to facet 0 and proceed in the -1 mode. If the latter occurs, the normal sequence in the -1 mode may then occur but the energy beam length and the time delay have thereby been increased by the two transits across the polygon. The angle of diffraction from the desired beam from facet 0 to facet 5 in the case of the $+1$ mode is $+\beta$ and in the case -3 mode, -2β . The intensity in each case has an absolute value of $1/f(2\beta)^2$ where $f(2\beta)$ is the amplitude of the diffracted beam as a function of the angle β , the angle of incidence previously referred to hereinabove. This $+\beta$ or -2β transition can occur at any facet in the sequence, not only at the transmitter, but in ten places in all. In each case the path length is increased by the same amount if all the radii or distances from the center are the same. Hence, the ten independent diffraction signals, while independently weak, may arrive in phase at the receiver and give a signal 20 db higher than an individual signal.

If the diffracted beam had continued in the $+1$ mode for another leg of the energy path before converting back to the -1 mode, the transition would still involve $+\beta$ or -2β diffraction pattern but would be longer by four transits rather than two. There are still ten points for this to occur.

By continuing the number of legs in the $+1$ mode before conversion, we can account for the regularly spaced signals, 2, 4, 6, 8, 10, 12, . . . transits after the main delayed signal.

If we consider the -2β diffraction as occurring rather than the $+\beta$, the beam instead of proceeding in the

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desired -1 mode goes into the -3 mode. It can continue in this mode and eventually strike the receiver, but of course not at normal incidence so that the signal will be very weak and need not be considered. The diffracted beam at facet 4 can however be diffracted or converted back to -1 or -5 modes. If the former occurs, the beam can proceed from facet 4 to facet 9 and thence to the receiver in the normal manner but the path will be shortened by the two legs of the path not traversed, namely from facet 0 to facet 5 and facet 5 to facet 10 (the difference between the legs from facet 0 to facet 4 in the -3 mode and from facet 10 to facet 4 in the -1 mode may be negligible). This -2β , $+2\beta$ diffraction pattern can occur at 9 different points and always will result in a path shortened by 2 transits. Hence, if the radii to the flats of the delay line are all the same, the delayed diffracted signals may all arrive in phase and add vectorially to give an effect 18 db greater than the individual ones. In like manner, we may account for the signals that occur 4, 6, 8, 10 . . . legs before the main one by assuming that 1, 2, 3, 4 . . . legs in the -3 mode occurs before the conversion back to -1 is made.

Fig. 6 illustrates an embodiment of the present invention for remedying such combined diffracted signals as described above. No change from the usual radially symmetrical line is apparent to the eye, but for purposes of illustration, Fig. 6 is an exaggerated view in that the structure of the radial line is made clearly elliptical to indicate that the lengths of radii of the structure are adjusted so that the difference in length of successive legs of the energy path of the beam is $\pm \frac{1}{2}$ wave length at the frequency of operation of the piezo-electric transducers 41 and 42. The method employed for accomplishing this difference is to progressively increase, then decrease the radii in steps of $\frac{1}{2}$ wave length. As noted above, such an adjustment in radii lengths results in a structure which has a slightly elliptical rather than circular appearance, which, although it is not noticeable to the eye, causes signals of the combinations discussed in reference to Fig. 3 to be reduced to the point of negligibility.

Since the change in structure due to adjustment in radii lengths is not perceptible to the naked eye, Figs. 1 and 3, for all practical purposes, are illustrative of the elliptical delay lines of the present invention as well as delay lines which are in fact radially symmetrical and over which the present invention is an improvement.

A typical line employing 15 megacycle crystals for transducers and having 33 facets ground thereon is radially dimensioned as shown in the following table:

Facet No.	Radius, inches	Facet No.	Radius, inches
0.....	2.59775	17.....	2.58100
1.....	2.59775	18.....	2.59100
2.....	2.58850	19.....	2.59775
3.....	2.58725	20.....	2.58850
4.....	2.58600	21.....	2.58725
5.....	2.58475	22.....	2.58600
6.....	2.58350	23.....	2.58475
7.....	2.58225	24.....	2.58225
8.....	2.58100	25.....	2.58100
9.....	2.58225	26.....	2.58225
10.....	2.58350	27.....	2.58475
11.....	2.58475	28.....	2.58600
12.....	2.58600	29.....	2.58725
13.....	2.58725	30.....	2.58850
14.....	2.58850	31.....	2.58975
15.....	2.58975	32.....	2.59100
16.....	2.58200		

NOTE.—Facets 0 and 1 are the transmitting and receiving crystal positions. Delay time approx. 1,000 micro sec.

In this delay line the path from facet 1 to facet 17 is not used and for this reason facet 17 may be left uncut. This places the receiving crystal adjacent the transmitting crystal and well out of the path of any diffracted energy proceeding directly from the transmitting crystal.

While what has been disclosed is at present considered the preferred embodiment of the invention, numerous

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changes apparent to those skilled in the art may be made without departing from the scope of the invention as sought to be defined in the appended claims.

The invention described herein may be manufactured and used by or for the Government of the United States of America for Government purposes without the payment of royalty thereon or therefor.

What is claimed is:

1. A delay line for delaying in time an ultrasonic signal comprising, a flat disc of quartz having a plurality of facets ground on the periphery thereof, means for introducing a signal into said delay line in such a direction that said signal is reflected successively from said facets in a predetermined sequence, said disc being of a slightly elliptical shape whereby successive legs of the reflection path of said signal progressively increase by fractions of a wave length of said signal and then progressively decrease by fractions of a wave length of said signal.

2. An ultrasonic delay line comprising, a solid propagation medium having an elliptical periphery, first and second electrical transducers, said transducers being mounted in contact with the periphery of said medium, means for electrically energizing said first transducer whereby a beam of acoustical energy is directed through said medium, a plurality of means for successively reflecting said beam from the periphery of said medium until said beam impinges on said second transducer, said last-mentioned means being so spaced that the path lengths between successive reflecting points differ by a fraction of a wave length of said acoustical energy, and means for extracting electrical energy from said second transducer upon the excitation of said second transducer by said beam.

3. An ultrasonic delay line comprising, a propagation medium in the form of a circular disc, means for producing and directing a beam of acoustical energy along a chord other than the diameter of said circular disc, a plurality of means for reflecting said beam along similar chords of said circular disc, said chords differing in length by a fraction of a wave length of said acoustical energy, and means for receiving said beam of acoustical energy.

4. An ultrasonic delay line comprising, a propagation medium of fused quartz in the form of a circular disc having a plurality of facets ground on the edge thereof, means for introducing ultrasonic energy unto said disc at one of said facets in such a direction that said energy is successively reflected by each of said facets, successive legs of the path taken by said energy beam differing in length.

5. An ultrasonic delay line comprising, a flat disc of fused quartz having n equally spaced facets ground on the edge thereof, n being an odd integer, said facets all lying in planes normal to the top and bottom surfaces of said disc, all but the first and the n th of said facets lying in planes perpendicular to the radii of said disc which extend thereto, said first facet and said n th facet lying in planes at an angle of $90/n^\circ$ to the radii of said disc which extend thereto, first and second crystal transducers, said first crystal transducer being mounted on said first facet for directing an ultrasonic wave substantially across said disc to a second of said facets, said second facet reflecting said ultrasonic wave substantially across said disc to a third of said facets, similar reflections continuing successively until said ultrasonic wave impinges on said n th facet, successive paths between said facets being of unequal lengths, and means connected to said second crystal transducer for removing electrical energy therefrom.

6. An ultrasonic delay line comprising, a flat disc of fused quartz having n equally spaced facets ground on the edge thereof, n being a multiple of 4, said facets all lying in planes normal to the top and bottom surfaces of said disc, all but the first and the n th of said facets lying

in planes perpendicular to the radii of said disc which extend thereto, said first facet and said n th facet lying in planes at an angle of $90/n^\circ$ to the radii of said disc which extend thereto, first and second crystal transducers, said first crystal transducer being mounted on said first facet for directing an ultrasonic wave substantially across said disc to a second of said facets, said second facet reflecting said ultrasonic wave substantially across said disc to a third of said facets, similar reflections continuing successively until said ultrasonic wave impinges on said n th facet, successive paths between said facets being of unequal lengths, and means connected to said second crystal transducer for removing electrical energy therefrom.

7. A delay line adapted to delay in time an ultrasonic energy beam comprising, a propagation medium having a plurality of reflection surfaces arranged approximately in a circle from which said beam is caused to be successively reflected in a predetermined sequence, said reflection surfaces being arranged to provide successive beam paths between reflection surfaces of different lengths.

8. A delay line adapted to delay in time an ultrasonic energy beam comprising, a propagation medium having a plurality of reflection surfaces arranged approximately in a circle from which said beam is caused to be successively reflected in a predetermined sequence, said reflection surfaces being arranged to provide successive beam paths between reflection surfaces differing in lengths by a fraction of a wave length of said ultrasonic energy beam.

9. A delay line adapted to delay in time an ultrasonic energy beam comprising, a supersonic propagation medium having a plurality of reflection surfaces arranged approximately in a circle from which said beam is caused to be successively reflected within said medium in a predetermined sequence, selected ones of said reflection surfaces being radially displaced from a true circle by a multiple of a small fraction of a wave length of said ultrasonic energy beam.

10. An ultrasonic delay line comprising, a flat disc

of fused quartz having n equally spaced facets formed on the edge thereof, n being an odd integer, said facets all lying in planes normal to the top and bottom surfaces of said disc, all but the first and the n th of said facets lying in planes perpendicular to the radii of said disc which extend thereto, said first facet and said n th facet lying in planes at an angle of $90/n^\circ$ to the radii of said disc which extend thereto, first and second crystal transducers, said first crystal transducer being mounted on said first facet for directing an ultrasonic wave substantially across said disc to a second of said facets, said second facet reflecting said ultrasonic wave substantially across said disc to a third of said facets, similar reflections continuing successively until said ultrasonic wave impinges on the n th facet, the radii to selected facets differing from the radii of other facets by multiples of a small fraction of a wave length of said ultrasonic wave, and means connected to said second crystal transducer for removing electrical energy therefrom.

11. A solid delay line adapted to delay in time an ultrasonic energy beam comprising, a supersonic propagation medium having a plurality of reflection facets elliptically arranged from which said beams is caused to be successively reflected in a predetermined sequence, selected ones of said reflection facets being so arranged that their radii differ in length by a fraction of a wave length of said ultrasonic energy beam.

12. A solid delay line of the type defined by claim 11 wherein the number of facets is an odd integer.

13. A solid delay line of the type defined in claim 11 wherein the number of facets is equal to a multiple of 4.

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