June 26, 1951 J. STAR 2,558,012

DELAY LINE

Filed March 27, 1948

Fig. 1

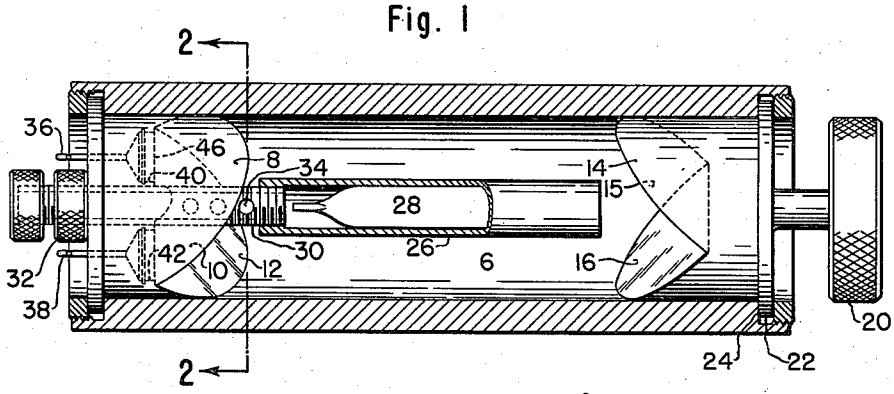


Fig. 2

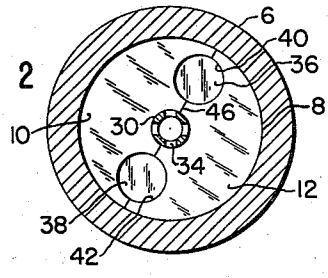


Fig. 3

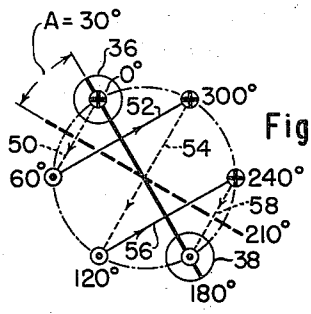


Fig. 4

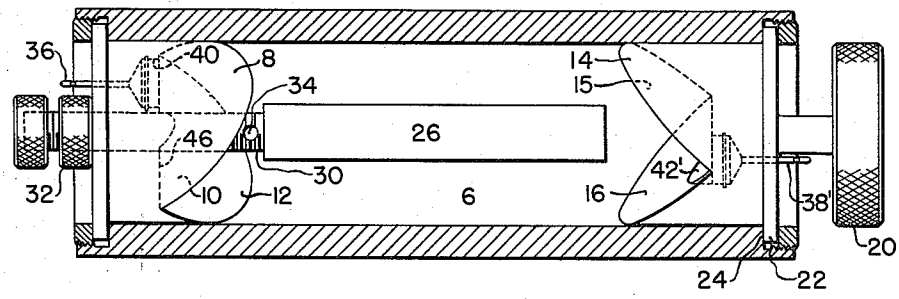
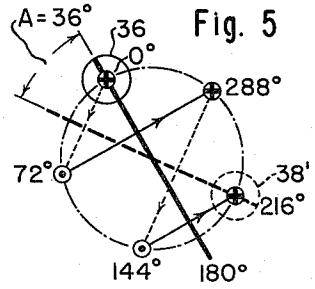


Fig. 5



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DELAY LINE

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3 Claims. (Cl. 178—44)

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The present invention relates to delay lines and more particularly to sonic delay lines in which the delay is represented by the time necessary for propagation of a sound wave through a liquid.

Such delay lines are useful in connection with radio signaling and radar equipment. When a definite delay is to be introduced it has been found most effective to introduce it sonically. To this end the signal is converted by means of a suitable transducer to sound energy which is then propagated through a liquid, preferably mercury, in a path of definite length. The sound energy is picked up on a second transducer and reconverted to an electrical signal at the required frequency.

This type of equipment has been found entirely satisfactory for delay times of fixed magnitude. When a variation of delay time is required it has sometimes been accomplished by means of a movable plunger. This type of variable delay line has however proved unsatisfactory because of the problems introduced by the resulting displacement of the mercury.

The principal object of the present invention is to provide a delay line in which the delay time can be changed in a simple and convenient manner.

To this end the present invention contemplates the use of multiple corner reflectors arranged at variable angles whereby the number of paths of transmission through the liquid may be varied. This permits a variation of the delay time in discrete steps as will hereinafter appear.

Other features of the invention consist of certain novel features of construction, combinations, and arrangements of parts hereinafter described and particularly defined in the claims.

In the accompanying drawings Fig. 1 is a sectional elevation of the preferred form of invention; Fig. 2 is a section on line 2—2 of Fig. 1; Fig. 3 is a diagram illustrating the operation of the apparatus; Fig. 4 is a sectional elevation of a modified form of apparatus; and Fig. 5 is a diagram illustrating the operation of the apparatus of Fig. 4.

The illustrated embodiment of the invention comprises a chamber 6 having at one end an accurately formed metal reflector 8 having internal reflecting surfaces 10 and 12. The planes

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10 and 12 are precisely perpendicular to each other.

At the other end of the apparatus is a similar corner reflector 14 likewise having mutually perpendicular surfaces 15 and 16. The reflector 14 is adapted for rotation in the casing which may be effected by any suitable means here indicated as a manual knob 20. The block is accurately machined to form a liquid-tight seal, and may be provided with a flange 22 seating against a shoulder 24 in the casing.

In the center of the cylinder 6 is a tube 26 containing an inflated rubber bag 28 which accommodates changes in the volume of mercury due to expansion and contraction under changes of temperature. The tube 26, as will be understood by those skilled in this art, is suitably mounted on a supporting tube 30 which is threaded through the corner reflector 8 and is secured externally of the device by a locknut 32. Suitable openings 34 in the tubes 30 permit the entrance of liquid into the compensating tube 26.

The apparatus is provided with two electroacoustic transducers indicated at 36 and 38 in Fig. 1. The transducers are preferably piezoelectric crystals adapted to convert high frequency electrical energy into sound energy or the reverse. As shown in Figs. 1 and 2 the two transducers are mounted at one end of the apparatus and are aligned with holes 40 and 42 respectively in the corner reflector 8. As here shown the two transducers are diametrically opposite and their centers are on the axis of the reflector, namely, the apex line 46 of the V formed by the intersection surfaces 10 and 12. As will be shown later other relative arrangements of the transducers may be used.

The operation will now be described. First, it must be kept in mind that in view of the perpendicular reflecting surfaces of the two blocks, all reflections occur at right angles to the direction of impingement and also at right angles to the direction of the axis of the block. In Fig. 3 is shown a diagram of the situation wherein the axis of the movable block 14 is at an angle of 30° with respect to the axis of the fixed block 8. Assuming that the transducer 36 is the transmitting transducer, namely the one which converts electrical energy into sound energy, and the transducer 38 is the one which

reconverts sound energy into electrical energy, sound rays emitted at 36 travel down through the mercury to the corner reflector at the opposite end. This direction of movement is indicated in Fig. 3 by a cross within a circle. At the opposite end of the apparatus the sound is reflected in the direction indicated by the dotted line 50, this line being perpendicular to the axis of the movable block 14. This direction 50 is determined by the fact that the ray strikes one face, say the face 15, of the movable block and is reflected over to the face 16 thereof, and is then reflected from the latter face, from which it comes back up through the mercury to impinge on the surface of the fixed block at an angle of 60° from the starting point. The path upward through the mercury is indicated by a dot within a circle. The next reflection occurs perpendicular to the axis of the fixed block as represented by the solid line 52. There follow another "downward" passage through the liquid at 300°, a reflection at the movable block along the dotted line 54, an "upward" passage at 120°, a reflection 56, a downward passage at 240°, another reflection 58 and a final upward passage at 180° to impinge directly on the transducer 38. Thus there are six longitudinal paths through the liquid. It will be noted that in this case, and also in general, the ends of the paths all lie in a circle, the radius of which is the distance from the center to either transducer.

In general, if the angle between the reflector axes is A, the points of successive impingement on the fixed block progress by an angle of 2A. The relation between the angle and the number of paths is expressed by the following equation:

$$nA=180°$$

where n is restricted to even integers.

The number of paths may be varied in discrete steps of two paths per step. For example, in apparatus having a delay of 100 microseconds per path, the delay may be varied from 200 microseconds up to the longest time for which the reflected beams remain distinct. At high frequencies the beams are very narrow, and there is no difficulty in operating over twenty or thirty paths in apparatus of reasonable size.

In the modified form of apparatus shown in Fig. 4, one transducer 36 is placed at one end of the apparatus in the fixed block and the other transducer 38′ is placed at the opposite end of the apparatus in the movable block. This provides an odd number of paths as indicated in Fig. 5. A ray may be considered to enter the fixed block from the transducer 36 and undergo multiple reflections at the corner reflectors. As in Fig. 3, it will be seen that if the axis of the movable block is arranged at an angle A from the axis of the fixed block, the points of reflection from the fixed block move progressively in steps of 2A. The equation connecting the angle and number of paths is likewise

$$nA=180°$$

but n is now restricted to odd integers. In Fig. 5, $n=5$ and $A=36°$. Thus, the angle A may be determined to give any desired odd number of paths. For apparatus in which a single path is 100 microseconds, the delay may be varied from 100 to, say, 2100 microseconds in steps of 200 microseconds.

The construction herein shown is simpler and more reliable than variable delay lines in which movable plungers are used. In the first place, there is no problem arising from the resultant displacement of mercury since the only displacement is that which occurs within the V formed by the surfaces of the movable block itself. Furthermore, the apparatus requires only a rotary seal as distinguished from a sliding seal which is more difficult to construct. The surfaces between the rotary block and the casing may be carefully ground and such surfaces are adequate for sealing mercury. The actual operation of the device may be handled in a suitable manner which will be apparent to those skilled in the art.

The invention has been described for a delay line in which the transducers are arranged in the axes of the corner reflectors, and in the case of Fig. 1, at diametrically opposite points. These arrangements give rise to a particularly simple geometry of reflection paths, but these arrangements are not essential. Thus, the transducers may be disposed at points not on the axes of the reflectors, even though it is difficult to set up a general equation in such cases. Furthermore, certain values of n may be excluded in special cases, as for example, where the center of a ray strikes the axis of one reflector and thus prevents complete passage of the ray from one transducer to the other. For these and similar reasons, the constructions herein shown, while not essential, are preferred.

Having thus described the invention, I claim:

1. A sonic delay line comprising a liquid-filled chamber, two corner reflectors, one at each end of the chamber, each reflector having two mutually perpendicular plane reflecting surfaces intersecting in an axis, an electro-acoustical transducer to generate a sonic ray and direct it against one of the reflectors, the reflectors facing each other with their axes displaced by a submultiple of 180° to cause the ray to follow multiple paths through the liquid, and a second transducer to receive the reflected sonic energy and convert it into electrical energy, the reflectors being relatively adjustable to change the angle A between the axes of the reflectors, whereby the number n of discrete paths of travel of the ray through the liquid is related to the angle A by the expression $nA=180°$, where n is an integer.

2. A sonic delay line comprising a liquid-filled chamber, two corner reflectors, one at each end of the chamber, each reflector having two mutually perpendicular plane reflecting surfaces intersecting in an axis, an electro-acoustical transducer disposed in the axis of one reflector to generate a sonic ray and direct it against the other reflector, the reflectors facing each other with their axes displaced by a submultiple of 180° to cause the ray to follow multiple paths through the liquid, and a second transducer disposed in the axis of the other reflector to receive the reflected sonic energy and convert it into electrical energy, the reflectors being relatively adjustable to change the angle A between the axes of the reflectors, whereby the relation between the angle A and the number n of discrete paths through the liquid is expressed by $nA=180°$, where n is restricted to odd integers.

3. A sonic delay line comprising a liquid-filled chamber, two corner reflectors, one at each end of the chamber, each reflector having two mutually perpendicular plane reflecting surfaces intersecting in an axis, an electro-acoustical transducer disposed in the axis of one reflector to generate a sonic ray and direct it against the other reflector, the reflectors facing each other with their axes displaced by a submultiple of 180° to

cause the ray to follow multiple paths through the liquid, and a second transducer disposed in the axis of the same reflector as the first transducer to receive the reflected sonic energy and convert it into electrical energy, the reflectors being relatively adjustable to change the angle A between the axes of the reflectors, whereby the relation between the angle A and the number n of discrete paths through the liquid is expressed by $nA=180°$, where n is restricted to even integers.

JOSEPH STAR.

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