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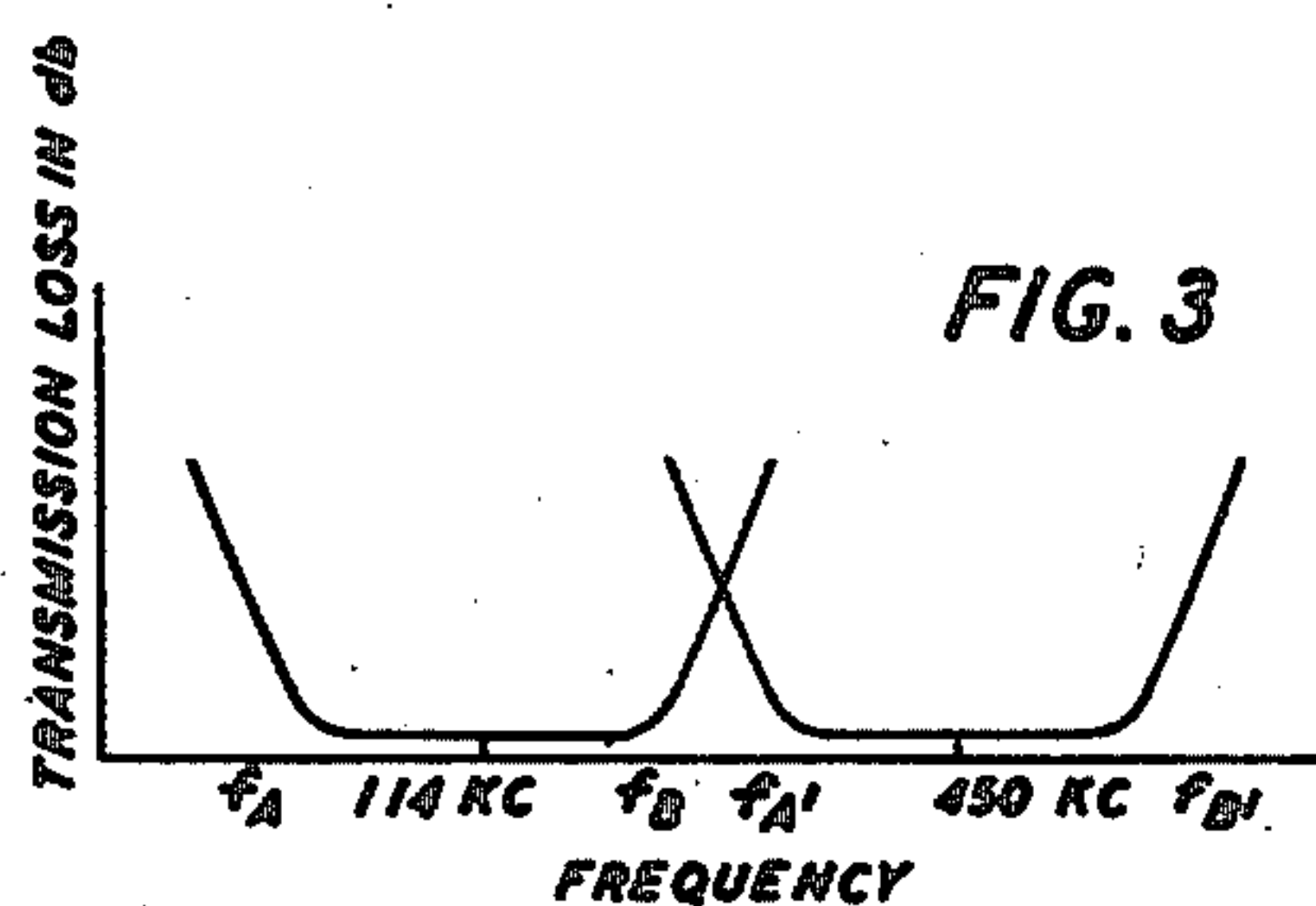
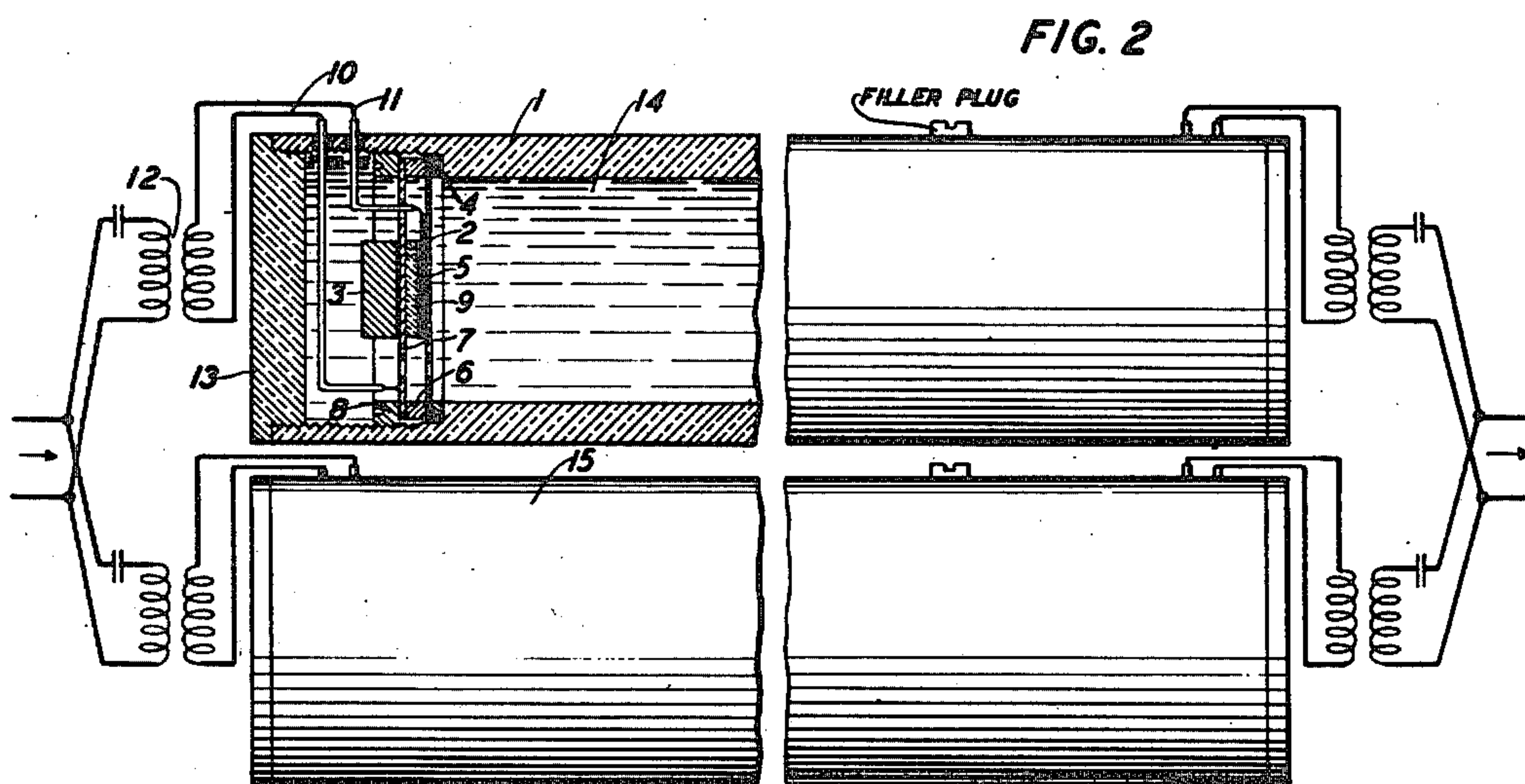
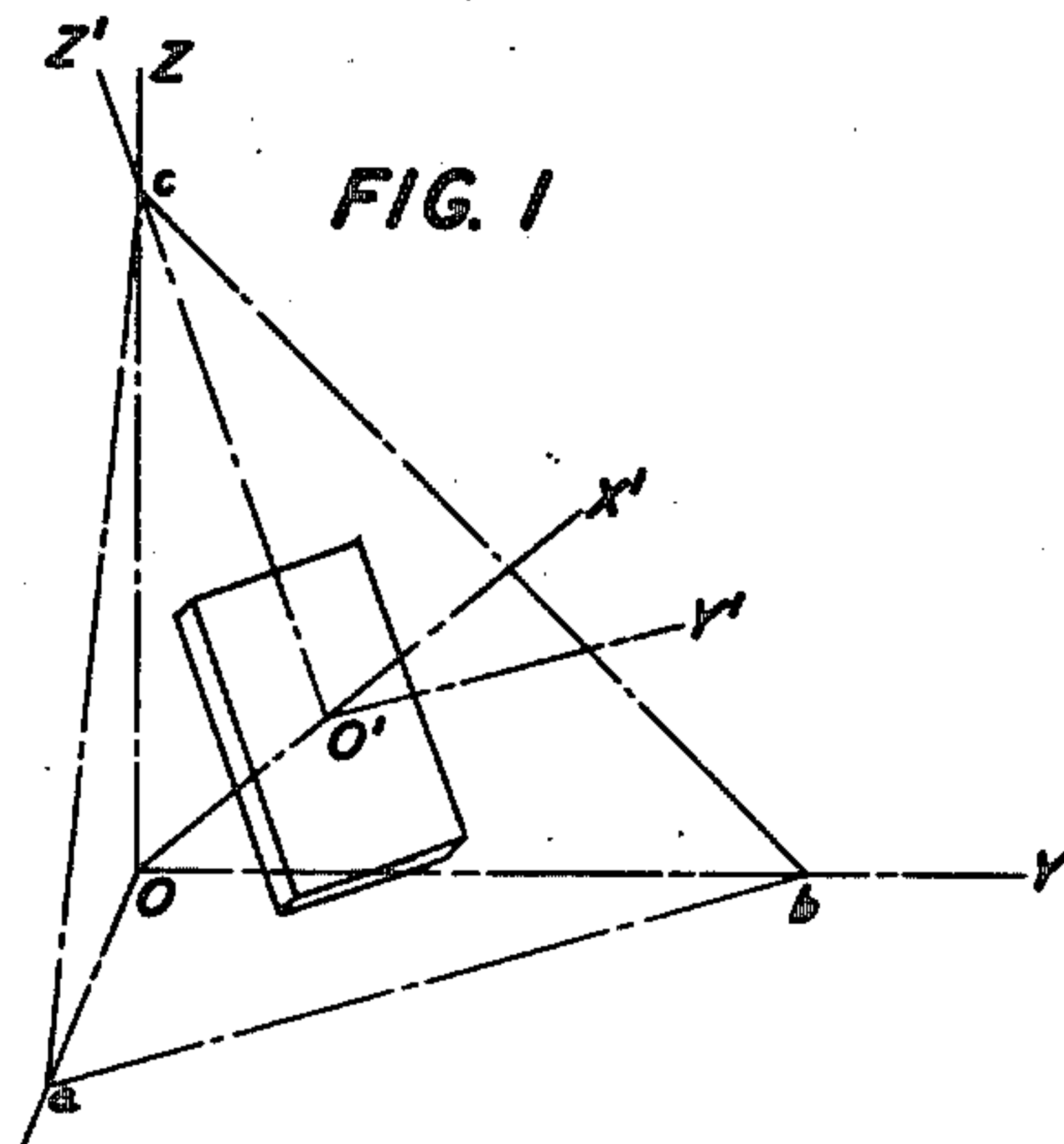
J. A. HALL ET AL

2,421,026

DELAY DEVICE

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2 Sheets-Sheet 1



J. A. HALL
INVENTORS W. P. MASON
BY *M. R. McKenney*
ATTORNEY

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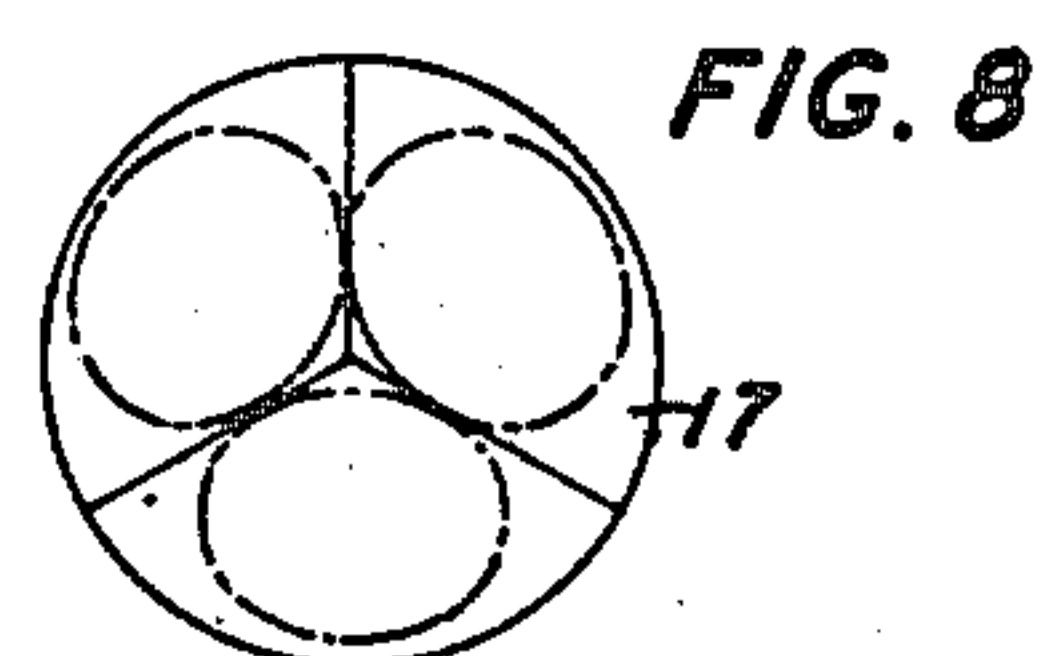
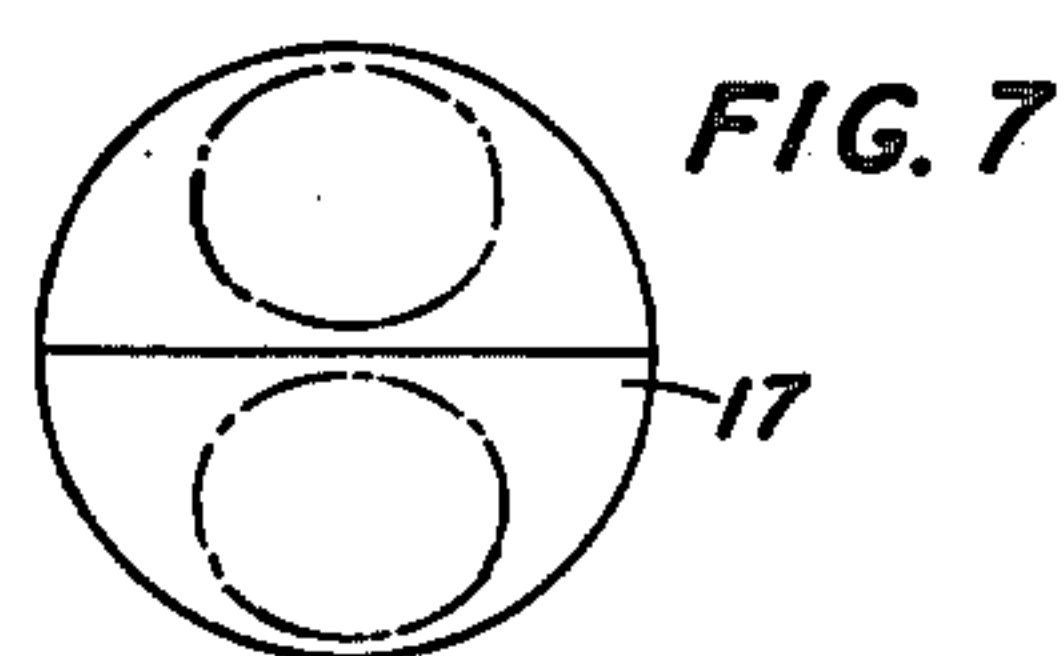
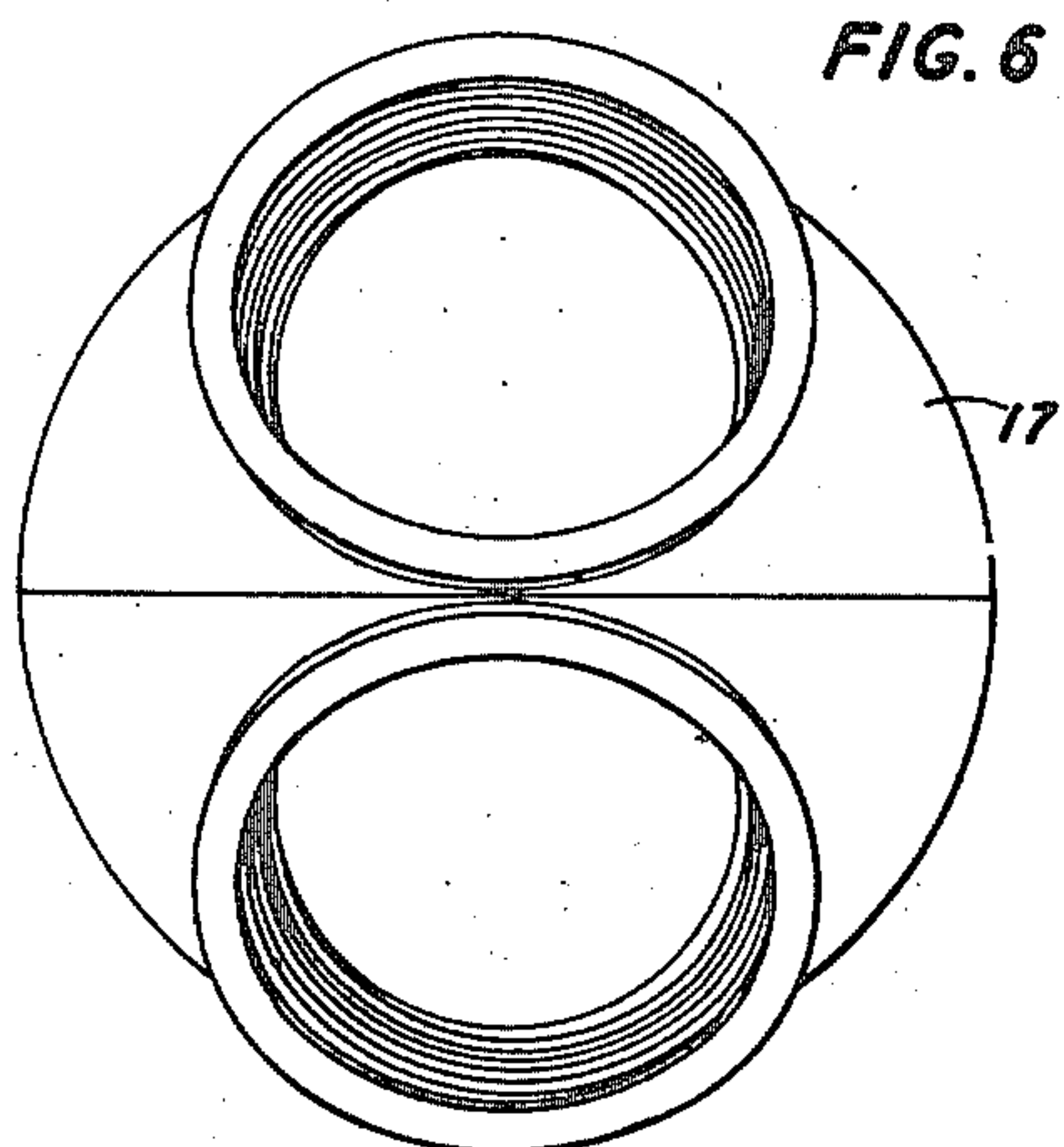
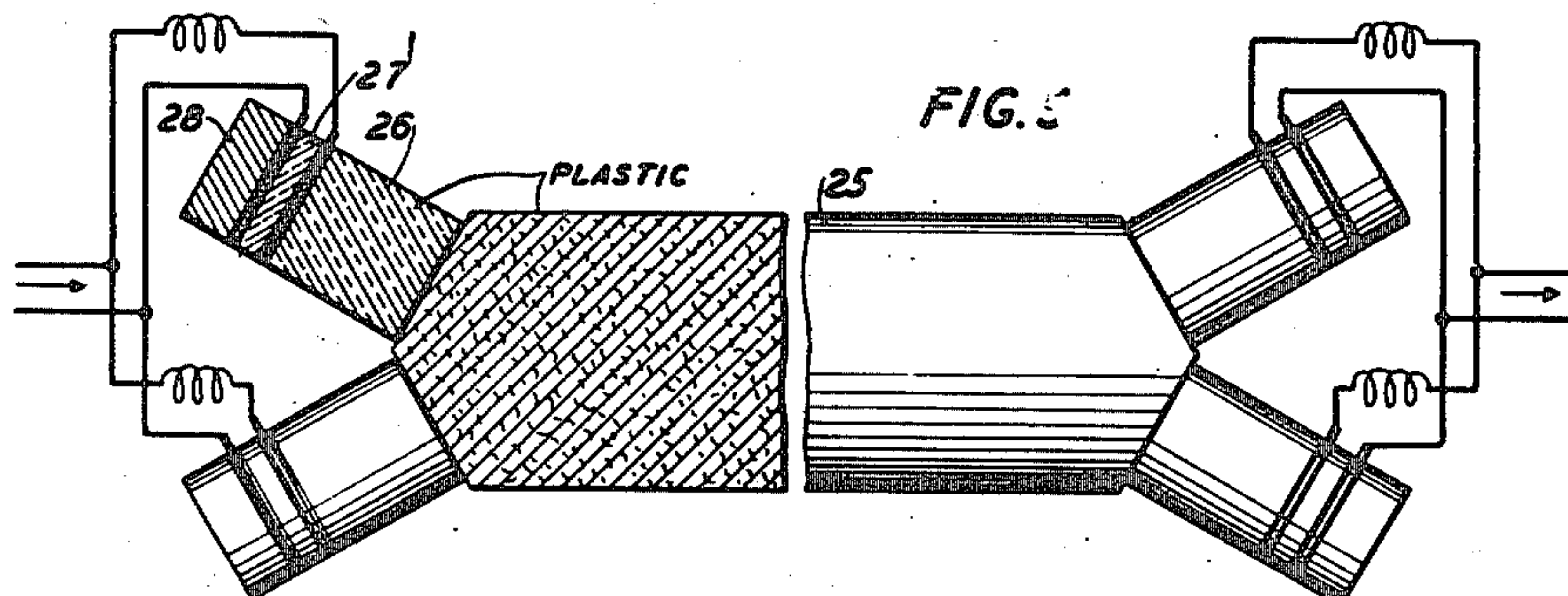
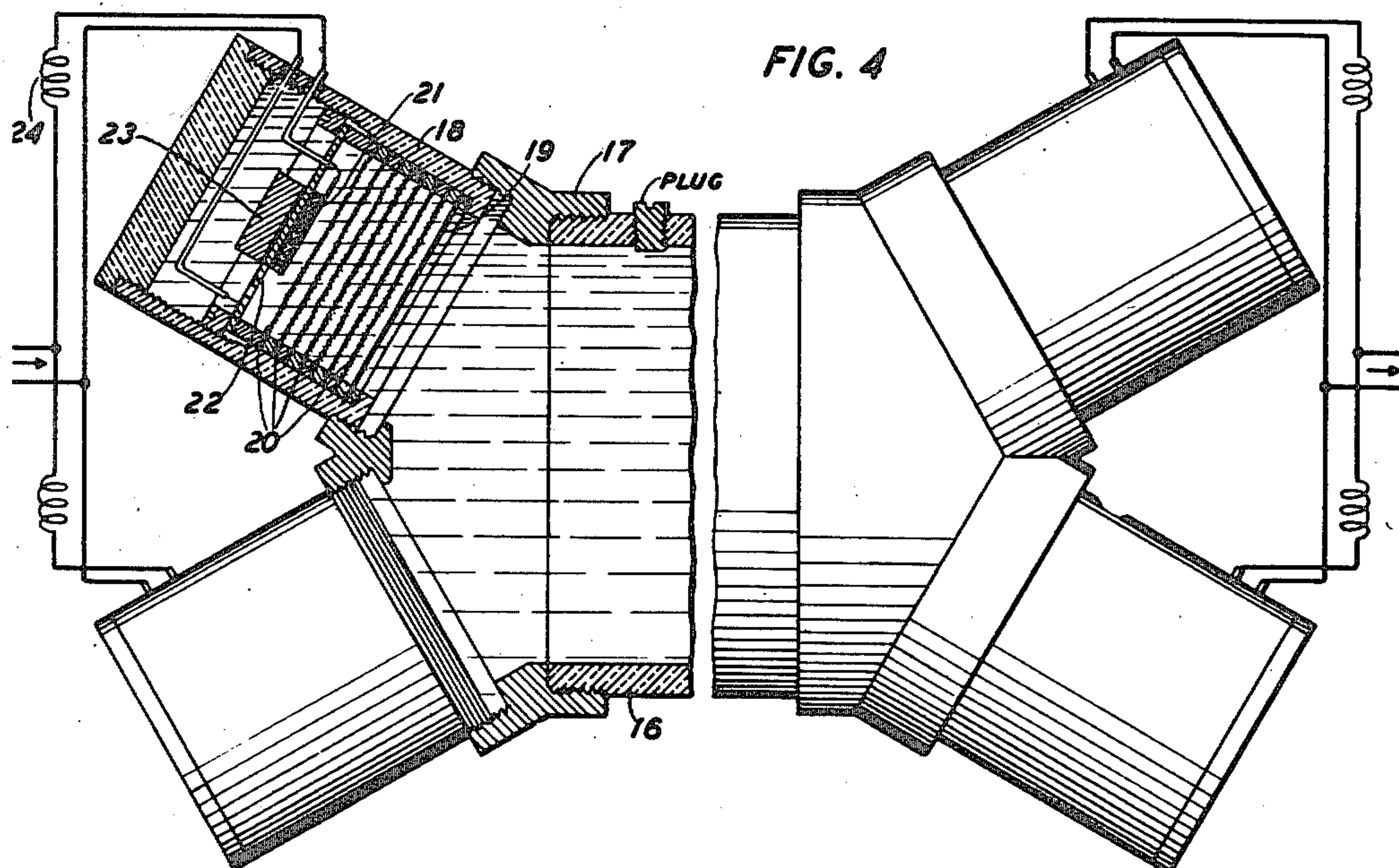
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DELAY DEVICE

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2 Sheets-Sheet 2



INVENTORS J.A. HALL
W.P. MASON

BY

M.R. McKenney

ATTORNEY:

UNITED STATES PATENT OFFICE

2,421,026

DELAY DEVICE

John A. Hall, Summit, and Warren P. Mason,
West Orange, N. J., assignors to Bell Telephone
Laboratories, Incorporated, New York, N. Y., a
corporation of New York

Application July 8, 1943, Serial No. 493,856

8 Claims. (Cl. 178—44)

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This invention relates to electrical delay circuits consisting generally of a pair of electromechanical transducers working through a link of material which will transmit mechanical vibrations at a constant and given rate.

The object of the invention is to produce a wide band delay circuit in the ultrasonic range. A secondary object is to produce such a device in a size and shape comparable to that of like apparatus of a lower range. Where electromechanical transducers in the form of piezoelectric crystals are employed the range is generally narrow and this becomes more pronounced as the frequency range is raised. Where it is desired to work in the ultrasonic region the tuning of the crystals ordinarily employed is so sharp that it is sometimes necessary to use several crystals with overlapping characteristics. However, where a very wide band is desired the number of crystals which must be employed becomes unduly large with a consequent increase in size of the two transducers.

In accordance with the present invention a wide band delay device is produced by constructing the transducers of a longitudinally vibrating crystal having an uncommonly wide range in itself so that the number of such crystals with overlapping characteristics which must be employed where a wider band is required than is provided by a single crystal, is materially reduced. Specifically, a crystal of Rochelle salt cut in such a manner that a line normal to its face makes equal angles with each of the three crystallographic axes is employed. Such a crystal, known as an L-cut crystal, produces a longitudinal vibration, that is a mechanical vibration in the direction in which the electrical force is applied.

Such a crystal will work at high frequencies while still of a convenient size and shape. Since its vibrations are longitudinal it is well adapted to use in a high frequency transducer.

Further, in accordance with the present invention and an important feature thereof is the use of a single mechanical link between several pairs of transducers each of a different frequency band. With overlapping characteristics each pair of transducers performs its function within its own field and the single mechanical link functions as a common mechanical transmission path therebetween.

Another feature of the present invention is the use of a low velocity medium as a mechanical link whereby the mechanical length thereof may be kept as short as possible. In one embodiment of the invention, a low velocity liquid is employed, while in another, a loaded plastic is used.

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Another feature of the invention is the use of attenuators incorporated in the separate legs of the mechanical link to prevent interference and reflections between the transducers in the different frequency bands.

Other features will appear hereinafter.

The drawings consist of two sheets having figures, as follows:

Fig. 1 is a geometrical diagram showing the relation of the faces of the crystal employed to the main crystallographic axes;

Fig. 2 is a diagram partly schematic and a partly broken away mechanical section showing how a pair of delay devices having overlapping characteristics may be connected into a single circuit to provide a wide band delay element;

Fig. 3 is a graph showing the overlapping characteristics of two delay devices;

Fig. 4 is a view similar to that of Fig. 2 showing how a single column of liquid may be used in common by two pairs of transducers;

Fig. 5 is a similar view showing a similar construction wherein a plastic is employed as the mechanical link between the several transducers;

Fig. 6 is an end view of the fitting which may be employed at the end of the liquid container of Fig. 4;

Fig. 7 is an end view of a plastic column as in Fig. 5, indicating the relation of the abutting faces of the various plastic parts, and

Fig. 8 is a similar view showing how a large number of transducers may be affixed to a plastic column where a still wider band device is desired.

It is known that the Rochelle salt crystal cut in such manner that a line normal to its principal face makes equal angles ($54^{\circ}44'$) with each of the major crystallographic axes will produce a longitudinal vibration, that is, a mechanical vibration in the direction in which the electrical field is applied. This is known as an L-cut crystal. Reference is made to an article entitled "The longitudinal piezoelectric effect in Rochelle-salt crystals" by Walter G. Cady in the Proceedings of the Physical Society, volume 49, part 6, November 1, 1937.

It is furthermore known that electrical apparatus of wide band characteristics may be produced by the multiple use of a plurality of components having overlapping characteristics. In this connection reference is made to application, Serial No. 407,456, filed August 19, 1941, by Bond and Mason for improvements in Piezoelectric vibrators.

It is the object of the present invention to produce a time delay device in the ultrasonic field;

by way of example, a device which will transmit a uniform band from 50 kilocycles to 750 kilocycles and which will introduce a delay which may be measured in microseconds.

The L-cut crystal is shown in Fig. 1, its principal face being in a plane, the traces of whose intersection with the three principal reference planes form an equilateral triangle *abc*. The X' axis of the cut crystal forms equal angles with the electrical, mechanical and optical axes of the mother crystal. Such a crystal produces a thickness vibration, and measurement of these crystals shows that a ratio of capacities of two to one can be obtained. Using this crystal alone with a ceramic wafer glued to the crystal and wedged to a steel backing plate and with the crystal coupled through a tuned transformer, a band width of 2.62 to 1 is possible. By combining two or more such crystals in parallel the band can be widened to any desired extent. As shown in Fig. 2, this may be accomplished by using two crystals in parallel connected together through tuned transformers. Each one would cover a 2.62 to 1 range. If the lower edges are separated by a ratio $FA'/FA=4.0$, as indicated in Fig. 3, so that the average points are three decibels or higher, a range of 10.5 to 1 can be transmitted with good efficiency. Calling $FA=70$ kilocycles, this gives $FB'=750$ kilocycles. Since the loss does not rise rapidly above the upper cut-off or below the lower cut-off a uniform transmission is obtained from 50 to 800 kilocycles.

The delay devices of Fig. 2 may be constructed of a tube 1 of suitable material such as metal, glass, plastic or other material having the necessary rigidity. Into each end may be assembled an electromechanical transducer comprising essentially an L-cut crystal 2 and its backing resonator 3. One method of assembly is shown to consist of the placement of a washer 4, a thin rubber diaphragm 5, another washer 6, a mounting disc 7, and an externally threaded nut 8 cooperating with the internally threaded portion of the body 1. The mounting disc 7 may be of conducting material and thus form one terminal of the crystal 2 and the other terminal may be formed of a plate of foil or thin sheet metal 9. Terminal wires 10 and 11 may be soldered to the disc 7 and the foil 9 respectively, and brought out in any convenient manner where they may be connected to a transformer 12. The mounting disc and the diaphragm 5 may be perforated to equalize the hydraulic pressure on all sides of the transducer. After the transducer has been thus assembled the end of the body 1 may be closed by a cap 13 and the interior of the device filled with an appropriate liquid 14.

Like transducers will be located at either end of the tube 1 and similar transducers, but of a different and overlapping range, will be mounted in the two ends of the tube 15.

Where a liquid column is used between the oppositely placed transducers it is desirable to keep it as short as possible for a given delay, and this requires a low velocity liquid. Heretofore castor oil has been used in apparatus of this nature but in order to reduce the length xylene hexafluoride may be used here since it gives a lower velocity than any other presently known liquid having other appropriate characteristics (878 meters per second—which is substantially half that of water).

One of the preferred embodiments of the invention is shown in Fig. 4. Here the main body of the device consists of a casing or tube 16 of

any appropriate rigid material. To each end of this body there may be attached a header 17 appropriately arranged to mount two or more transducer units as indicated by Figs. 7 and 8.

Each transducer unit such as that shown in section in the upper left-hand portion of Fig. 4, consists of a body 18 into which are assembled in the manner heretofore explained the various components. In this case there is a diaphragm 19, a plurality of fine mesh screens 20 constituting an attenuator, the crystal 21, its mounting plate 22 and its backing resonator 23.

To put two or more channels on one line requires either a filter for separating out the two channels on the two ends and for preventing their reaction on each other, or a certain amount of loss associated with each channel which prevents reflections and interactions between the driving elements. The use of filters at these high frequencies appears not to be feasible on account of the very small sizes of the elements involved. The absorption method appears much more practicable and it is that which is illustrated. Here we have the tube 16 filled with xylene hexafluoride or other suitable liquid. Each end section is filled with metal screens 20 and a damping liquid separated from the liquid of the main body by a soft rubber diaphragm 19. The screen and liquid are adjusted so that they introduce a loss of about five decibels from the xylene hexafluoride to the crystal. The L-cut Rochelle salt crystals are mounted on a backing plate of steel which is hermetically connected to the chamber. The output from the crystal goes through a coil 24 to annul the crystal reactance and this section is connected in parallel with the other crystal channel section which is tuned to a different frequency. Any interaction between the two sending or receiving crystals is prevented by the attenuation of the two stub branches. These also terminate the xylene hexafluoride line so that no appreciable reflections can occur in it. They do introduce some loss in the overall performance which has to be made up by vacuum tube amplifiers and which may be calculated as follows: The two stub lines each puts in five decibels. In addition there will be a loss due to the fact that the received wave is divided into two parts, one of which is useful and the other wasted. This introduces three decibels loss on each end. In addition there would be the loss in the xylene hexafluoride line which might amount to three or four decibels around one megacycle. Hence, the total loss through the delay unit would be around twenty decibels.

By way of example, suppose it is desired to construct a delay device for 600 microseconds. Since the velocity is 878 meters per second, the length will be:

$$878 \times 600 \times 10^{-6} = .526 \text{ meters} = 52.6 \text{ centimeters}$$

Adding 8 centimeters for the crystals and backing plates, the total lengths would be about two feet. With water or other liquids this length would be increased to at least three and one-half feet.

Another embodiment of the invention is shown in Fig. 5. In this construction the main body 25 of the device is made of a plastic material such as cellulose acetate butyrate or some of the polyesters, having substantially the same velocity as water, loaded with heavy metal particles. By mixing such heavy metal particles (permalloy or tungsten) with the molding powder the velocity and attenuation can both be lowered giving a

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shorter device. To get the equivalent of the resistance termination, a plastic with a large loss (such as cellulose acetate) can be bonded on the end and the crystal and backing plate glued to them as shown in Fig. 5. The stub branches are, therefore, constructed of a body 26, a crystal 27 and a backing plate 28 with the usual layers of cement and the metal conducting foil on either side of the crystal.

It should be noted that the stub branches may be applied at any desired angle to the ends of the mechanical delay line. They may have their longitudinal axes parallel to the longitudinal axis of the main body or at an angle thereto as shown.

Cellulose acetate has a loss of about one decibel per wavelength at the higher frequencies and a velocity of 2,500 meters per second. Hence at one megacycle a wavelength is one-quarter centimeter and it would take only one and one-quarter centimeters to provide the requisite high frequency loss. By this construction a compact and economical wide band delay device may be produced.

What is claimed is:

1. An electromechanical delay device comprising a plurality of pairs of transducers having overlapping characteristics, a common mechanical transmission medium for said transducers, and mechanical vibration attenuators interposed between each said transducer and said mechanical transmission medium.

2. A wide band electromechanical delay device for use in the megacycle range comprising a common low velocity mechanical transmission delay medium having coupled to each terminal thereof a plurality of wide band longitudinally vibrating piezoelectric crystal electromechanical transducers having different but overlapping bands, each said transducer being coupled to said common medium by a separate stub branch thereof and means for preventing interference between the various transducers at either of said terminals.

3. A wide band electromechanical delay device comprising a common mechanical transmission delay element consisting of a pipe-like housing having a plurality of stub terminations at either end thereof and containing a low velocity liquid medium, a plurality of different but overlapping band transducers mounted on said stub terminations at each end of said pipe-like element, and connections between said transducers at either end thereof whereby said device may be connected in a circuit as a single element thereof.

4. A wide band electromechanical delay device comprising a common mechanical transmission delay element consisting of a pipe-like housing having a plurality of stub terminations at either end thereof and containing xylene hexafluoride, a plurality of different but overlapping band transducers mounted on said stub terminations at each end of said pipe-like element, and con-

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nections between said transducers at either end thereof whereby said device may be connected in a circuit as a single element thereof.

5. A wire band electromechanical delay device comprising a common mechanical transmission delay means having a plurality of separate branches at each end thereof, and a plurality of transducers each coupled with said transmission medium through a said branch thereof, the said transducers at each end thereof being connected in multiple circuit to effectively constitute a single transducer and having different but overlapping frequency band characteristics to effectively constitute a wide frequency band transducer, the effective frequency band at one end of said transmission medium being the same as the effective frequency band at the other end thereof.

6. An electromechanical delay device comprising a plurality of pairs of transducers having overlapping characteristics, a common solid transmission medium connecting said transducers and a separate stub branch of said transmission medium for each said transducer.

7. An electromechanical delay device comprising a plurality of pairs of transducers having overlapping characteristics, a common transmission medium connecting said pairs of transducers and a separate stub branch of said transmission medium for each said transducer, said medium being constructed of material such as cellulose acetate butyrate or a polyester plastic.

8. An electromechanical delay device comprising a plurality of pairs of transducers having overlapping characteristics, a common low velocity transmission medium connecting said transducers and a separate stub branch of said transmission medium for each said transducer, said medium being constructed of material such as cellulose acetate butyrate or a polyester plastic, said material being loaded with metallic particles.

JOHN A. HALL.

WARREN P. MASON.

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