

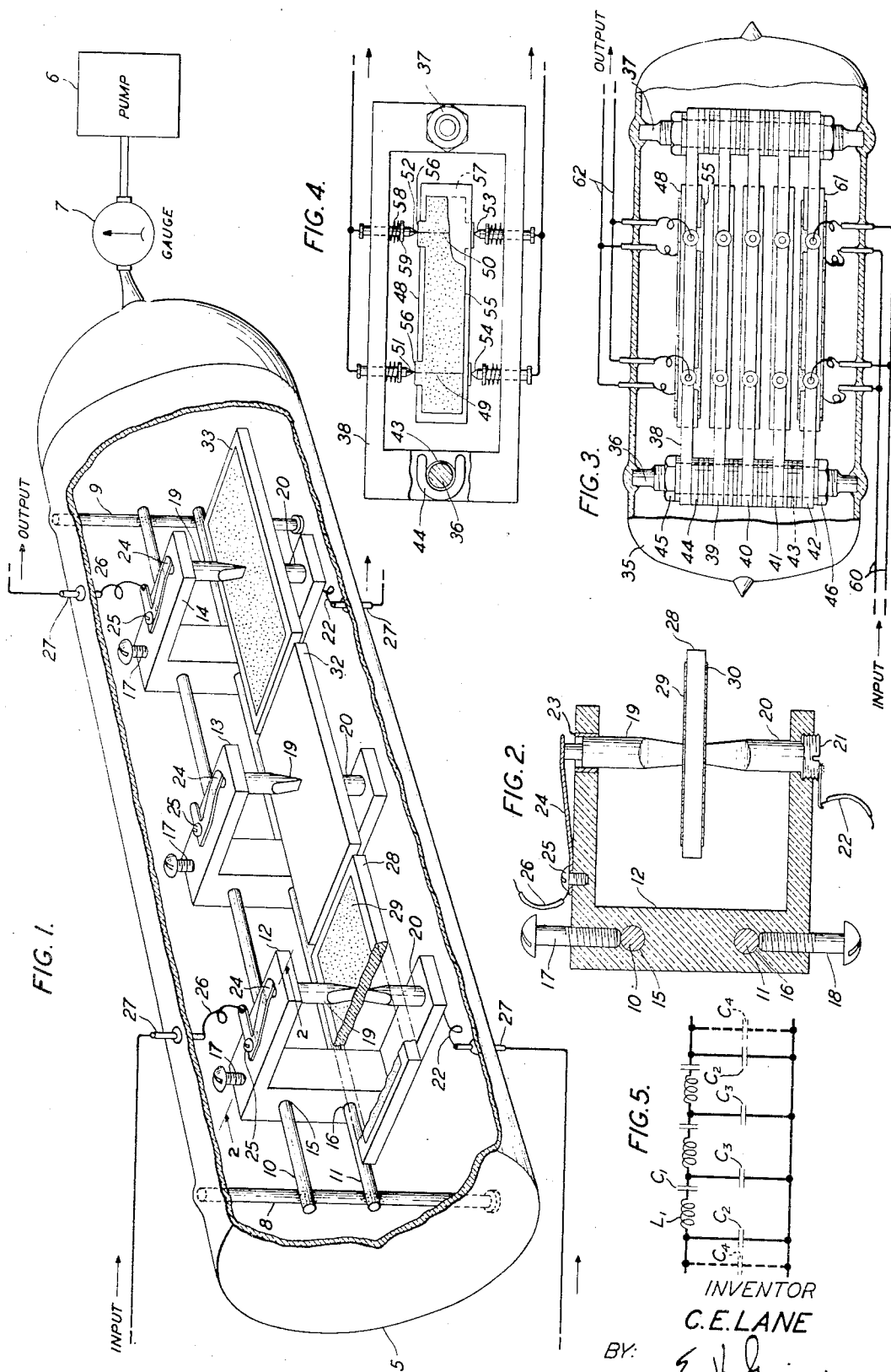
Sept. 12, 1944.

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2,358,087

ELECTROMECHANICAL FILTER

Filed Oct. 29, 1942



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UNITED STATES PATENT OFFICE

2,358,087

ELECTROMECHANICAL FILTER

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Application October 29, 1942, Serial No. 463,803

8 Claims. (Cl. 178-44)

This invention relates to electrical wave selective apparatus and more particularly to electromechanical filters having air-coupled resonators.

An object of the invention is to provide a narrow band-pass filter presenting high attenuation to waves having frequencies outside of the narrow band to be transmitted by the filter.

Another object of the invention is to provide a narrow band filter which may have the stability attending the use of piezoelectric resonators and in which the structure enables the band width to be varied at will during assembly of the filter elements.

Another object of the invention is to enable the width of the pass band of a narrow band-pass filter to be varied without changing the magnitudes of its resonant elements.

A feature of the invention is the employment of a series of mechanical resonators which are coupled elastically by means of the intervening atmosphere.

Another feature of the invention relates to the resonator supports which permit the spacing of adjacent resonators to be varied in order to change the pass band width of the filter.

In accordance with the invention the input and output terminal elements of an electromechanical filter may be electromechanical transducers of any kind, as for example, piezoelectric resonators. Each of the elements may be coupled mechanically with adjacent mechanical resonators through the air intervening between their contiguous surfaces. If the filter involves more than two resonator elements, the elements intervening between the terminal elements may be non-piezo active in character. The individual resonators should be so mounted that in assembly of the filter the separation of the resonators may be varied in accordance with a predesign to enable the filter to present a desired width of pass band. Moreover, since the coupling between the resonators is provided by the intervening gas or atmosphere that coupling is affected by the atmospheric pressure. It may be brought to any desired point and fixed at that point by sealing the assembly filter structure into a hermetically sealed container and by adjustment of the atmospheric pressure therewithin to a suitable magnitude.

The invention may be understood from a consideration of the following detailed specification taken in connection with the accompanying drawing in which:

Fig. 1 illustrates in perspective a three-section electromechanical filter utilizing extensional vibrations of its component resonators;

Fig. 2 is a vertical section of a resonator mounting on the line 2-2 of Fig. 1;

Fig. 3 is a side view of an electromechanical filter comprising stacked flexural resonators;

Fig. 4 is a plan view of the top resonator of Fig. 3; and

Fig. 5 is an electrical analogue of the filter of Fig. 1.

Referring to Fig. 1, a hermetically sealed envelope 5 of suitable dielectric material is shown associated with a pump 6 which may be employed either to reduce the atmospheric pressure within the envelope 5 to any desired subatmospheric pressure indicated by gauge 7 or to raise the interior pressure of envelope 5 to a pressure above normal atmospheric pressure. The envelope may be sealed in the usual manner after the desired pressure is attained.

The envelope 5 is shown partly broken away in Fig. 1 to disclose the interior filter structure. Mounted in the envelope 5 are vertical metallic supports 8 and 9 the ends of which may be sealed into the container wall in well-known manner. Two rigid supporting rods 10 and 11 are spot welded or otherwise secured near their ends to the supports 8 and 9. Before attaching the rods 10 and 11 to the supports a plurality of holders 12, 13 and 14 of U-shape and consisting of Isolantite or other suitable dielectric material are slipped on to the rods, the holders having spaced openings 15, 16 which are just large enough to accommodate the rods. After proper positioning, each holder may be fixed in its position against longitudinal displacement by means of set screws 17 and 18 which are threaded into the holders to bear against rods 10 and 11. The holders 12, 13 and 14 are each provided with aligned anvils 19 and 20 mounted respectively in the upper and lower legs of the holders. The lower anvil 20 may be forced through a snugly fitted opening in the lower leg and may be retained in position by a short set screw 21 which serves the additional function of a pressure adjusting element and a conducting terminal for the circuit conductor. The upper anvil 19 is mounted slidably in a metallic bushing or sleeve 23 which lines an opening through the upper leg of the holder and is so positioned as to align the longitudinal axes of anvils 19 and 20. A metallic spring 24 bearing on the upper shank of anvil 19 is held in position by a screw 25 and serves

as the electrical terminal of conductor 26. Conductors 22 and 26 are soldered or otherwise electrically connected to the input circuit lead-in tips 27 as shown.

The chisel pointed anvils 19 and 20 engage a piezoelectric resonator 28 at its nodal area. The resonator 28 is provided with conducting coatings or platings 29 and 30 and is held clamped along a nodal line for longitudinal vibration in position by the spring 24, the set screw 21, and the intervening anvils. The resonator is designed for longitudinal vibration so that its extensional motion is toward the adjacent resonator 32 which is similarly clamped in holder 13. Resonator 32 may for convenience consist of the same material as resonator 28 but as it need not be piezoelectric in character, it may consist of an entirely different material. It should, however, be designed to have such mass and elasticity as to vibrate in a longitudinal mode at substantially the same frequency. Moreover, it should have the same superficial end areas in order to make its end couplings to the adjacent atmosphere the same as those of the terminal resonator. As shown in Fig. 1, the resonator 32 is not provided with conducting coatings but it may be coated or loaded in any desired manner if necessary in order to adjust its resonance frequency for longitudinal vibrations to the desired point. Resonator 33 mounted in holder 14 is in all respects like resonator 28.

The transmission characteristics of the filter of Figs. 1 and 2 are dependent primarily upon the predetermined design of the resonators 28, 32 and 33. If an input electromotive force of the frequency which the filter is designed to transmit be applied to the input conductors the resonator 28 will be set in extensional vibration in such manner as to impress a corresponding vibration upon the atmosphere intervening between it and the resonator 32. The amount of coupling between the resonators 28 and 32 will depend upon the areas of the ends of the resonators and also upon the pressure of the atmosphere within the envelope 5 and upon the distance or separation between the contiguous end surfaces of resonators 28 and 32. As has been previously explained, the atmospheric pressure within envelope 5 may be set at any desired point. The distance between resonators 28 and 32 may be adjusted during assembly of the apparatus to meet different requirements with respect to the width of the pass band. As is well known, if the coupling between the resonators be loose, as may be effected by lowering the atmospheric pressure and increasing the separation between the resonators, the pass band will become narrow. If, on the other hand, it is desired to widen the band the atmospheric pressure within the envelope 5 may be increased and the distance or separation between the contiguous ends of the resonators may be reduced. Preferably one of the holders as, for example, holder 12 is first clamped firmly in position by tightening its set screws 17 and 18. Spacers having a thickness in accordance with precalculated design may be introduced between the resonators 28 and 32 to enable separation of these resonators to be definitely fixed. Thereupon, the set screws of the holder supporting the resonator 32 may be tightened and the separating spacer withdrawn. In similar fashion resonator 33 may be adjusted with reference to resonator 32. It will, of course, be understood that while only three resonators are shown, as many resonators as desired may be used. One end resonator as, for example, 28 may

serve as the input element and the other end resonator, 33, may serve as the output element.

In operation, the atmosphere between the successive resonators provides an elastic coupling from one resonator to the next. For a small separation of the piezoelectric resonator the coupling is given by Equation 5.50, page 172, W. P. Mason's text-book, "Electromechanical Transducers and Wave Filters," D. Van Nostrand, Incorporated, New York, 1942.

$$C_2 = \frac{t}{\rho v^2 S_1} \quad (1)$$

where C_2 is the compliance or elasticity; t is the separation between the contiguous ends of the coupled resonators; ρ is the density of the atmosphere; v is the velocity of propagation of compressional waves in the atmosphere and S_1 is the area of the end of the resonator. From Lamb's "Dynamical Theory of Sound" published by Edward Arnold, London, 1910, page 162, Equation 13, we have

$$v = \sqrt{\frac{\gamma p}{\rho}}$$

or

$$v^2 = \frac{\gamma p}{\rho} \quad (2)$$

where γ , a constant relating specific heats of air is equal to 1.41, p represents the pressure of the atmosphere in dynes per square centimeter and ρ its density. Substituting the value of v from Equation 2 in Equation 1 we have

$$C_2 = \frac{t}{\gamma p S_1} \quad (3)$$

In an actual design the resonators consisted of quartz of the so-called 5 degree X cut. The thickness of the resonators was 2 millimeters, the width, 18.3 millimeters and the length 45.7 millimeters. These resonators operate in longitudinal vibration at a frequency of approximately 60 kilocycles. The electrical analogue of a mechanical structure similar to that disclosed in Fig. 1, is illustrated in Fig. 5. In this circuit, the individual meshes each have series inductance L_1 , series capacitance C_1 and shunt capacitance C_2 . They are coupled by shunt capacitance C_3 . The effective mass of a piezoelectric crystal of the dimensions previously given referred to the end of the crystal would be about one-half of the total mass or 2.2 grams. This corresponds to a series inductance L_1 of 51.4 henries in the electrical analogue. With the ends of the two crystals spaced .01 centimeter apart, the elasticity of the air coupling at atmospheric pressure is 1.9×10^{-6} centimeter-gram-second units. This gives in the electrical analogue a value of 885 micromicrofarad for C_3 . The value of C_1 is .137 micromicrofarad. For a mid-shunt termination C_2 may be made equal to one-half C_3 by adding shunt capacitance units C_4 indicated in dotted lines to supplement the direct capacitance C_2 of the crystals. With these magnitudes the filter will have a band width of about 20 cycles and an image impedance at the mid-band frequency of about 3000 ohms. Using the same resonators the band width will vary inversely as the spacing between the crystals and directly as the pressure of the air around the crystals. Hence, the band widths may be set to any predesired value within reasonable limits either by changing the spacing or by holding the spacing fixed and changing the surrounding atmospheric pressure.

Although the piezoelectric resonators have been

described as constructed of quartz it will be understood that any piezoelectric material capable of extensional vibration and having the necessary mechanical properties may be utilized. The resonator 32 may be metallic or dielectric in character since its function is wholly vibrational.

Fig. 3 discloses another modification of electromechanical filter in accordance with the invention in which flexural vibrations are utilized. A hermetically sealed envelope 35 is equipped with two vertical metallic supporting rods 36 and 37 the ends of which are anchored in the walls of the envelope. Carried by the supporting rods are a series of frames 38, 39, 40, 41, 42 of suitable dielectric material, the ends of which are apertured as at 43 (Fig. 4) to enable the frames to be stacked by sliding rods 36 and 37 through the apertures. In order to space the frames at the desired separation U-shaped spacing elements 44 may be slipped therebetween astride the rods. The assemblage of frames 38 to 42 inclusive, is held firmly clamped in position on the rods by nuts 45 and 46 engaging threaded portions of the rods.

The mounting of the resonators in the frames will be apparent from Fig. 4 which shows frame 38 and the resonator 48 supported thereby. The resonator consists of an elongated flat plate of piezoelectric material having nodes for flexural vibration along the broken lines 49 and 50 of Fig. 4. At the extremities of these nodal lines and centrally of the piezoelectric plate in its thickness direction the plate is engaged by the conical tips of anvils 51, 52, 53 and 54 which serve to clamp the plate in position and to provide electrical contacts therefor. As shown in Fig. 4, the upper coating 55 is provided with tabs 56 extending down partly along the margin of the piezoelectric plate to be engaged by anvils 51 and 52 while the lower coating 57 is provided with corresponding tabs up-turned along the opposite margin of the piezoelectric plate to engage and make electrical contact with anvils 53 and 54. Each of the anvils slides freely through a circular aperture in a side of the frame 38 and is held in resilient clamping engagement with the piezoelectric plate 48 by means of a helical spring 58 which is compressed between the inner side wall of the frame 38 and a shoulder 59 on the anvil. As in the case of Fig. 1 only the two terminal elements need be piezoelectric in character.

In assembly of the apparatus of Fig. 3, the separation of the resonators may be fixed by the thickness of the spacers 44. It is, accordingly, possible to set this separation at any predesigned magnitude. Moreover, the internal pressure of the envelope 35 may be made equal to any pre-calculated pressure.

In operation, if an input electromotive force of the band of frequencies for which the filter be designed be applied to the input terminals 60, the resonator 61 supported within the frame 42 will be set in flexural vibration about its nodal lines 49 and 50. The resulting displacement of the intervening atmosphere will cause the resonators of the overlying frames to be successively set into vibration until finally the output resonator 48 supported by frame 38 is set in vibration thus developing a piezoelectric electro-

motive force which it impresses upon the output circuit 62. It is, accordingly, apparent that with the structure of Figs. 3 and 4 as, also, with the structure of Figs. 1 and 2, there is provided a narrow band-pass filter of high selectivity in which the width of the band transmitted may be varied to an extent by variation of the separation of the resonators and of the pressure of the atmosphere by which they are surrounded without requiring resonators of different dimensions to be constructed for each condition encountered.

What is claimed is:

1. A wave filter comprising a plurality of longitudinally aligned piezoelectrical elements each having a natural longitudinal mode of vibration of approximately the same frequency, said elements being coupled only by the intervening gaseous medium.

2. A wave filter comprising a plurality of piezoelectric resonators of substantially equal resonance frequency, means for mechanically coupling each resonator to an adjacent mechanical resonator and means for coupling the mechanical resonators in sequence to each other solely by a surrounding gaseous medium.

3. In combination, a plurality of piezoelectric resonators, a gaseous medium mechanically connecting said resonators to provide an elastic coupling between the resonators and means for varying the spacing of said resonators to vary the coupling.

4. In combination, a plurality of piezoelectric resonators, an atmospheric medium mechanically connecting said resonators to provide an elastic coupling between the resonators and means for determining the pressure of the atmospheric medium to vary the coupling between said resonators.

5. A plurality of piezoelectric resonators mounted adjacent each other in an atmospheric medium whereby vibrations of one may induce vibrations in the adjacent one only through the elastic coupling of the atmospheric medium, one of said resonators having input terminals and electrodes connected thereto and another of said resonators having output electrodes and output terminals connected thereto.

6. A wave filter comprising a plurality of piezoelectric resonators of substantially equal resonance frequency for flexural vibrations, each of said elements being coupled to a physically adjacent element only by the intervening atmospheric medium.

7. A series of mechanical resonators each coupled through a surrounding gaseous medium to the succeeding resonator to transmit a vibrational driving force thereto, the terminal resonators of the series being piezoelectric in character and having electrodes and electric connections thereto whereby the series of resonators may serve as an electric wave filter.

8. A narrow band-pass filter comprising a chain of resonators each designed to resonate at the same frequency in one mode of vibration and mounted for vibration in that mode, the resonators being coupled solely by the intervening atmosphere, the end resonators of the chain being piezoelectric in character and the intervening resonators being non-piezoelectric.

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