April 18, 1939. C. A. BIELING 2,155,035

PIEZOELECTRIC CRYSTAL APPARATUS

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FIG. 1

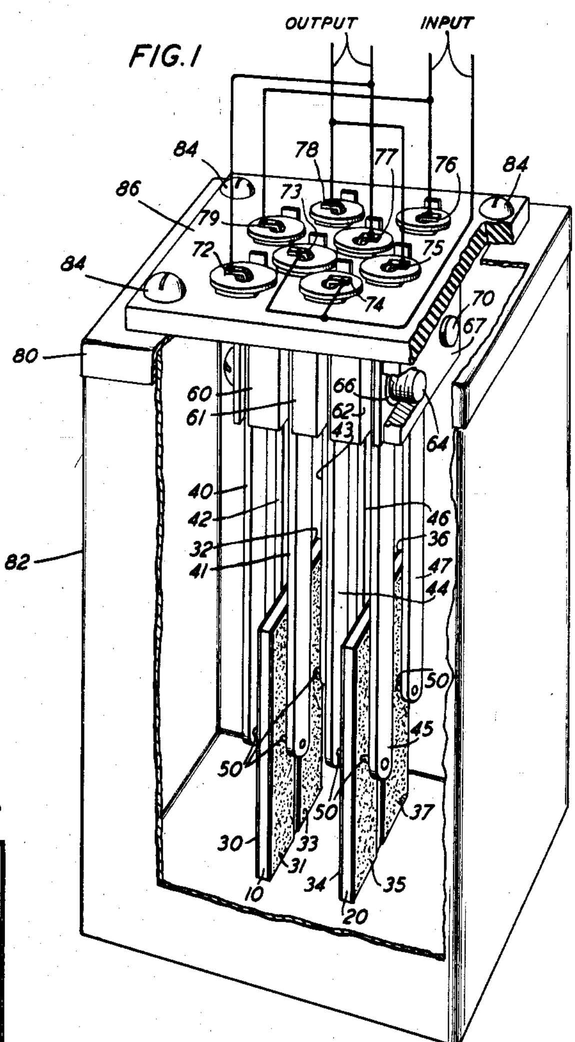
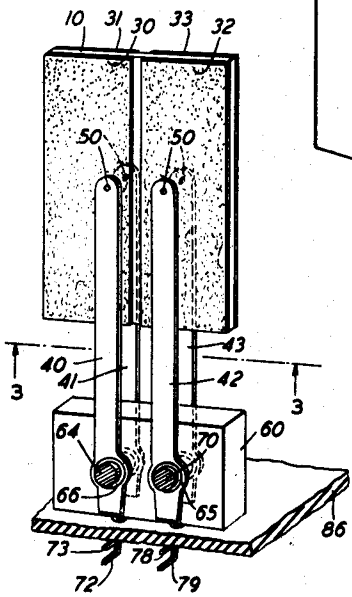


FIG. 2



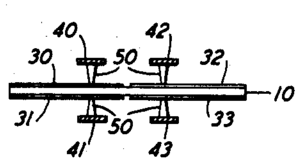


FIG. 3

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FIG. 4

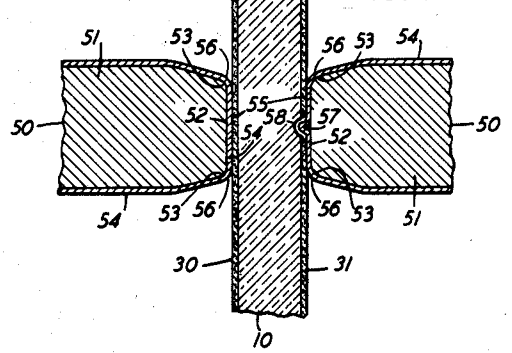

FIG. 6

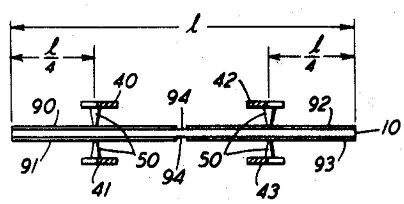

FIG. 8

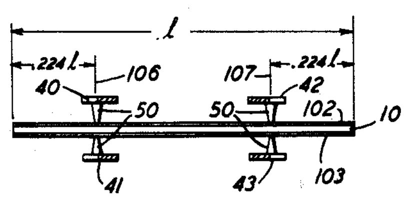

FIG. 5

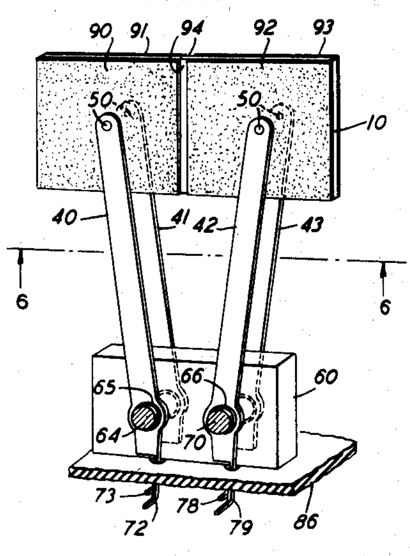

FIG. 7

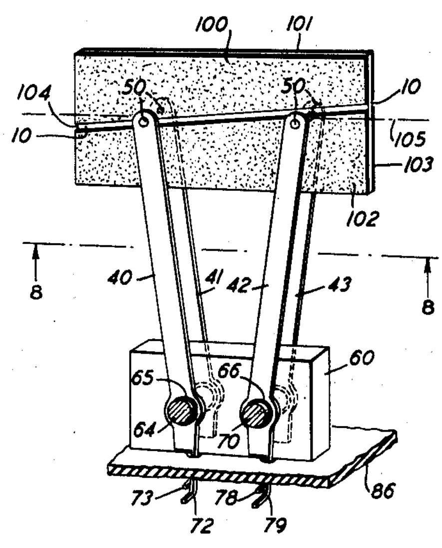

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FIG. 9

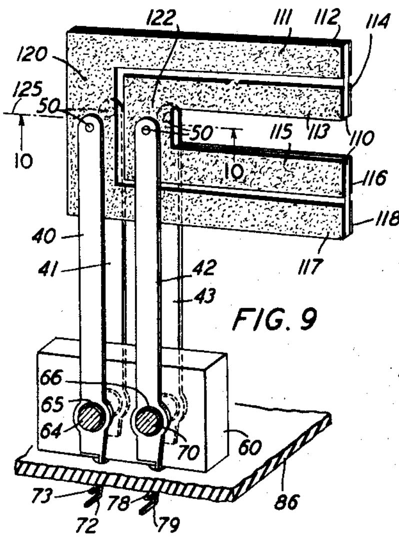


FIG. 10

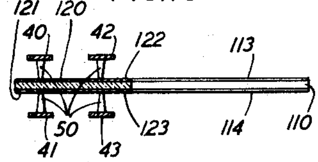


FIG. 11

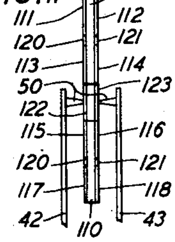


FIG. 12

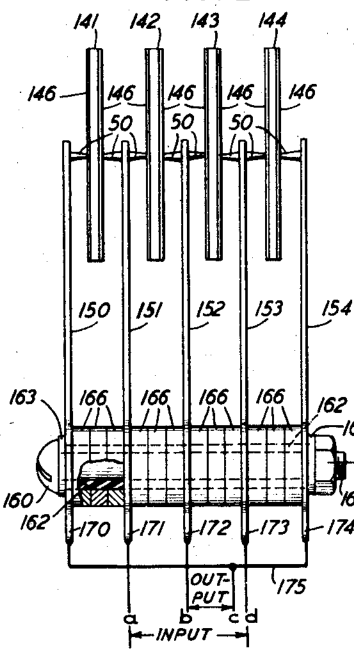


FIG. 13

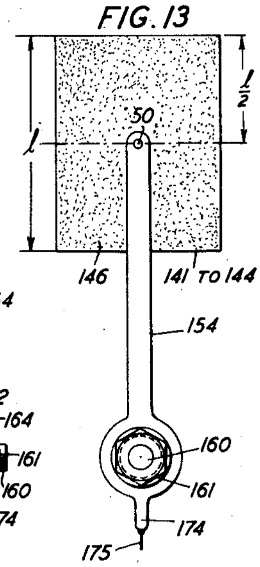


FIG. 14

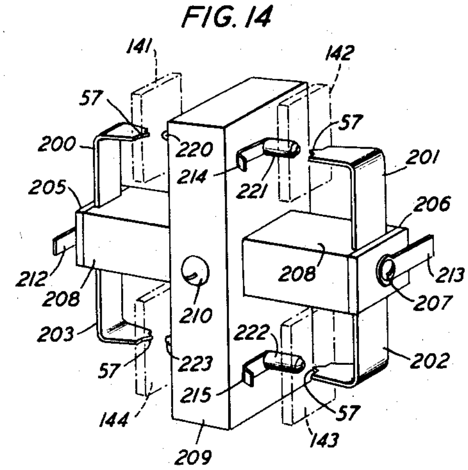
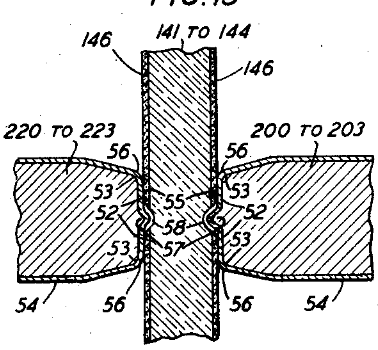


FIG. 15



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Patented Apr. 18, 1939

2,155,035

UNITED STATES PATENT OFFICE

2,155,035

PIEZOELECTRIC CRYSTAL APPARATUS

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Application January 2, 1936, Serial No. 57,187

21 Claims. (Cl. 171—327)

This invention relates to piezoelectric apparatus and particularly piezoelectric crystal holders suitable for electric wave filter systems, oscillation systems or electromechanical vibrating systems generally.

One of the objects of this invention is to permit unrestricted and independent simultaneous vibration of a plurality of piezoelectric crystal elements.

Another object of this invention is to improve the constancy of frequency of vibrating piezoelectric crystal elements.

Another object of this invention is to mount in the same holder piezoelectric bodies of various shapes, sizes and modes of motion.

Another object of this invention is to clamp a piezoelectric crystal element under uniform contact pressure.

A further object of this invention is to clamp a piezoelectric crystal element in such a manner that its position will be maintained.

Still another object of the invention is to reduce wear of the electrodes integral with the faces of a piezoelectric crystal element.

In accordance with this invention, a plurality of piezoelectric crystals may be supported from a single or common mechanical supporting structure in such manner that each crystal although mechanically interconnected with other crystals is free to vibrate at its own frequency with minimum losses and a minimum amount of mechanical vibratory coupling between the plurality of vibrating crystals. The crystals may have the same or different frequencies and yet vibrate independently at their respective frequencies although supported from a single or common mechanical structure. The supporting structure may be such as to support a plurality of crystals having divided or split electrodes with a resulting saving in the number of crystals employed.

The crystal supporting structure is such as to result in a lowered cost, economy of space, simplification of electrical connections, reduction of and minimum unbalance in distributed capacities, and balanced capacity between the interconnected elements. The plurality of crystals may be clamped under substantially equal pressures. A plurality of resiliently supported metallic clamping projections may nodally clamp the crystals and also serve as electrical contacts with metallic electrodes which may be integral with or otherwise closely associated with the crystal surfaces.

Resilient means in the form of cantilever springs suitably supported at one end only thereof may support the crystal clamping projections disposed at the free ends thereof. The cantilever springs may be separately pivotally mounted at one end only thereof to revolve about suitably spaced centers to electrically connect one or more sections of crystal electrodes and to support or accommodate in the same holder one or more crystals of various shapes, sizes and modes of vibration. To secure uniform contact pressure with the crystal and to reduce wear of the crystal electrodes, the clamping areas of each of the clamping projections may have rounded corners and may be composed of or heavily coated with non-corrosive metal or metals relatively softer or less hard than the metal of the crystal electrode in contact therewith. To nodally locate or center the crystal with respect to any of the clamping areas, a small projection may extend from the center of the clamping area of the clamping projection to cooperate with a small hole or depression in the surface of the crystal at a nodal point thereof.

While the crystal or crystals herein referred to may be any suitable piezoelectric body of any suitable cut or orientation, the invention is described particularly with reference to mounting quartz piezoelectric crystal plates or bars of the so-called Curie or perpendicular cut, that is, one so cut that its major or electrode surfaces are parallel to the optic axis and perpendicular to an electric axis. The electrode faces of the crystal plate may be coated wholly or partly with a layer or layers of suitable conductive material such as for example aluminum, platinum, or chromium on top of platinum which may be applied in vaporized form in a vacuum, for example, to closely unite the material with the surfaces of the plate to form electrodes integral with the crystal element.

The apparatus hereinafter described is suitable for mounting crystals which cover a very large range of frequencies. The lengths of the crystal plates may range for example from over five inches to less than half an inch for vibration in a longitudinal mode of vibration.

For a clearer understanding of the nature of this invention and the additional features and objects thereof, reference is made to the following description taken in connection with the accompanying drawings, in which like reference characters indicate like or similar parts and in which:

Fig. 1 is a perspective view of one embodiment of the invention;

Fig. 2 is a perspective view of part of the device shown in Fig. 1;

Fig. 3 is a view taken on the line 3—3 of Fig. 2.

Fig. 4 is an enlarged sectional view of a crystal clamping arrangement.

Fig. 5 is a perspective view of the device shown in Fig. 1 adapted to mount a piezoelectric crystal vibrating in the longitudinal mode of motion at the second harmonic frequency;

Fig. 6 is a view taken on the line 6—6 of Fig. 5.

Fig. 7 is a perspective view of the mounting of Fig. 1 adapted to support a piezoelectric crystal vibrating in the flexural mode of motion;

Fig. 8 is a view taken on the line 8—8 of Fig. 7.

Figs. 9 to 11 are views of the mounting of Fig. 1 adapted to support a tuning fork type of piezoelectric crystal; Fig. 10 being a view taken on the line 10—10 of Fig. 9, and Fig. 11 being a side view of part of the device shown in Fig. 9.

Figs. 12 and 13 are respectively front and side views of another embodiment of the invention;

Fig. 14 is a perspective view of still another embodiment of the invention; and

Fig. 15 is an enlarged sectional view of a crystal clamping arrangement suitable for the holder shown in Fig. 14.

Referring to the drawings, Figs. 1 to 11 illustrate a piezoelectric crystal holder adapted to mount and drive one or more piezoelectric crystals vibrating in various modes of motion such as longitudinally, in shear, or flexurally, for example and having one or more well defined nodal areas.

In Fig. 1, two piezoelectric quartz crystals 10 and 20 each having four equal area metallic electrodes 30 to 37 disposed lengthwise thereof and integral therewith are nodally clamped and held in position by eight cantilever leaf springs 40 to 47 each having a metallic clamping projection 50 secured to its free end for nodally clamping and making individual electrical connection with the several electrodes 30 to 37 of the piezoelectric crystals 10 and 20. Three insulating spacers 60, 61 and 62 composed of a phenol product as Bakelite or of Isolantite or other suitable high resistance dielectric, separate the leaf springs 40 to 47 a suitable distance apart. A bolt 64 extends through openings in the insulating spacers 60, 61 and 62 and also extends through openings in the springs 40, 41, 44 and 45 and is suitably insulated therefrom by two insulating collars 65 and 66 surrounding the bolt 64. A nut unit 67 engages the threaded bolt 64 to clamp together the springs 40, 41, 44 and 45 and the spacers 60, 61 and 62. Another bolt 70 engaging the nut 67 similarly clamps together the springs 42, 43, 46 and 47 and the spacers 60, 61 and 62. The bolts 64 and 70 and the nut unit 67 are suitably insulated from the springs 40 to 47.

The clamping forces exerted by the clamping projections 50 on the piezoelectric crystals 10 and 20 may be controlled by varying the thicknesses of the spacers 60 and 62 disposed between the springs 40 to 47. The values of spring tension for the springs 40 to 47 may be computed by the formula

$$\frac{W}{d}=\frac{Ebh^3}{4l^3}$$

where W is the force, d is the deflection of the spring, E is Young's modulus of the spring material, b is the width of the spring, h is the thickness of the spring and l is the distance from the support of the spring to the center of the clamping contact 50.

The springs 40 to 47 may be constructed of any suitable resilient material such as steel, phosphor bronze or phenol fibre, for example. Where the springs 40 to 47 or the clamping projections 50 are composed of an insulating material, they may be coated wholly or partly with metallic or conductive material such as tin to form suitable individual electrical connections between the crystal electrodes 30 to 37 and the corresponding terminal lugs 72 to 79 of the springs 40 to 47. Such metallic coating may be applied to the surfaces of the springs 40 to 47 and the projections 50 by any suitable method such as for example by spraying molten metal thereon by means of a Schoop metal spray gun for example.

The eight springs 40 to 47 may extend through or have connections extending through suitable insulated openings in a copper cover 80 of a copper can or container 82 which houses the assembly comprising the piezoelectric crystals 10 and 20, the springs 40 to 47 and the common supporting means therefor which includes the spacers 60 to 62 and the bolts 64 and 70. The assembly may be supported from the cover 80 of the can 82 by four bolts 84 and a suitable insulating member 86.

The eight terminal lugs 72 to 79 connected with the eight metallic springs 40 to 47 may be utilized to connect the eight divided or split platings 30 to 37 of the piezoelectric crystals 10 and 20 of suitable frequencies in any desired circuit such as for example in a lattice type filter circuit as illustrated in Fig. 1 wherein the terminal lug 72 connected with the terminal lug 77 interconnects the electrode 30 of crystal 10 and the electrode 36 of the crystal 20, the terminal lug 73 connected with the terminal lug 74 interconnects the crystal electrodes 31 and 34, the terminal lug 75 connected with the terminal lug 78 interconnects the crystal electrodes 33 and 35, and the terminal lug 76 connected with the terminal lug 79 interconnects the crystal electrodes 32 and 37. The terminals 74 and 76 may be the input terminals and the terminals 72 and 78 may be the output terminals of such filters as shown in Fig. 1.

The clamping projections 50 may be constructed of any suitable metal or metals such as gold or silver for example, or as shown in Fig. 4, the clamping projections 50 may have an internal core 51 of metal such as for example soft brass or alternatively of insulating material such as for example a phenol product as Bakelite. The tips or clamping areas of the clamping projections 50 as the clamping areas 55 of Fig. 4 are flat and also coplanar where used in contact with any single surface of a crystal and may be of circular, square, rectangular or other suitable configuration to best suit the nodal area of the vibrating crystal such as the crystal 10 clamped therebetween.

As shown in Fig. 4, the flat areas 52 of the cores 51 of the clamping projections 50 may be disposed in parallel relation with respect to the flat electrodes 30 and 31 of the crystal 10 and may have rounded corners or edges 53. The cores 51 and particularly the flat areas 52 and the rounded corners 53 thereof may be covered with a heavy layer 54 of tin or other suitable metal or metals of similar properties relatively softer than the metal coatings 30 to 37 of the piezoelectric crystals 10 and 20.

The layer of tin 54 may have a thickness of about .004" for example and may be applied to the projections 50 electrolytically or by metal spray for example. The contact portions of the clamping areas 55 of the tin deposit 54 are flat to conform to the corresponding flat surfaces of the metallic coatings 30 to 37 of the piezoelectric crystals 10 and 20 and may have rounded outer edges or corners 56 to prevent concentration of stresses at such corners of the clamped areas 55 to thereby prevent wear of the platings 30 to 37 which may result in lowering the so-called Q or ratio of reactance to resistance of the piezoelectric crystals 10 and 20.

If desired, the outer surfaces of the projections 50 may be gold or silver plated and such plating or the tin deposit 54 or both may serve to make good electrical contact at all times and being relatively pliant under pressure exerted by the springs 40 to 47, the continuity of contact with the metallic films 30 to 37 on the surfaces of the piezoelectric crystals 10 and 20 is not interrupted and wear of the crystal electrodes 30 to 37 is reduced.

A small projection 57 may extend from the center of the clamping area 55 into a larger depression 58 in the crystal electrode 31 at a nodal point of the crystal 10 to nodally locate and center the crystal 10 with respect to the clamping projections 50. It will be understood that by reversal of parts, the projections may extend from the crystal electrode 31 at the nodal point of the crystal 10 into an opening or depression in the clamping area 55 of the clamping projections 50.

As shown in Figs. 1 to 3, the crystals 10 or 20 of Fig. 1 may be mounted for longitudinal vibration at the fundamental frequency thereof. In this instance, the nodal-area of the crystal 10 or 20 is located on a line passing essentially through the width of the crystal midway between the small ends. The clamping areas of the clamping projections 50 nodally clamp the crystals 10 and 20 along such nodal lines as shown in Figs. 1 to 3 and are sufficiently small in area to prevent excessive damping of vibrations. The clamping areas of the projections 50 may be square, circular, rectangular or any suitable shape. Every corresponding set or pair of clamping projections 50 is disposed in coaxial alignment. For example, the clamping projections 50 of the springs 40 and 41 are coaxially aligned with each other and the clamping projections 50 of the springs 42 and 43 are in coaxial alignment with each other. The coaxial alignment position of the corresponding pairs of clamping projections 50 may be obtained for example by suitably locating them on the free ends of the springs 40 to 47 and by rotating the pivotally mounted springs 40 to 47 about the clamping bolts 64 and 70. The springs 40 to 47 exert sufficient pressure to clamp and rigidly hold the crystals 10 and 20 therebetween.

As a modified arrangement, it will be understood that in place of mechanically separate springs, the springs 41 and 44 for example may be placed back-to-back to mechanically form a single spring having two projections 50 contacting with the crystal electrodes 31 and 34 in the same manner as shown in Fig. 1. The electrical connections may be separated if desired by insulating material disposed between the springs. Similarly the springs 43 and 46 for example may be mechanically combined but electrically separated. In such mechanical arrangement, the coaxial projections 50 exert substantially equal pressures on both crystals 10 and 20.

The metal container comprising the copper can 82 and its cover 80, as shown in Fig. 1, may be hermetically sealed if desired. To avoid the condensation of moisture on the crystals 10 and 20 or on other elements housed within the enclosing container 80, 82, dry air may be blown through the container through small openings therein immediately preceding the final sealing of the container, or the container may be evacuated before final sealing thereof. While a particular form of container 80, 82 has been illustrated in Fig. 1, it will be understood that any suitable form may be utilized to house any of the various crystal holders illustrated herein.

Figs. 5 and 6 show the crystal clamping means of Figs. 1 to 3 pivotally adjusted about the bolts 64 and 70 to mount and drive one or more piezoelectric crystals, such as the crystal 10, at a longitudinal harmonic mode of vibration along the length l. While in Figs. 5 and 6 the second harmonic mode of vibration of the crystal 10 is illustrated, it will be understood that the holder is also suitable for mounting and connecting crystals vibrating in other modes of harmonic vibration. In the case of the second harmonic longitudinal mode of motion, as illustrated in Figs. 5 and 6, the crystal 10 may have two pairs of electrodes comprising four separate equal-area metallic coatings 90 to 93 integral therewith. The platings 90 to 93 are divided or separated at 94 midway between the small ends of the crystal 10. The distance of separation at 94 may be any suitable distance. The side edges and the small end edges of the crystal 10 are, in the example shown, free of metallic coating.

The nodal points or areas of the crystal 10, when driven as shown in Figs. 5 and 6 at its second harmonic mode of longitudinal motion, are located on lines passing through the width of the crystal 10 between the sides and 0.25 the length l of the crystal from its small ends as shown in Fig. 6. The projections 50 of the springs 40 to 43 nodally clamp the crystal 10 at such nodal points or areas. The clamping areas may be sufficiently small to prevent excessive damping of the vibrations of the crystal 10 and may be circular, square, rectangular or of other suitable shape. Where the clamping areas of the projections 50 are rectangular in shape, the axis of greatest length thereof may extend in the direction of the nodal lines of the crystal 10. The projections 50 of the cooperating springs 40 and 41 as well as of every other pair of corresponding springs are disposed in coaxial alignment. All springs such as the springs 40 and 41 or 42 and 43 may exert sufficient pressure to rigidly clamp and hold the crystal therebetween. The spacing between the projections 50 of the pivotally mounted springs for example may be varied to any desired amount by rotation of the springs about the bolts 64 and 70.

Figs. 7 and 8 show the crystal clamping means of Figs. 1 to 3 pivotally adjusted about the bolts 64 and 70 to nodally mount one or more piezoelectric crystals such as the quartz crystal 10 for flexural vibration. The nodal points or areas of the crystal 10 when driven in the flexural mode of motion are located on a line 105 passing through the length l of the crystal 10 midway between the side edges and 0.224 times the length l of the crystal from its small ends. The projections **50** of the springs **40** to **43** nodally clamp the crystal **10** at such nodal points formed by the intersections of lines **105**, **106** and **107** shown in Figs. 7 and 8. The clamping areas of the projections **50** may be sufficiently small to prevent excessive damping of the vibrations of the crystal **10**. A circular clamping area is preferred for mounting crystals of this type vibrating in flexure as shown in Figs. 7 and 8.

To drive the crystal **10** in the flexural mode of vibration as shown in Figs. 7 and 8, the crystal **10** may have electrodes divided at **104** into four separate metallic coatings **100** to **103** integral with the two major surfaces of the crystal **10**. The coaxial projections **50** of the springs **40** and **41** make contact with the equal area metallic platings **100** and **101**. The coaxial projections **50** of the springs **42** and **43** make contact with the equal area metallic platings **102** and **103**.

As an alternative method of dividing the metallic platings of the crystal **10** to provide two separate electrical circuits in a single crystal **10**, the division **104** between the platings instead of being disposed as shown in Figs. 7 and 8 at a small angle with respect to the line **105** passing through the length of the crystal midway between the side edges of the crystal, may be disposed along such midway line **105**. The coaxial projections **50** of the springs **40** and **41** being then disposed on the line **106** slightly above such midway line **105** to make contact with the two oppositely disposed upper plates and the coaxial projections **50** of the springs **42** and **43** being disposed on the line **107** slightly below such midway line **105** to make contact with the two oppositely disposed lower plates.

Figs. 9, 10 and 11 show the crystal clamping means of Figs. 1 to 3 adapted to nodally mount and drive one or more tuning fork piezoelectric crystals such as the U-shaped quartz crystal **110** having four sets or pairs of metallic electrodes **111** to **118** integral therewith and connected by metallic connection plates **120** to **123** also integrally adhering to the U-shaped quartz crystal **110**. The connection plating **120** interconnects the electrodes **111** and **117** which are equal in areas and also oppositely disposed with respect to the electrodes **112** and **118** interconnected by connection plating **121**. Similarly, electrodes **113** and **115** interconnected by connection plating **122** are equal in area and oppositely disposed with respect to the electrodes **114** and **116** interconnected by connection plating **123**. The nodal points of the crystal **110** are located on a line **125** passing through the yoke of the crystal **110** midway between the two forks thereof. The coaxial projections **50** of the cantilever springs **40** and **41** nodally clamp the piezoelectric crystal **110** at such nodal points and make contact with the connection plates **120** and **121** respectively at such nodal points. Similarly, the coaxial projections **50** of the cantilever springs **42** and **43** nodally clamp the crystal **110** and make contact with the connection plates **122** and **123** respectively. The clamping areas of the projections **50** may be of such form as hereinbefore described as to prevent excessive damping of vibrations of the crystal **110** and to provide uniform contact pressure. Electrical connections with the connection platings **120** and **121** are established by the projections **50** and the springs **40** and **41**. Electrical connections with the connection platings **122** and **123** are established by the projections **50** and the springs **42** and **43**.

It will be understood that the arrangement disclosed in Figs. 1 to 11 may be utilized as an all-purpose holder to support one or more piezoelectric bodies of various sizes and shapes vibrating in various modes of motion and with uniform contact pressures exerted thereon by the plurality of cantilever springs **40** to **47** which may adjustably pivot or revolve about the bolts **64** and **67** to accommodate crystals of various sizes and which also may serve as metallic connectors to connect or interconnect one or several sections of the metallic electrode platings of the piezoelectric crystals, and that a plurality of piezoelectric elements although mechanically interconnected by a common supporting structure may be indedependently driven at the same or different frequencies without mechanical coupling therebetween by reason of the vibration absorption characteristics and other properties of the structure disposed between such plurality of piezoelectric elements.

Figs. 12 and 13 show a multiple crystal holder for clamping four piezoelectric crystals **141** to **144**. All of the crystals **141** to **144** are nodally clamped and electrically connected by the metallic coaxial clamping projections **50** secured to the free ends of five cantilever springs **150** to **154**. Each of the springs **150** to **154** is pivotally supported at one end only thereof by a bolt **160** extending through coaxial openings in the springs **150** to **154**, and engaging a nut **161**. An insulating collar **162** may surround the bolt **160** to insulate the bolt **160** from the springs **150** to **154** when the springs **150** to **154** are metal or metal coated. Similarly, insulating washers **163** and **164** may insulate the bolt **160** and nut **161** from the springs **150** and **154** respectively. Insulating spacers **166** may separate the springs **150** to **154** a suitable distance apart to allow for the thicknesses of the piezoelectric elements **141** to **144** and to provide a suitable pressure on the clamping projections **50** to nodally and resiliently clamp the piezoelectric crystals **141** to **144**. The springs **150** to **154** may be constructed of insulating material as phenol fibre, or of steel, phosphor bronze or other suitable resilient material. Where the springs **150** to **154** are made of phenol fibre or other insulating material, they may be metallically coated in whole or in part to provide electrical connections between the metallic contacts **50** and the corresponding terminals **170** to **174**. The crystals **141** to **144** may be of suitable piezoelectric material such as quartz having metallic electrodes **146** integral with each of the oppositely disposed major surfaces thereof. The crystal electrodes **146** may be formed of suitable conductive material such as for example thin equal-area coatings of platinum alone or chromium on top of platinum deposited on both major surfaces of each of the crystals **141** to **144**. The piezoelectric crystals **141** to **144** as shown in Figs. 12 and 13 are adapted to vibrate in the longitudinal mode along the length *l* but it will be understood that other piezoelectric elements may be utilized to vibrate in any desired mode of motion. The coaxial clamping projections **50** may be silver rods or wires secured to the springs **150** to **154** or as hereinbefore described in connection with Fig. 4, may have metal cores or phenol fibre cores coated with suitable metal or metals to secure electrical connection with the electrodes **146** of the piezoelectric crystals **141** to **144**. The clamping areas of the clamping projections **50** may be coated with a layer of metal such as tin or other conductive material which is relatively soft with respect to the metal coatings 146 of the crystals 141 to 144 as hereinbefore described.

The piezoelectric crystals 141 and 143 may be of equal frequency to form the lattice arms of an electric wave filter structure. To form the series arms of such filter structure, the piezoelectric crystals 142 and 144 may be of equal frequency with respect to each other but of different frequency with respect to the crystals 141 and 143. The mechanical structure is of such vibration absorption characteristics as to prevent mechanical coupling between the piezoelectric crystals 141 to 144 vibrating at the same or different frequencies. To form the connections for the lattice structure, the crystals 141 to 144 are connected in series circuit relation in the form of a Wheatstone bridge by means of a circuit including the metallic electrodes 146 of the crystals 141 to 144, the metallic clamping projections 50, the metallic springs 150 and 154, and a connection 175 between the terminals 170 and 174. Connections *a* and *d* connected with the terminal lugs 171 and 173 respectively may form the input terminals for the lattice structure. Terminals *b* and *c* connected respectively with the terminal lug 172 and the connection 175 may form the output terminals thereof.

While in Figs. 12 and 13 the piezoelectric crystals 141 to 144 have been illustrated as being connected to form an electric wave filter structure of the lattice type, it will be understood that some or all of the crystals 141 to 144 may be connected in any desired circuit, such as for example in a network of the ladder or T type. It will be understood that the two supporting projections 50 associated with any of the springs 151 to 153 may, if desired, be electrically separated as by insulating material disposed therebetween to establish any connections with the crystals that may be desired.

Fig. 14 shows another form of multiple crystal holder nodally clamping a plurality of piezoelectric crystals 141 to 144. The crystals 141 to 144 may be of the same type and have the same filter circuit connections as those of like reference characters disclosed in connection with Figs. 12 and 13. In Fig. 14, four metallic bent cantilever springs 200 to 203 are each rigidly supported at one end only thereof by brass brackets 205 and 206 secured by screws 207 to opposite ends of a phenol fibre or other suitable insulating block 208. The block 208 extends through a central opening in another phenol fibre insulating block 209 and may be secured thereto by a bolt 210. Four similar metallic clamping projections 220 to 223 may be secured to each end of the phenol fibre block 209 for nodally clamping the crystals 141 to 144 with respect to the coaxial free ends of the corresponding springs 200 to 203. The clamping projections 220 and 221 and also the projections 222 and 223 may consist of two separate metallic members as shown extending through two separate openings in the phenol fibre block 209 where electrical connection therebetween is desired as for example to form a filter structure of the type shown in Fig. 12. Where no connection between the metallic projections 220 and 221 or between the projections 222 and 223 is desired, they may be separated and insulated from each other. The crystal clamping areas of the springs 200 to 203 are coaxially disposed with respect to the corresponding clamping areas of the projections 220 to 223 to nodally clamp the crystals 141 to 144 therebetween. It will be understood that the clamping areas of the springs 200 to 203 and those of the projections 220 to 223 may be constructed as to shape, extent of areas, metallic coating, rounding of corners and in all other respects like those of the projections 50 hereinbefore described.

If desired, small depressions 58 may be made at the nodal points of the crystals 141 to 144 to cooperate with small projections 57 disposed at the centers of the clamping areas 55 of the clamping projections 220 to 223 and of the springs 200 to 203 as shown in Fig. 15 and as described in connection with Fig. 4, to more readily locate the nodal points of the crystals and retain the crystals in clamped position.

It will be understood that any of the various embodiments of the invention disclosed herein may nodally and resiliently clamp a plurality of piezoelectric crystals for independent simultaneous vibration, that the crystals clamped in any of the holders disclosed may be quartz or other suitable material of any suitable cut and orientation, may have the same or differing frequencies, may vibrate in various modes of motion as in the fundamental or harmonic mode of motion, and may have electrodes of divided or split plating as illustrated in Figs. 1 to 11 or of the non-divided plating as illustrated in Figs. 12 to 15, that any of the springs may be pivotally mounted at an extreme end or intermediate the ends thereof, that any of the contact clamping areas of the clamping projections 50, 200 to 203, or 220 to 223 may have rounded corners and may be composed of suitable metal such as silver or may be coated with metal relatively softer than that of the crystal electrodes in contact therewith to establish good electrical connections, to exert uniform pressures, to reduce wear on the crystal electrodes and to maintain the crystal at a high value of ratio of reactance to resistance, that any of the clamping projections may have a small additional projection extending from the clamping area thereof insertable in a small depression formed in the crystal and crystal electrode at a nodal point of the crystal to center and position the crystal, that the clamping or contact areas of the clamping projections may be rectangular, round or other shape to suit the nodal points or areas of the particular crystal clamped therebetween and sufficiently small in areas to prevent excessive damping of vibrations of the crystal, that, as pressure changes tend to change the response frequency of the crystal, the springs may be adjusted to equalize or otherwise control the degree of pressure of the clamping areas on the frequency of the crystal, that any of the various features herein disclosed may be applied to any or all of the various embodiments of the invention illustrated in the figures and disclosed in the specification.

While this invention contemplates other forms to resiliently and nodally clamp a plurality of piezoelectric elements without coupling therebetween, it will be noted that the cantilever form of springs, such as the springs 40 to 47, 150 to 154 or 200 to 203 is a very useful form for this purpose, particularly where such crystals are used in an electric wave filter structure as shown in Figs. 1, 12 or 14 for example, and while particular arrangements of the springs 40 to 47, 150 to 154 and 200 to 203 have been illustrated in Figs. 1, 12 and 14 respectively, it will be understood that these or similar cantilever springs may be suitably supported at or adjacent one end thereof from any suitable form, shape or size of insulating block or supporting means and may extend from the supporting points in any desired direction to clamp any suitable crystal or crystals by means of the clamping projections disposed at or near the free ends thereof. Thus, while in Figs. 1 and 2, the corresponding pairs of the springs **40** to **47** extend from the supporting points **64** and **70** in substantially parallel directions and while in Figs. 5 and 7 they extend in non-parallel directions, it will be understood that they may extend in any desired directions by suitable spacing or disposition of the supporting points **64** and **70** with respect to the insulating supporting means utilized or by suitable spacing or disposition of the clamping projections **50** with respect to the crystals and crystal electrodes utilized. For example, the four pairs of the springs **40** to **47** of Fig. 1 may be rotated outwardly about their supporting points **64** and **70** from the parallel position shown in Figs. 1 and 2, beyond the acute angular positions as shown in Figs. 5 and 7 up to the 180 degree position, for example as illustrated by springs **201** and **202** or **200** and **203** in Fig. 14, in which 180 degree angular position the pairs of springs **40** to **47** of Fig. 1 may conveniently accommodate four filter crystals connected in closed series circuit relation as illustrated in Fig. 14.

Or, instead of being rotated outwardly about the supporting points **64** and **70** to the 180 degree relative positions as last-mentioned, the corresponding parallel pairs of springs **40** to **47** of Fig. 1 may be rotated about the clamping projections **50** to the 180 degree positions so that the parallel pairs of springs **40** to **47** of Fig. 1 are supported by suitable insulating blocks (not shown) disposed at the sides of the crystals **10** and **20** rather than from the blocks **60**, **61** and **62** disposed at the top as shown in Fig. 1. It will be understood that single springs of the type shown in Fig. 14 may be utilized in place of the cooperating pairs of the springs **40** to **47** of Fig. 1 to clamp the crystals **10** and **20** of Fig. 1.

While in Fig. 1, the pairs of springs **40** to **47** as for example the pair of springs **40** and **41** have a common axis supporting point **64**, as an alternative arrangement, the supporting points for the pair of springs **40** and **41** for example may be spaced apart along the surface of the insulating block **60** to form a V-shaped arrangement of springs with the coaxial clamping projections **50** of such springs **40** and **41** forming the apex of the V arrangement.

The pressure exerted on the crystal by any of the springs illustrated herein may be adjusted to any suitable value by any suitable means such as by adjusting screws disposed intermediate the supporting point and free end of any of the springs; as for example, between the supporting point **207** and the free end **57** of the spring **201** of Fig. 14, a screw (not shown) may engage the spring **201** and the insulating block **209** to adjust the pressure exerted on the crystal **142** by the spring **201**.

It will be understood that the crystals such as the crystals **10** and **20** of Fig. 1, and the crystals **141** to **144** of Figs. 12 and 14 may have suitable frequencies and interconnections as illustrated in Figs. 1, 12 and 14, for example to constitute an electric wave filter structure adapted to pass a selected band of frequencies and attenuate all other frequencies.

It will be noted that in Figs. 12 and 14, the four crystals **141** to **144** are connected in closed series circuit relation to constitute an electric wave filter system having input and output circuits as illustrated in Fig. 12. In Fig. 14, the input circuit terminals may be terminals **214** and **215** corresponding respectively to the terminals **171** and **173** of Fig. 12, and the output circuit terminals of Fig. 14 may be terminals **212** and **213** corresponding respectively to the terminals **175** and **172** of Fig. 12.

In order to adjust the anti-resonance of such crystals within desired limits, auxiliary adjustable air condensers suitable for use at radio frequencies may be connected in parallel circuit relation with each crystal. Such condensers may consist of short lengths of brass tubing having adjustable concentric brass pins or screws movable longitudinally within the tube to adjust the capacity thereof as illustrated for example in True United States Patent 1,676,417 of July 10, 1928, and may be inserted in suitable holes or cavities in the supporting insulating block, as in the block **209** of Fig. 14, adjacent the corresponding crystals to form a compact unit particularly useful at high frequencies.

Although this invention has been described and illustrated in relation to specific arrangements, it is to be understood that it is capable of application in other organizations and is therefore not to be limited to the particular embodiments disclosed, but only by the scope of the appended claims and the state of the prior art.

What is claimed is:

1. An electric wave filter system including electromechanical vibratory apparatus comprising a plurality of piezoelectric bodies, common supporting structure therefor, and means carried by said structure and including springs having free ends, and a clamping projection secured to the free end of each of said springs for nodally individually clamping and electrically interconnecting said plurality of bodies for independent simultaneous vibration to obtain said wave filter.

2. An electric wave filter system including electromechanical vibratory apparatus comprising a plurality of piezoelectric bodies each having electrodes formed integral therewith, common supporting structure, and means carried by said structure and engaging said electrodes for clamping said plurality of bodies to hold said bodies against bodily movement out of a predetermined position and for independent simultaneous vibration, and means including said clamping means and said electrodes for establishing such electrical connections with said plurality of bodies as to obtain said wave filter.

3. An electric wave filter system including electromechanical vibratory apparatus comprising a plurality of piezoelectric bodies each having electrodes formed integral therewith, common supporting structure, and resilient means including springs each having one end carried by said structure and an opposite free end, conductive clamping projections secured directly to the free ends of said springs and conductively engaging said electrodes for clamping and electrically connecting said plurality of bodies for independent simultaneous vibration at different frequencies to obtain said wave filter.

4. Electromechanical vibratory apparatus comprising a plurality of piezoelectric bodies each having electrodes formed integral therewith, and means including a plurality of cantilever springs each having free ends and supported at one end only for nodally clamping said plurality of bodies from said free ends of said springs.

5. An electromechanical vibrator comprising an electrically deformable body having electrodes

formed integral therewith, at least one of said electrodes having a depression therein at a nodal point of said body, and means nodally clamping said body having a projection insertable in said depression to nodally position said body with respect to said projection.

6. Holder means for a single piezoelectric crystal having a plurality of pairs of opposite electrodes formed integral therewith comprising a plurality of pairs of spaced and oppositely disposed clamping members between which the crystal is clamped and held within a nodal region at opposite points on each of said pairs of electrodes, and means including springs having free ends secured to at least some of said members for pressing said members against said crystal.

7. An electromechanical vibrator comprising a vibratory body having plated electrodes formed integral and closely united therewith, a support, and means carried by the support for rigidly nodally clamping the body and engaging said electrodes to hold the body against bodily movement out of a predetermined position, said clamping means including a leaf spring having a free end and a conductive clamping member secured to and supported by said free end and disposed in electrical contact with one of said electrodes.

8. An electromechanical vibrator comprising a piezoelectric body, a pair of coaxial clamping projections, and means including a spring having a free end secured to and supporting one of said projections for rigidly nodally clamping said body between said projections to hold the body against bodily movement out of a predetermined position.

9. An electromechanical vibrator comprising a piezoelectric body having opposite electrodes formed integral therewith, a pair of conductive coaxial clamping projections oppositely disposed in contact with said electrodes, and means including a spring having a free end secured to one of said projections for rigidly clamping said body within a nodal region to hold the body against bodily movement out of a predetermined position between said projections.

10. An electromechanical vibrator comprising a piezoelectric body having electrodes formed integral therewith, a pair of conductive coaxial clamping members disposed in contact with said electrodes, and means including a spring having a free end secured to and supporting one of said members for clamping said body at oppositely disposed points of relatively small area within a nodal region to hold said body nodally against bodily movement out of a predetermined position between said members, said members having metal tips relatively softer than said electrodes in contact therewith.

11. An electromechanical vibrator comprising a piezoelectric body having electrodes formed integral therewith, a pair of conductive coaxial clamping members disposed in contact with said electrodes, and means including a spring having a free end secured to and supporting one of said clamping members for clamping said body at oppositely disposed points of relatively small area within a nodal region to hold said body nodally against bodily movement out of a predetermined position between said clamping members, said clamping members having metal tips disposed in contact with said electrodes, said metal tips having rounded corners adjacent said electrodes and being relatively softer than said electrodes in contact therewith.

12. An electromechanical vibrator comprising a piezoelectric body having electrodes formed integral therewith, a pair of conductive coaxial clamping members disposed in contact with said electrodes, and means including a spring pivotally supported at one end only and having a free end secured to and supporting one of said clamping members for clamping said body at oppositely disposed points of relatively small area within a nodal region to hold said body nodally against bodily movement out of a predetermined position between said clamping members, said clamping members having metal tips disposed in contact with said electrodes, said metal tips having rounded corners adjacent said electrodes and being relatively softer than said electrodes in contact therewith.

13. An electromechanical vibrator comprising a piezoelectric body having electrodes formed integral and closely united with opposite surfaces thereof and having a depression therein within a nodal region, a pair of conductive coaxial clamping members oppositely disposed in contact with said electrodes, and means including a spring pivotally supported at one end only and having a free end secured to and supporting one of said clamping members for clamping said body at oppositely disposed points of relatively small area within said nodal region to hold said body nodally against bodily movement out of a predetermined position between said clamping members, said clamping members having metal tips disposed in contact with said electrodes, said metal tips having rounded corners and being relatively softer than said electrodes in contact therewith, at least one of said metal tips having a projection insertable in said depression to nodally position said body with respect to said projection.

14. Electromechanical vibratory apparatus comprising a piezoelectric body, a pair of oppositely disposed clamping members between which said body is clamped, and means including a pair of springs each pivotally supported at one end and having opposite free ends attached to and individually supporting said clamping members, for clamping said body at oppositely disposed points of relatively small area to hold said body against bodily movement out of a predetermined position between said clamping members.

15. Electromechanical vibratory apparatus comprising a piezoelectric body having oppositely disposed electrodes formed integral therewith, a pair of opposite conductive clamping members disposed in contact with said electrodes, and means including a pair of springs each pivotally supported at one end and having opposite free ends attached to and individually supporting said clamping members, for clamping said body at oppositely disposed points of relatively small area to hold said body against bodily movement out of a predetermined position between said clamping members.

16. Apparatus for mounting a piezoelectric body having electrodes formed integral therewith comprising means including clamping members for clamping said body therebetween, at least one of said clamping members having a projection insertable in a depression in one of said electrodes and in the surface of said body adjacent thereto to position said body with respect to said clamping members.

17. Apparatus for mounting a plurality of piezoelectric bodies for independent simultaneous vibration comprising common supporting structure, and means carried by said structure for

nodally individually clamping said plurality of bodies at oppositely disposed points of relatively small area to hold each of said bodies against bodily movement out of a predetermined position.

18. Apparatus for mounting a plurality of piezoelectric bodies each having opposite electrodes formed integral therewith comprising a plurality of pairs of oppositely disposed conductive clamping projections engaged in electrical contact with said electrodes of said plurality of bodies at oppositely disposed points of relatively small area, a common support, means carried by said common support for resiliently and individually clamping said plurality of bodies between said plurality of pairs of projections to hold each of said bodies against bodily movement out of a predetermined position.

19. Mounting apparatus for a piezoelectric crystal comprising a plurality of pairs of oppositely disposed clamping projections for clamping the crystal therebetween, means for supporting the projections on one side of the crystal, and means including separate springs having free ends secured to and independently supporting the projections on the opposite side of the crystal.

20. Mounting apparatus for a piezoelectric crystal having two pairs of opposite electrodes formed integral therewith comprising two pairs of conductive clamping projections for nodally clamping the crystal therebetween and establishing individual electrical contacts with the two pairs of electrodes thereof, means for supporting one pair of said projections, and means including springs individually secured to the other pair of said projections for independently supporting said other pair of projections.

21. Apparatus for mounting a piezoelectric body having a plurality of pairs of electrodes formed integral with opposite surfaces thereof comprising a plurality of pairs of oppositely disposed conductive clamping projections between which said body is held in contact with said corresponding electrodes, and means including a plurality of cantilever springs having free ends secured individually to said corresponding projections for clamping said body therebetween at oppositely disposed points of relatively small area to hold said body against bodily movement out of a predetermined position.

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