

July 26, 1938.

R. A. SYKES

2,124,596

PIEZOELECTRIC CRYSTAL APPARATUS

Filed Feb. 19, 1936

3 Sheets-Sheet 1

FIG. 1

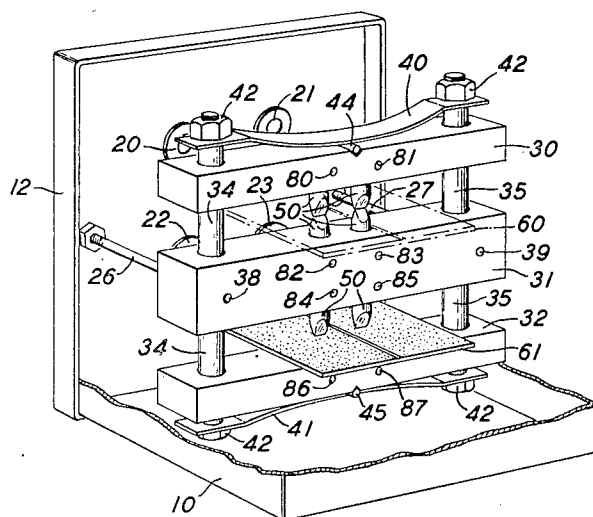


FIG. 2

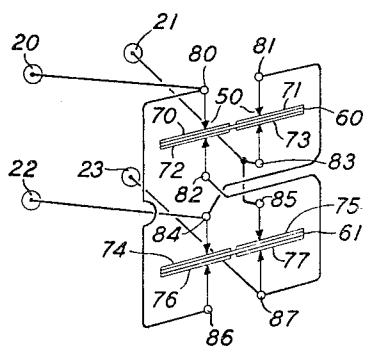
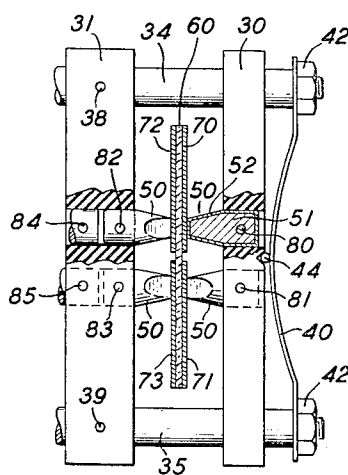


FIG. 3



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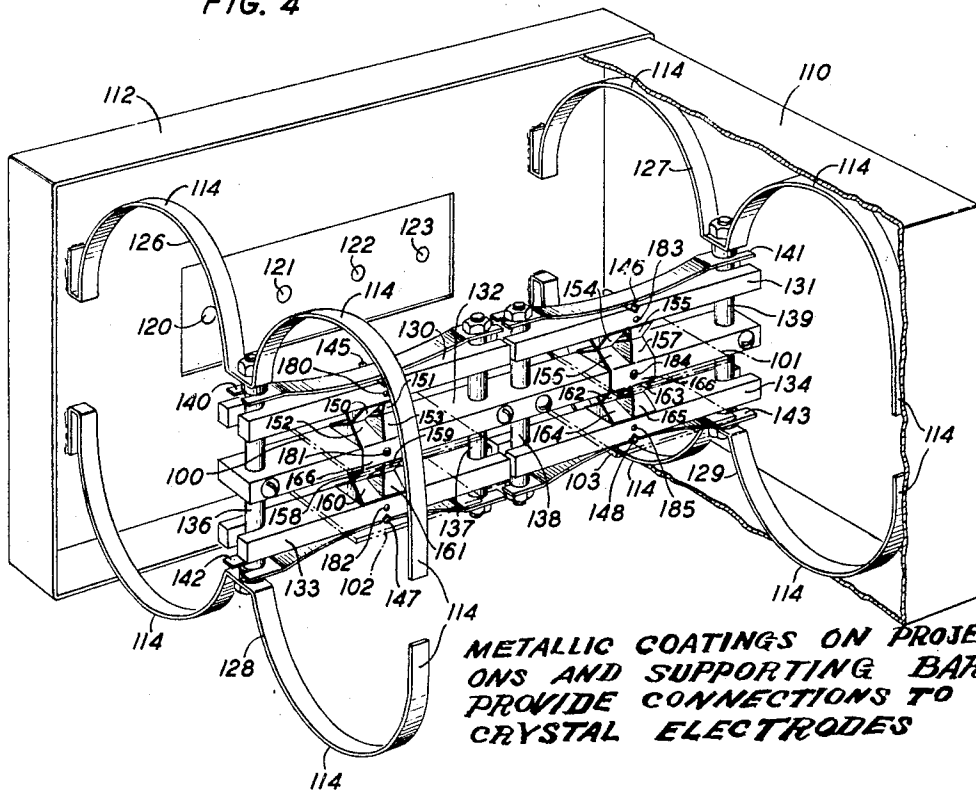
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3 Sheets-Sheet 2

FIG. 4



METALLIC COATINGS ON PROJECTIONS AND SUPPORTING BARS PROVIDE CONNECTIONS TO CRYSTAL ELECTRODES

FIG. 6

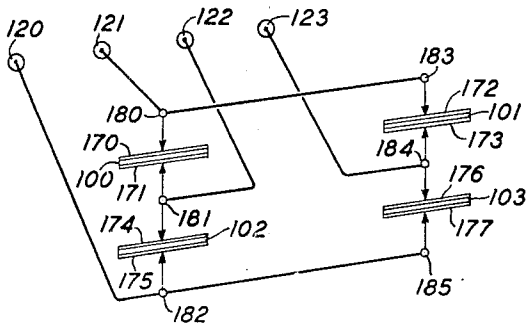
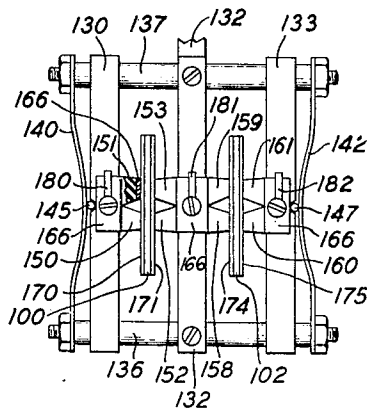


FIG. 5



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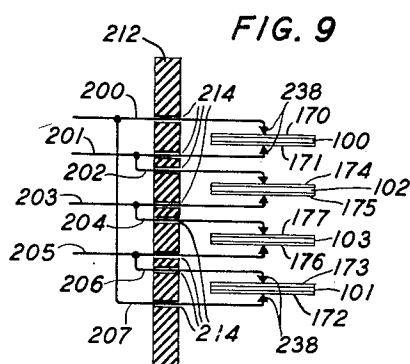
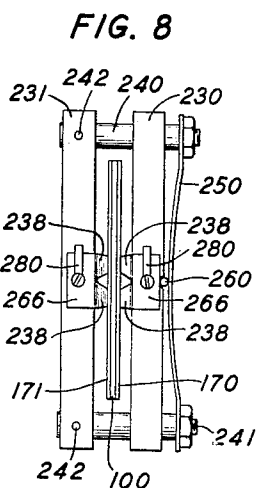
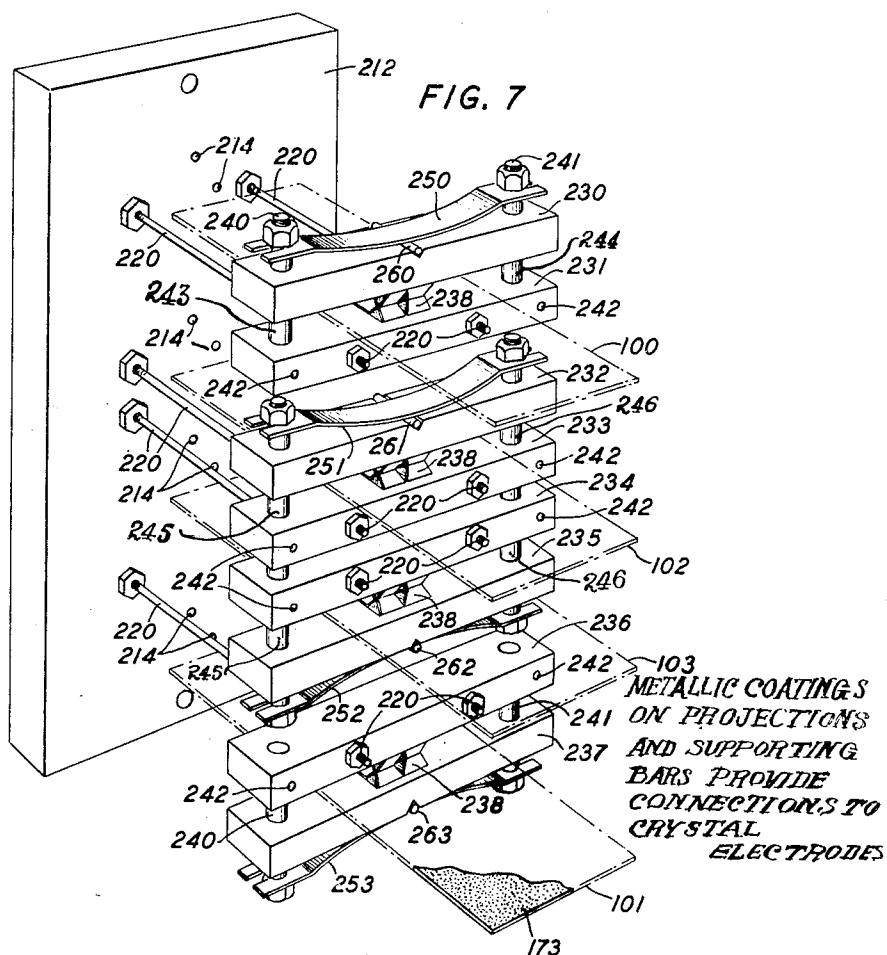
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PIEZOELECTRIC CRYSTAL APPARATUS

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3 Sheets-Sheet 3



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UNITED STATES PATENT OFFICE

2,124,596

PIEZOELECTRIC CRYSTAL APPARATUS

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Application February 19, 1936, Serial No. 64,692

29 Claims. (Cl. 171—327)

This invention relates to piezoelectric apparatus and more particularly to piezoelectric crystals and 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 vibration of a plurality of piezoelectric crystal elements.

Another object of this invention is to improve the constancy of frequency and efficiency of vibrating piezoelectric crystal elements and to control the capacity thereof.

Another object of this invention is to mount in the same holder a plurality of piezoelectric bodies vibrating at different frequencies.

Another object of this invention is to reduce strain in a clamped piezoelectric body.

A further object of this invention is to utilize an insulating body to provide an electrical connection with a piezoelectric crystal element.

Still another object of the invention is to reduce the effect of mechanical shock on a piezoelectric crystal element.

In accordance with one feature of this invention, a plurality of piezoelectric crystals of the same or different frequencies may be supported from a single or common mechanical structure in such manner that each crystal although mechanically interconnected with other crystals is free to vibrate independently at its own resonance frequency with minimum losses and a minimum amount of mechanical vibratory coupling between the plurality of vibrating crystals. The crystals may have divided or split metallic electrodes with a resulting saving in the number of crystals employed. The plurality of crystals may be clamped under substantially equal pressures. A plurality of resiliently supported clamping projections may nodally clamp the crystals and as well serve as electrical contacts with metallic electrodes integral or closely associated with the crystals.

The crystal supporting structure of this invention may be such as to result in lowered cost, economy of space, simplification of electrical connections, reduction of and minimum unbalance in distributed capacities, and balanced capacity between the interconnected elements.

Resilient means in the form of leaf springs each suitably supported at both ends thereof may exert suitable pressures on corresponding slidable insulating members which may support crystal clamping projections intermediate the ends thereof. To secure uniform contact pressure on the crystal and to reduce wear of the

crystal electrodes, the flat clamping or contact areas of each of the clamping projections may have rounded corners and may be 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 the clamping areas of the clamping projections, a small projection, if desired, 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.

It is desirable that the so-called "Q" or ratio of reactance to resistance of a piezoelectric body be maintained at a high and constant value and inasmuch as such value is adversely affected by strains in the piezoelectric body, it is desirable to clamp the crystal body under uniform contact pressures. For this purpose, the clamping areas of any two or more clamping projections disposed on the same side of any piezoelectric body may be made coplanar with respect to each other to conform to the flat surface of the piezoelectric body disposed in contact therewith.

The clamping projections may be made of yieldable material such as a phenol product produced by the condensation of phenol or a phenol derivative in the presence of formaldehyde. Bakelite is an example of such material. Such product being yieldable does not strain the piezoelectric body if the clamping faces thereof are not exactly coplanar with respect to each other or with respect to the surfaces of the piezoelectric body disposed in contact therewith. The corners of the clamping faces or areas of the clamping projections may be rounded if desired to prevent concentration of pressure. To provide electrical connections, the surfaces of the phenol product clamping projections may be covered in part or wholly with metal. The metal coatings may be of relatively soft metal such as gold which being relatively soft and subject to cold flow aids in providing uniform contact pressure on the piezoelectric body disposed in contact therewith.

The metal covering may extend continuously over the surface of any clamping projection as well as over the surface of the corresponding insulating supporting member for the clamping projection to establish an electrical connection between one of crystal electrodes and a terminal mounted upon the supporting member.

The crystal holder may be supported by suitable springs which may depend from the cover

of a container enclosing the holder. The springs may make contact with two oppositely disposed inner side walls and the inner bottom wall of the container to absorb mechanical shocks in two or more transverse directions thereby to reduce the effect of such shocks upon the piezo-electric material and the holder therefor.

While the crystal or crystals herein referred to may be any suitable piezoelectric body whatever of any suitable cut, orientation or mode of vibration the invention is described particularly with reference to quartz piezoelectric crystal plates or bars so cut that the two major or electrode surfaces are parallel to the optic axis and perpendicular to an electric axis thereof and driven in the longitudinal mode of vibration. The electrode faces of the crystal plates may be covered in whole or in part with a layer or layers of conductive material such as for example aluminum, platinum or chromium on top of platinum applied, for example, in vaporized form in a vacuum, which metallic material is closely united or made integral with the surfaces of the piezoelectric element to form the electrodes thereof. The electrodes may partially cover the two major surfaces of the piezoelectric crystal element to reduce the capacity thereof, to increase the efficiency thereof, to guard against excessive voltages applied thereto, to increase the frequency band width of an electric wave filter, or to provide a filter of higher impedance.

The apparatus hereinafter described particularly may be made suitable for mounting crystals which cover a very large range of frequencies. Where the frequencies range from 20 kilocycles to 250 kilocycles, for example, the lengths of the crystal plates may range from over five inches to less than half an inch for example for vibration at a fundamental frequency in a longitudinal mode of vibration. Where quartz crystals vibrating in the harmonic mode of motion are employed, the frequencies may be extended up to and above 1,000 kilocycles for example.

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 this invention;

Fig. 2 is a perspective diagram of the electrical connections of the wave filter device shown in Fig. 1;

Fig. 3 is a view, partly in section, of part of the device shown in Fig. 1;

Fig. 4 is a perspective view of another embodiment of this invention;

Fig. 5 is a view partly in section of a part of the device shown in Fig. 4;

Fig. 6 is a perspective diagram of the electrical connections of the wave filter device shown in Fig. 4;

Fig. 7 is a perspective view of still another embodiment of this invention;

Fig. 8 is a view of part of the device shown in Fig. 7; and

Fig. 9 is a diagram of connections of the wave filter device shown in Fig. 7.

Referring to the drawings, Figs. 1 to 3 show one embodiment of this invention which may include an enclosing copper box 10 of cubical shape having a copper cover 12 that acts as a support for the crystal holder disposed within the box 10. The container 10 may be hermetically sealed or

evacuated to exclude moisture. On the cover 12 and insulated therefrom are four terminals 20 to 23 for making electrical connections with the unit disposed within the container 10. The cover 12 may support two brass rods 26 and 27, or springs as shown in Fig. 4, to hold the crystal holder proper. The crystal holder itself of Figs. 1 to 3 includes three rectangular rods 30, 31 and 32 of phenol fibre such as Bakelite, or alternatively of Isolantite or other suitable high resistance insulating material, supported by two brass rods 34 and 35. The brass rods 34 and 35 are rigidly fastened by pins 38 and 39 to the center insulating rod 31 and act as guides for the two outside insulating rods 30 and 32 which are slidable thereon. The outside insulating rods 30 and 32 are resiliently held in place by means of two curved pieces of spring brass 40 and 41 each supported at both ends by nuts 42 engaging the threaded ends of the rods 34 and 35. The pressure of the springs 40 and 41 may be maintained at the centers of the insulating rods 30 and 32 by means of small round or cylindrical rollers or pins 44 and 45 placed at the centers of the springs 40 and 41 in grooves at the centers of the insulating bars 30 and 32. The three insulating rods 30, 31 and 32 support eight equal metal-covered phenol fibre or metal clamping electrodes or contacts 50 which act as supports for rigidly nodally clamping two piezoelectric crystals 60 and 61 and also serve as individual electrical connections with eight equal-area electrode plates 70 to 77 integral with the crystals 60 and 61. The clamping contacts 50 are held in place by eight separate small brass terminals 80 to 87 extending through the respective clamping projections 50 and through the supporting rods 30 to 32. The terminal pins 80 to 87 also serve as individual electrical connections with the eight metallic clamping projections or contacts 50.

Fig. 2 shows the wiring connections between the eight clamping contacts 50 of the crystal holder and the four terminals 20 to 23 on the cover 12 that may be utilized to form an electric wave filter system employing the piezoelectric crystals 60 and 61 of suitable differing frequencies. In the arrangement illustrated the crystal electrodes 70 to 77 are connected in the form of a symmetrical lattice filter network having input and output terminals 20 to 23. The terminals 20, 21 may be the input terminals and the terminals 22, 23 may be the output terminals, for example. The metal terminal pins 80 to 87 are connected with the crystal electrodes 70 to 77, respectively, by the eight electrically separate metal coated clamping contacts of projections 50. To connect the crystal electrodes 70 to 77 in the form of a lattice network, connections by wires or other suitable connectors are made, respectively, between the terminal pins 80 and 86, 84 and 81, 83 and 85, and 87 and 82. Four wires may form connections, respectively, between the pin 80 and the cover terminal 20, the pin 83 and the cover terminal 21, the pin 84 and the cover terminal 22, and the pin 87 and the cover terminal 23.

Fig. 3 shows in detail a view of one of the symmetrical sides of the holder shown in Fig. 1. The eight metal-covered phenol fibre or metal clamping contacts 50 supported by the insulating rods 30 to 32 may each have a core 51 of phenol fibre or alternatively brass. The core 51 is coated with a relatively heavy coat 52 of metal or metals, such as gold or gold on tin or other metal or metals preferably relatively soft with respect to the metal of the crystal electrodes 70 to 77 in

contact therewith. The soft metal coating 52 may be utilized to prevent rubbing off the relatively hard metal plating such as chromium plating, which may form the top surface of the eight electrodes 70 to 77 of the crystals 60 and 61. Moreover, the soft metal coating 52 will cold flow to make a uniform contact over the flat surfaces on the crystal plates 60 and 61, thus making better electrical contact, avoiding point contacts, providing uniform contact pressures, reducing wear of the crystal electrodes and maintaining a high value of ratio of reactance to resistance of the piezoelectric bodies 60 and 61. For the same purposes, the cores 51 of the clamping electrodes 50 may be formed of phenol fibre which being yieldable does not strain the crystals 60 and 61 if the flat rectangular contact areas thereof disposed in contact with the crystal electrodes 70 to 77 are not exactly coplanar. The phenol fibre cores 51 may be formed integral with or inserted in the phenol fibre bars 30 to 32 and the metal coatings 52 thereon may form the electrical connections respectively between the eight terminals 80 to 87 and the eight crystal electrodes 70 to 77.

The piezoelectric bodies 60 and 61 may each consist of a rectangular section cut from a natural crystal of clear Brazilian quartz. The angular orientation of each crystal element 60 and 61 with respect to the crystallographic axes of the crystal may be such that the principal or electrode surfaces thereof are parallel to a plane perpendicular to one of the natural faces of the crystal. The width dimension of each rectangular element 60 and 61 may be in the direction of the optic axis or, for example, at an angle of approximately -18.5 degrees to the optical axis of the crystal where small shear coupling to the longitudinal mode of motion is desired as disclosed and claimed in copending application for Patent Serial No. 702,334, filed December 14, 1933, by W. P. Mason and R. A. Sykes (25-1). It will be understood that the crystal elements 60 and 61 may be cut from any suitable piezoelectric material and may have any suitable orientation, and may be cut to any suitable shape to provide the frequency or frequencies desired.

The crystals 60 and 61 are integrally coated with metallic electrodes 70 to 77 on both major surfaces thereof for the purpose of securing electrical connection therewith. The metallic coatings 70 to 77 may be any suitable metallic material such as, for example, aluminum, platinum or chromium or a suitable combination of these or other suitable materials, applied for example in vaporized form in a vacuum. By dividing the plating on both major surfaces of each crystal element 60 and 61 along a center line parallel to the longest dimension as shown in Figs. 1 to 3, a single crystal 60 or 61 is made to serve in place of two separate crystals in the opposite arms of the lattice network shown in the electric wave filter system of Fig. 2.

The electrical separation or division between the integral metallic platings of the crystals 60 and 61 as, for example, the platings 70 and 71 of the crystal 60 of Figs. 1 to 3, may be obtained in any suitable manner as, for example, by mechanical or chemical means after the surfaces of the crystal have been plated, or during the process of plating by using a suitable screen. The screen may be, for example, in the form of a flat ribbon wire of suitable narrow width as between .005 and .015 inch, for example, disposed centrally along the major surfaces of the crys-

tal and held in close contact therewith in order to prevent the deposition of metal on that part of the surface of the crystal directly in contact with the wire thereby to provide a suitable high resistance separation, as shown in Figs. 1 to 3, between the metal deposits 70 and 71 deposited on the crystal 60 at both sides of such wire. The screen may be removed after completion of the process of depositing the metal. It will be understood that the division or separation between the platings 70 and 71, for example, may be formed in other ways as, for example, by suitable chemical or mechanical means after the surfaces of the crystal have been plated. For example, the undesired plating may be removed by using carborundum dust or by burning with an electric arc of suitable voltage to form a suitable separation between the metal platings 70 and 71.

The crystals 60 and 61 are rigidly held by suitable pressure applied by the phosphor bronze springs 40 and 41 through the clamps 50 to the crystals 60 and 61 along the nodal points thereof. Electrical contact between the several clamping projections 50 and the metallic platings 70 to 77 of the crystal elements 60 and 61 may be obtained by the metallic coating 52 applied to the phenol fibre cores 51. While the holders in Figs. 1 to 3 have been shown as accommodating two piezoelectric bodies 60 and 61 it may be adapted to hold additional piezoelectric bodies if desired. The particular arrangement illustrated in Figs. 1 to 3 is, however, useful in connection with electric wave filter systems.

It will be noted that each of the piezoelectric crystal plates 60 and 61 and also 100 to 103 shown in Figs. 4 to 9 is held between two spaced pairs of clamping projections such as the projections 50 formed along the center line of the two insulating blocks 30 and 31 of Figs. 1 to 3 for example. The spacing between the projections 50 on each insulating block 30 to 32 is provided so that the projections 50 will make definite contact with the crystal in at least two places on each major face of the crystal to prevent rotation of the crystal when vibrating and also to provide individual electrical connections, as shown in Figs. 1 to 3. Each crystal plate 60 and 61 and also the crystals 100 to 103 of Figs. 4 to 9 is clamped along a line which is approximately perpendicular to the mechanical axis midway between the two small ends of the crystal. This line coincides substantially with a nodal zone of the particular crystals illustrated when vibrating in the longitudinal mode of motion at the fundamental or an odd harmonic frequency and since the crystal is almost at rest in this region the damping effect caused by the clamping is, therefore, reduced to a minimum. The clamping projections 50 as well as all others herein disclosed may have small bearing or clamping areas contacting with the respective crystal electrodes. The bearing area may be made only as large as is necessary in order to hold the crystal securely in position. The larger this area is made, the greater will be the damping effect upon certain crystals and, therefore, in such case, it is desirable to keep the area small and of any suitable configuration to suit the nodal area of the crystal in contact therewith. The smaller the clamping area, the less effect will changes in the clamping pressure have upon the frequency of vibration of the crystal plate. The pressure of the projections 50 against the crystals 60 and 61 may be regulated by adjusting the compression of the springs 40 and 41 under the control of the screw-threaded nuts 42 as illus-

trated in Fig. 1 until the crystals 60 and 61 are held firmly in place by the projections 50.

The individual pairs of clamping projections 50 are coaxially disposed. The clamping areas of the projections 50 may be any suitable shape, such as circular, square, or rectangular, to suit the nodal areas of the piezoelectric elements 60 and 61 clamped therebetween. The clamping areas of any two or more clamping projections 50 disposed in contact with the same side of any piezoelectric element 60 or 61 are coplanar.

It will be understood that the slidable supporting bars 30 and 32 of Figs. 1 to 3 may have end grooves as shown in Fig. 4 instead of holes as shown in Fig. 1, for slidable relation with respect to the rods 34 and 35, that instead of having openings slidable on rods 34 and 35, the insulating bars 30 and 32 may have end projections slidable in corresponding grooves in an associated supporting structure (not shown), that the springs 40 and 41 may be single or multiple layer springs supported at both ends by any suitable means, that the individual connections between the terminals 80 to 87 and the eight corresponding clamping electrodes 50 may be made by metallic coatings deposited on the surfaces of the insulating bars 30 to 32, and that metallic coatings may be deposited on such surfaces of the insulating bars 30 to 32 as well as on the surfaces of the clamping electrodes by any suitable method, such as, for example, by spraying molten metal thereon by means of a Schoop gun, for example, and afterwards removing such parts of the deposited metal that may not be desired thereon to form suitable electrical connections.

Figs. 4, 5 and 6 illustrate another embodiment of this invention adapted to clamp in a common structure four piezoelectric bodies 100 to 103 of suitable frequencies without mechanical vibratory coupling therebetween. Referring to Fig. 4, a copper box 110 and a copper cover 112 for the box 110 holds and encloses the piezoelectric unit. The container 110, 112 may be hermetically sealed or evacuated if desired. On the cover 112 are four insulated terminals 120 to 123 for making outside electrical connections. Four strips of spring brass 126 to 129 are soldered or otherwise secured to the cover 112. The springs 126 to 129 act as supports for the crystal holder and being in resilient contact with two oppositely-disposed inner walls and the inner bottom wall of the can 110 at twelve contact points 114, also act as absorbers of mechanical shocks in three transverse or orthogonal directions. The springs 126 to 129 secured to the cover 112 of the container 110 may be detachable with respect to the crystal holder in any suitable manner such as is disclosed in U. S. Patent 1,978,188, granted October 23, 1934 to D. F. Ciccolella. It will be understood that the springs 126 to 129 may be utilized in connection with any of the several crystal holders illustrated in any of the figures hereof.

The crystal holder of Figs. 4 to 6 includes five rectangular rods 130 to 134 similar to the rods 30 to 32 of Fig. 1 and composed of a high resistance insulating material, such as phenol fibre or alternatively lavite, glass, or Isolantite, for example. Four brass rods 136 to 139 rigidly support the center insulating rod 132 and slidably support the four shorter insulating rods 130, 131, 133, and 134 in end grooves or slots therein. Four phosphor bronze springs 140 to 143 each supported at both ends by the brass rods 136 to 139 maintain pressure at the center of the four insulating rods 130, 131, 133, and 134 by means

of four small round or cylindrical rods 145 to 148 set in corresponding transverse grooves in the respective insulating rods 130, 131, 133 and 134. Sixteen metal-covered phenol fibre projections 150 to 165 integral with or insertable in the insulating rods 130 to 134 on both sides of the centers thereof serve to nodally clamp the four piezoelectric crystals 100 to 103. Upon the surfaces of the clamping projections 150 to 165 are metal coverings 166 of copper foil or preferably of the same type as the metal coatings 52 of Figs. 1 to 3. The metal coverings 166 serve as electrical contacts to the eight equal area electrodes 170 to 177 integral with the major surfaces of the four piezoelectric crystals 100 to 103.

It will be understood that the clamping electrodes 150 to 165 may be constructed in the same manner as the clamping electrodes 50 of Figs. 1 to 3, that the metallic coatings 166 upon the surfaces of the clamping electrodes 150 to 165 may be of the same metallic material as the metallic coatings 52 of Figs. 1 to 3, and that the metallic crystal electrodes 170 to 177 integral with the crystals 100 to 103 may be of the same metallic material as the electrodes 70 to 77 of the crystals 60 and 61 of Figs. 1 to 3.

The crystals 100 to 103 may be of any suitable piezoelectric material having any suitable shape, cut and orientation with respect to the crystalline axes thereof and adapted to vibrate at any selected frequency or frequencies in the fundamental or harmonic mode of motion as desired. As illustrated, the crystals 100 to 103 are quartz elements, cut to have their electrode faces perpendicular to the X or electric axis, are driven in the longitudinal mode of motion by the electrodes 170 to 177, and are nodally clamped midway between the small ends thereof.

Fig. 5 is a view of a section of the holder shown in Fig. 4 and shows more clearly the details of the arrangement wherein the insulated clamping projections 150 to 165 have metal coatings 166 disposed in contact with the electrodes 170 to 177 of the crystals 100 to 103 which may be of different frequencies. The two crystals 100 and 102 shown in Fig. 5 will not, in general, be of the same frequency. The metal coatings 166 extend over the surfaces of the insulating bars 130 to 134 to provide electrical connections between the terminals 180 to 185 mounted thereon and the crystal electrodes 170 to 177. It will be understood that the metallic coatings may be deposited by molten metal spray, or otherwise, on the surfaces of the insulating bars 130 to 134 to form any suitable connections.

Fig. 6 shows perspective the electrical connections between the crystal electrodes 170 to 177 and the terminals 120 to 123 on the cover 112 to form a lattice network type of electric wave filter system. In this case, the four crystals 100 to 103 are connected as shown in the form of a Wheatstone bridge and may include suitable condensers connected in circuit therewith in a known manner. The crystals 100 and 103 are of equal frequency. The crystals 101 and 102 are of equal frequency with respect to each other but of different frequency from that of the crystals 100 and 103 in order to pass a selected band of frequencies. Metallic coatings 166 on the surfaces of the clamping projections 150 to 165 and on the surfaces of the insulating bars 130 to 134 establish electrical connections respectively between the terminal 180 and the crystal electrode 170, between the crystal electrode 171, the terminal 181 and the electrode 174, between the electrode 175 and the terminal 75

182, between the terminal 183 and the electrode 172, between the electrode 173, the terminal 184 and the electrode 175, and between the electrode 177 and the terminal 185. The terminal 180 is connected with the terminal 183. The terminal 182 is connected with the terminal 185. The cover terminals 120 to 123 are connected, respectively, with the terminals 182, 180, 181, and 184.

clamping projections 238 and on the surfaces of the insulating bars 230 to 237, and the interconnections therebetween. The circuit connections shown in Fig. 9 are the same as those shown in Fig. 6. The cover plate 212 may have eight openings 214 therein to permit the wires 200 to 207 to pass therethrough for the connections as shown in Fig. 9.

It will be understood that the unit illustrated in Figs. 7 to 9 instead of being rigidly supported by the eight brass rods 220 may be resiliently supported by springs like the springs 126 to 129 shown in Fig. 4, to absorb mechanical shocks in three transverse directions.

While the embodiments of the invention illustrated in Figs. 4 and 9 show piezoelectric elements 100 to 103 having metal plated electrodes 170 to 177 of the non-divided type of plating, it will be understood that these holders may, if desired, be adapted to clamp and electrically connect piezoelectric crystals of the divided plating type shown in Figs. 1 to 3.

The copper container 10 of Fig. 1 or 110 of Fig. 4 may be utilized to enclose any of the several crystal holders illustrated herein, and may be hermetically sealed to exclude moisture from the crystals and insulating materials. It is desirable that the insulation of parts be maintained at a high and constant resistance value to prevent unbalance between the interconnected circuits of the filter systems illustrated. The vapor sealed within the enclosing container such as the container 10 of Fig. 1 or 110 of Fig. 4 may have moisture removed therefrom prior to sealing or the container may be evacuated to eliminate moisture and air load on the crystals. Connectors passing through the copper enclosure may be sealed in any suitable manner such as for example by a glass bead surrounding each lead-in wire and sealing a flanged opening in the copper container.

The copper contains 10 or 110 enclosing the crystal holders may be grounded or otherwise fixed in potential to prevent capacity effects between the crystal holder and external apparatus.

It will be understood that as to any of the several crystal holders illustrated, the crystal clamping projections may be made either wholly of metal or of yieldable insulating material covered in whole or in part with metallic material disposed on the surfaces thereof, that such metallic material may extend continuously over the surface of the corresponding supporting member for the clamping projection to establish an electrical connection between the corresponding crystal electrode and a terminal mounted upon the supporting member, that the metallic material may cover parts of the surfaces of any of the insulating supporting members of the clamping projections to form any suitable electrical connections, and that the metallic material may be applied to the selected parts in any suitable manner.

Where the clamping projections 50 of Figs. 1 to 3, 150 to 165 of Figs. 4 to 6, and 238 of Figs. 7 to 9 and the corresponding supporting members therefore 30 to 32 of Figs. 1 to 3, 130 to 134 of Figs. 4 to 7, and 230 to 237 of Figs. 7 to 9 are made of phenol fibre such as bakelite, the selected surfaces thereof may be metal plated in the following manner: Sandblast lightly and evenly the selected surfaces to be plated, using for example 40 to 50 mesh silica sand at approximately ten pounds pressure. Remove any finely divided silica dust which adheres to the surfaces after sandblasting by blowing off with compressed

Figs. 7, 8, and 9 illustrate another embodiment of the invention. Referring to Fig. 7, a rectangular mounting and terminal plate 212 of suitable insulating material, such as Isolantite or Bakelite, supports eight equal brass rods 220, which, in turn, support four crystal holders, each consisting of two rectangular rods 230 and 231, 232 and 233, 234 and 235, and 236 and 237, of phenol fibre or other suitable insulating material having sixteen equal-size phenol fibre clamping projections 238 disposed equal distances from the center line of the rods 230 to 237 for nodally clamping the four crystals 100 to 103 at nodal points thereof in the same manner as shown in Figs. 4 to 7. Six brass rods 240, 241, 243, 244, 245 and 246 are rigidly fixed by eight pins 242 to the insulating bars 231, 233, 234, and 236 which are supported by the rods 220 from the mounting plate 212. The rods 240 and 241 are fixed to the insulating bar 235, the rods 243 and 244 are fixed to the insulating bar 231, and the rods 245 and 246 are fixed to the insulating bars 233 and 234. The remaining insulating bars 230, 232, 235 and 237 are slidable on the corresponding brass rods 240, 241, 243, 244, 245 and 246 as illustrated in Fig. 7. Four phosphor bronze springs 250 to 253, each supported at both ends by the corresponding brass rods 240, 241, 243, 244, 245, 246 serve to hold the slidable insulating rods 230, 232, 235, and 237 in place and exert enough pressure between the clamping contacts 238 to prevent the vibrating crystals 100 to 103 from moving in its supports. Metallic coverings 266 as illustrated in Fig. 8, like the metallic coatings 166 of Figs. 4 to 6, or 52 of Figs. 1 to 3, are placed over the surfaces of the sixteen insulating projections 238 and over the surfaces of the insulating bars 230 to 237 to serve as electrical connections with the electrode plates 170 to 177 integral with the surfaces of the piezoelectric crystals 100 to 103 and also to serve as electrical connections with the corresponding terminals 280 mounted upon the insulating bars 230 to 237 in the same manner as shown in Fig. 5.

Fig. 8 which is a sectional view of part of the crystal holder of Fig. 7, shows more clearly the metallic electrode platings on the crystal surfaces as well as the metallic coatings 266 placed over the surfaces of the pairs of phenol fibre projections 238, the corresponding coplanar and coaxial clamping areas of which nodally clamp the crystals 100 to 103 in the same manner as those of the clamping projections 150 to 164 shown in Figs. 4 to 6.

Four cylinder roller rods or pressure centering pins 260 to 263 like the rods 44 and 45 of Figs. 1 to 3 and the rods 145 to 148 of Figs. 4 to 6 are set in corresponding central transverse grooves in the insulating bars 230, 232, 235 and 237 midway between or equidistant from the coplanar pairs of clamping projections to maintain uniform pressure of the springs 250 to 253 on any pair of coplanar clamping projections 238 that are attached to the same or any one insulating bar 230 to 237.

Fig. 9 shows the electrical connections between the crystal electrodes 170 to 177, the corresponding metallic coatings 266 on the surfaces of the

air. The sandblasting is utilized to obtain a rough or etched surface on the Bakelite for proper adherence of the tin when applied by the molten metal spray method. Coat the clean sandblasted areas of the bakelite with a covering of tin by the metal spray method using a metal spray gun. The coating of tin may be from 5 to 10 mills thick deposited continuously over the entire surface to be coated and free from lumps or nodules. Wire the tin-coated parts together by winding or twisting copper wire around the tinned sections. Several parts may be wired together leaving sufficient space between each to allow for electroplating. Clean the wired parts in an electrolytic alkali cleaner for ten to thirty seconds, after which rinse first in clean hot water and then in clean cold water. Dip the parts in a sodium cyanide cleaner and rinse again in clean cold water. Copper plate the tinned parts. Wash the parts in clean cold water and immediately, without allowing the parts to dry, gold plate the copper-covered tin parts of the bakelite. Wash the parts carefully, first in clean cold water, then in clean hot water, and force dry by air blast or steam oven.

While in Figs. 1 to 3 the holder is shown adapted to mount two crystals 60 and 61 of the centrally divided plating type and in Figs. 4 to 9, the holders are shown adapted to mount four crystals 100 to 103 of the non-divided plating type, it will be understood that these holders or sections thereof may be secured together in a common structure to mount one or more crystals of the divided plating type, as the crystal 60, and one or more crystals of the non-divided plating type, as the crystals 100 to 103, in order to suit any particular filter system.

The several crystal holders herein illustrated are adapted for use in mounting piezoelectric crystal plates which vary in size over a considerable range. The crystal elements may have, for example, a frequency of vibration varying in the fundamental longitudinal mode of motion from 50 kilocycles or less up to and above 1,000 kilocycles for the harmonic mode of motion. The dimensions of the component parts of the holder may be varied, if necessary, to suit the crystals employed.

It will be understood that this invention is adapted to support several different frequency piezoelectric crystals from a single or common mechanical structure in such manner that each crystal shall be free to vibrate with low dissipation and shall have a minimum amount of mechanical vibratory coupling between the plurality of crystals to permit isolated resonance thereof and that the arrangement results in economy of space and cost, simplification of wiring, reduction of capacity, and a simplified mounting to insulate against mechanical shock and vibration. Reduction in distributed capacity of interconnections is of particular importance where the shunt capacity across the crystals is of small value.

While in Figs. 1 to 9 of the drawings, the quartz crystals 60, 61 and 100 to 103 have been illustrated as having both of their major faces substantially wholly plated with the metallic platings 70 to 77 of the crystals 60 and 61 and with the metallic platings 170 to 177 of the crystals 100 to 103 to form the electrodes therefor, these electrode surfaces of each crystal may be partially plated by metallic plating covering or integral with only a selected part of the total area of both major surfaces of each crystal in

order to function for such purposes as reduce the internal capacity in the crystals, to increase the driving efficiency thereof, to permit higher voltages to be applied thereto without damage thereto to provide a filter of higher impedance, and to provide a filter of substantially greater band frequency width.

The efficiency of a crystal is related to the ratio of external to internal capacities thereof. Where a crystal such as those illustrated herein is about seventy per cent metal plated centrally on both major surfaces thereof substantially in the direction parallel to the optic axis or perpendicular to the direction of vibration thereof as expressed in generic terms and intermediate the small ends of the crystal, the crystal may be driven more efficiently than when its two major surfaces are wholly plated. Similarly, where such central and oppositely disposed pair of partial platings disposed perpendicular to the direction of vibrations, cover only about half of the major surfaces of the crystal, the crystal may be driven nearly as efficiently as if the whole area of the two major surfaces were plated. Such partial platings disposed perpendicular to the direction of vibrations in a crystal and of suitably selected percentage of plating may be utilized to increase the driving efficiency of crystal to obtain very low values of series capacity in crystals physically of normal size without the use of a condenser in series therewith to provide an electric wave filter system, for example, of substantially greater frequency band width or of higher impedance, to obtain selected values of reduced internal capacity of a crystal to suit the particular design, or to permit higher voltages to be safely applied thereto.

It will be understood that the partial platings oppositely disposed on the electrode surfaces of a crystal may be disposed parallel to the direction of vibrations of the crystal to control the reduced internal capacity thereof or to provide a filter of higher impedance. In the quartz plates 60, 61 or 100 to 103, for example, a decrease in internal capacity thereof may be readily obtained with equal area partial platings on both major surfaces thereof extending longitudinally and centrally along the length thereof parallel to the direction of vibrations therein and perpendicular to the optic axis thereof and covering only part of the optic axis; or such crystals may be driven with the same or better efficiency with oppositely disposed partial platings on both major surfaces thereof intermediate the small ends and extending from side to side in the direction parallel to the optic axis of the crystal and perpendicular to the direction of vibrations therein.

To guard against voltage breakdown over the edges between the two plated surfaces of a crystal, particularly at frequencies of resonance where, in general, the voltages are higher, the partial platings may be disposed only on the central area of each electrode surface of the crystal element back from the marginal edges of the crystal to increase the distance between the two plated surfaces of the crystal.

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. Electromechanical vibratory apparatus

comprising a plurality of piezoelectric bodies subjected to simultaneous vibrations at their respective frequencies, common supporting structure therefor, and means carried by said structure for individually clamping said plurality of bodies at oppositely disposed points of relatively small area to hold said bodies nodally against bodily movement out of a predetermined position, characterized in this that the clamping means includes a slidable insulating member, a spring exerting pressure on said slidable member and means supporting said spring and said member at both ends thereof and that the clamping means permits the simultaneous vibrations of said bodies without mechanical vibratory coupling therebetween.

2. An electromechanical vibrator comprising an electrically deformable body having electrodes integral therewith, and means including a plurality of projections for clamping said body, characterized in this that the projections are of yieldable insulating material and have metal coverings on the surfaces thereof disposed in contact with the respective electrodes.

3. Apparatus according to claim 2, wherein an insulating member supports a projection and the metal covering extends continuously over the surfaces of the member and the projection to establish an electrical connection between one of the electrodes and a terminal mounted upon the insulating member.

4. Piezoelectric apparatus comprising a crystal holder, a container enclosing the holder, a cover for the container and a plurality of springs depending from the cover, characterized in this that the spring support the holder and contact two oppositely-disposed inner side walls and the inner bottom wall of the container to absorb mechanical vibrations and shocks in at least two transverse directions.

5. Electromechanical vibratory apparatus comprising a plurality of piezoelectric bodies, means interconnecting said bodies for obtaining independent simultaneous vibrations thereof, common supporting structure therefor, and means carried by said structure for individually clamping said plurality of bodies without mechanical vibratory coupling therebetween, said clamping means including a slidable insulating member, a spring exerting pressure on said member, and means supporting said spring and said member at both ends of said spring and of said member.

6. Electromechanical vibratory apparatus comprising a plurality of piezoelectric bodies each having electrodes integral therewith, common supporting structure therefor, and means carried by said structure and including a plurality of metal-covered yieldable projections engaging said electrodes for clamping said plurality of bodies.

7. Electromechanical vibratory apparatus comprising a plurality of piezoelectric bodies each having electrodes integral therewith, means interconnecting said bodies for obtaining independent simultaneous vibrations thereof, common supporting structure therefor, and means carried by said structure and including a spring supported at both ends thereof for clamping said plurality of bodies without mechanical vibratory coupling therebetween, one of said bodies having one frequency of vibration and another of said bodies having another frequency of vibration.

8. Electromechanical vibratory apparatus comprising a plurality of piezoelectric bodies each having electrodes integral therewith, and means

including metal-covered yieldable projections nodally clamping said plurality of bodies.

9. Electromechanical vibratory apparatus comprising a plurality of piezoelectric bodies each having electrodes integral therewith, and means for mounting said plurality of bodies in a common supporting structure without mechanical vibratory coupling therebetween and including a plurality of springs each supported at both ends for nodally clamping said plurality of bodies, and connections including said clamping means disposed in electrical contact with said electrodes for obtaining independent simultaneous vibrations of said bodies.

10. An electromechanical vibrator comprising an electrically deformable body having electrodes integral therewith, and means for clamping said body including a plurality of phenol product projections each having a metallic covering thereon disposed in contact with at least one of said electrodes.

11. An electromechanical vibrator comprising an electrically deformable body having electrodes integral therewith, and means for clamping said body including a plurality of projections each composed of yieldable insulating material and each having a metallic covering thereon disposed in contact with at least one of said electrodes.

12. An electromechanical vibrator comprising an electrically deformable body having electrodes integral therewith, and means for clamping said body including a plurality of phenol fibre projections having coplanar clamping areas and having metallic coverings thereon disposed in contact with at least one of said electrodes.

13. An electromechanical vibrator comprising an electrically deformable body having an electrode integral therewith and means for clamping said body including an insulating member having a terminal thereon and a clamping projection of yieldable insulating material extending from said member, said member and projection having a continuous metal covering on the surfaces thereof for establishing electrical connection between said crystal electrode and said terminal.

14. Piezoelectric apparatus comprising a crystal holder, a container enclosing said holder, a cover for said container, and a plurality of springs depending from said cover, supporting said holder and contacting two oppositely-disposed inner sides and the inner bottom surface of said container.

15. Piezoelectric crystal apparatus comprising a crystal holder, a container enclosing said holder, and resilient means supporting said holder and contacting the oppositely-disposed inner walls of said container in at least two transverse directions.

16. Piezoelectric apparatus comprising a plurality of piezoelectric crystals each having electrode plates integral therewith, a holder for said plurality of crystals, a metal container and a metal cover therefor enclosing said crystal holder, and means including a plurality of springs depending from said cover and contacting two oppositely-disposed inner side walls and the inner bottom wall of said container for supporting said crystal holder and for absorbing mechanical shocks in at least two transverse directions, said crystal holder comprising a common supporting structure, and means carried by said common supporting structure for nodally and resiliently clamping said plurality of crystals for independent vibration, said clamping means including a plurality of insulating members each including

a pair of phenol product clamping projections secured thereto and having flat coplanar clamping areas, a leaf spring, means supporting said leaf spring at both its ends and exerting pressure on one of said insulating members, a terminal mounted upon one of said insulating members, and means establishing an electrical connection between one of said crystal electrode plates and said terminal comprising metallic covering extending continuously over the surface of said one of said insulating members and over the surface of at least one of the pair of corresponding clamping projections secured thereto.

17. An electromechanical vibrator comprising a piezoelectric body having an electrode formed integral therewith, and means including a projection for clamping said body, characterized in this, that the projection comprises insulating material having a metallic covering thereon disposed in contact with the electrode to establish electrical connection with the piezoelectric body.

18. Apparatus according to claim 17 wherein a member supports the projection and the metallic covering extends over the surfaces of the member and the projection to establish electrical connection with the electrode.

19. Apparatus comprising a piezoelectric crystal holder, a container enclosing the holder and springs depending from an inner wall of the container and supporting the holder, characterized in this that the springs contact three other inner walls of the container to absorb mechanical shocks in at least two transverse directions.

20. Electromechanical vibratory apparatus including a plurality of piezoelectric bodies each having electrodes formed integral therewith common supporting structure therefor, means carried by said structure and including a plurality of pairs of projections of yieldable material for individually clamping each of said bodies and means interconnecting said electrodes for causing simultaneous vibrations of said plurality of bodies.

21. Electromechanical vibratory apparatus including a plurality of piezoelectric bodies each having electrodes formed integral therewith, supporting structure therefor, means carried by said structure and including a plurality of pairs of projections of yieldable material for individually clamping each of said bodies, and means including metallic material disposed between said projections and said electrodes for establishing such electrical connections with said plurality of bodies as to cause simultaneous vibrations thereof.

22. Electromechanical vibratory apparatus including a plurality of piezoelectric bodies having different frequencies of vibration and having electrodes formed integral therewith, supporting structure therefor, means carried by said structure and including projections of yieldable insulating material having metallic coverings thereon disposed in electrical contact with said electrodes for connecting and individually clamping said bodies at oppositely disposed points of relatively small area within nodal regions to hold said bodies nodally against bodily movement out of predetermined positions, and means including said metallic coverings disposed in contact with said electrodes for establishing such electrical connections with said plurality of bodies as to cause independent simultaneous vibrations thereof at their respective frequencies.

23. Piezoelectric crystal apparatus including a plurality of piezoelectric crystals each having a

plurality of pairs of opposite electrodes formed integral with opposite surfaces thereof, common supporting structure therefor, means carried by said structure and including a plurality of pairs of clamping projections of yieldable material for individually clamping each of said crystals at nodal areas thereof, and means interconnecting said pairs of electrodes for causing simultaneous vibrations of said plurality of crystals.

24. Piezoelectric crystal apparatus including a plurality of piezoelectric crystals each having a plurality of pairs of electrodes formed integral with opposite surfaces thereof, common supporting structure therefor, means carried by said structure and including a plurality of pairs of clamping projections for individually clamping each of said crystals at nodal areas thereof, and means interconnecting said pairs of electrodes for causing simultaneous vibrations of said plurality of crystals.

25. Piezoelectric crystal apparatus including a plurality of piezoelectric crystals each having a plurality of pairs of electrodes formed integral with the surfaces thereof, common supporting structure therefor, means carried by said structure and including a plurality of pairs of clamping projections for individually clamping each of said crystals, and connections including said clamping projections disposed in conductive contact with said electrodes for causing simultaneous vibrations of said plurality of crystals.

26. Piezoelectric crystal apparatus including a pair of piezoelectric crystal plates having different frequencies and each having two pairs of electrodes formed integral with two opposite surfaces thereof, common supporting structure therefor, means carried by said structure and including two pairs of conductive clamping projections for individually clamping each of said plates therebetween at oppositely disposed nodal regions, and means including said pairs of projections disposed in contact with said pairs of electrodes for establishing such individual electrical connections with said pairs of electrodes as to cause simultaneous vibrations of said crystal plates at their respective frequencies.

27. Piezoelectric apparatus including in combination, a plurality of piezoelectric crystals subjected to simultaneous vibrations at their respective frequencies, said crystals having divided electrodes formed integral and closely united with each of the opposite faces thereof, a holder for said plurality of crystals comprising, for each of said crystals, a plurality of pairs of oppositely disposed conductive supports between which the crystal is clamped and held within a nodal region, said supports making individual electrical contacts with the corresponding divided electrodes of the crystal at a plurality of points on each side of the crystal, and means for controlling the pressure of said supports against the crystal including a spring exerting force on relatively movable members secured to said supports.

28. Electromechanical vibratory apparatus including a plurality of piezoelectric bodies having plated electrodes closely united therewith, and having selected different frequencies of vibration, common supporting structure therefor, means carried by said structure for individually and resiliently clamping said bodies without mechanical vibratory coupling therebetween and at oppositely disposed points of relatively small area within nodal regions to hold said bodies nodally against bodily movement out of predetermined positions, and means including said

clamping means disposed in individual electrical contact with said electrodes for establishing such electrical connections with said plurality of bodies as to cause independent simultaneous vibrations thereof at their respective frequencies, each of said bodies comprising a piezoelectric quartz crystal rectangular parallelepiped plate having a pair of electrodes formed integral with one of the two opposite major surfaces of said plate, and another pair of electrodes formed integral with the other of said major surfaces of said plate and disposed opposite said first-mentioned pair of electrodes, said clamping means including for each of said crystal plates two pairs of conductive clamping projections having small clamping surfaces disposed in individual electrical contact with said two pairs of electrodes at the nodal areas of said crystal plate, the clamping surfaces of each pair of said two pairs of projections being substantially coplanar, a member supported at both its ends and secured intermediate its ends to one pair of said two pairs of projections, a slidable member supported at both its ends and secured intermediate its ends to the other pair of said two pairs of projections, and a leaf spring supported at both its ends and exerting pressure intermediate its ends on said slidable

member for clamping said crystal plate between said two pairs of projections.

29. Electromechanical vibratory apparatus including a plurality of piezoelectric bodies having plated electrodes integrally and closely united therewith, common supporting structure therefor, means carried by said structure for individually and resiliently clamping said bodies without mechanical vibratory coupling therebetween, and at oppositely disposed points of relatively small area within nodal regions to hold said bodies nodally against bodily movement out of predetermined positions, said clamping means including, conductive clamping projections disposed in electrical contact with said electrodes, and secured to relatively slidable members supported at both ends thereof, and springs supported at both ends and exerting pressure intermediate the ends thereof upon at least some of said members for clamping said bodies between said projections, and means including said clamping projections disposed in electrical contact with said electrodes for establishing such electrical connections with said bodies as to cause simultaneous vibrations thereof at their respective frequencies.

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