

[72] Inventor **Arnold Lazarus**
43 Dore St., San Francisco, Calif. 94103
[21] Appl. No. **12,354**
[22] Filed **Feb. 18, 1970**
[45] Patented **Nov. 30, 1971**

[54] **METHOD AND APPARATUS FOR SOUND AND VIBRATION DETECTION**
13 Claims, 4 Drawing Figs.

[52] U.S. Cl. **84/1.14,**
84/1.16, 310/8.4
[51] Int. Cl. **G10d 5/00**
[50] Field of Search 84/1.01,
1.16; 310/8.4-8.6; 179/121 D, 121 C, 121 T, 132,
139; 73/67.1-67.9, 133 D; 324/56

[56] **References Cited**

UNITED STATES PATENTS			
1,744,916	1/1930	Nicolson.....	179/110.1
2,280,226	4/1942	Firestone.....	73/67.8
2,728,868	12/1955	Peterson.....	310/8.4
2,963,911	12/1960	Courtney-Pratt et al.	310/8.4 X
3,381,149	4/1968	Wiggins et al.	310/8.5 X
3,437,851	4/1969	Cady	310/8.5 X

3,453,920 7/1969 Scherer 84/1.16
3,538,232 11/1970 Bachtig et al. 310/8.4 X

OTHER REFERENCES

Norman H. Crowhurst, *Electronic Musical Instrument Handbook*, pp. 37- 38, 112- 113, Howard W. Sams & Co., Inc., The Bobbs-Merrill Co., Inc., Indianapolis, New York (Gr. 214)

Primary Examiner—D. F. Duggan
Assistant Examiner—Ulysses Weldon
Attorney—Lindenberg & Freilich

ABSTRACT: A triple-axis shockproof and waterproof vibration transducer is disclosed for detecting vibrations in general and sound from a musical instrument in particular, especially one having a resonant cavity. The transducer includes three piezoelectric vibration detectors, each oriented to detect vibrations along a different one of three orthogonal axes established by walls of a sealed enclosure filled with silicon rubber. All detectors are connected in parallel to the input of a noninverting operational amplifier which adds the separate voltages produced proportional to vibrations along the three orthogonal axes. A universal wax is employed to attach the transducer to the optimum point of the instrument as determined empirically.

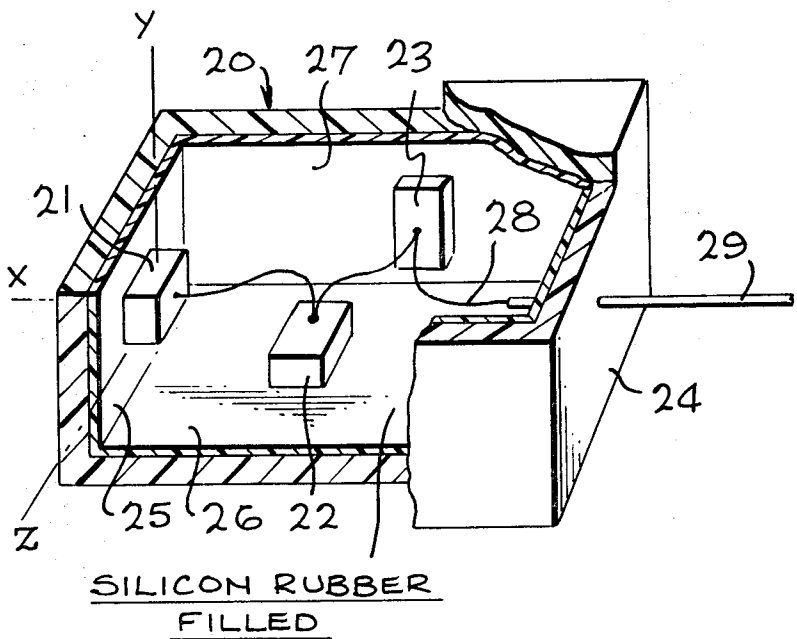


Fig. 1

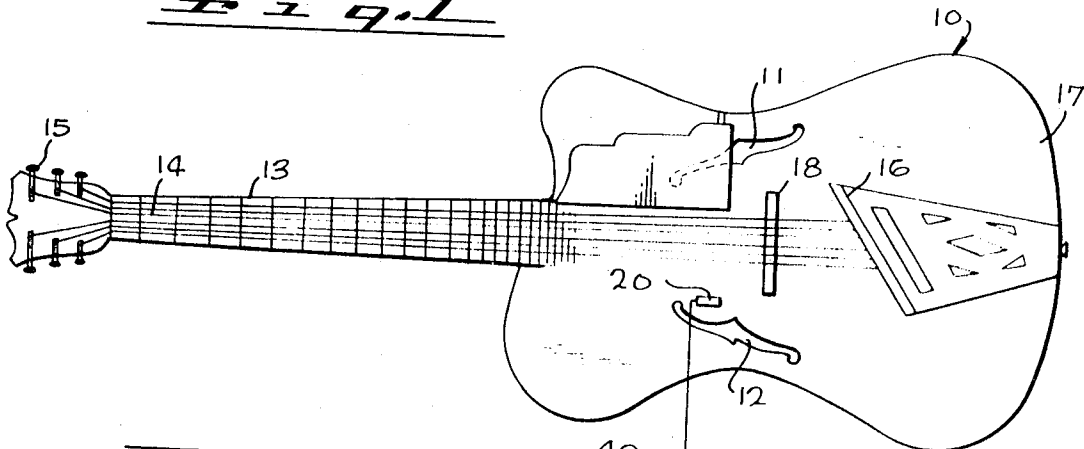


Fig. 2

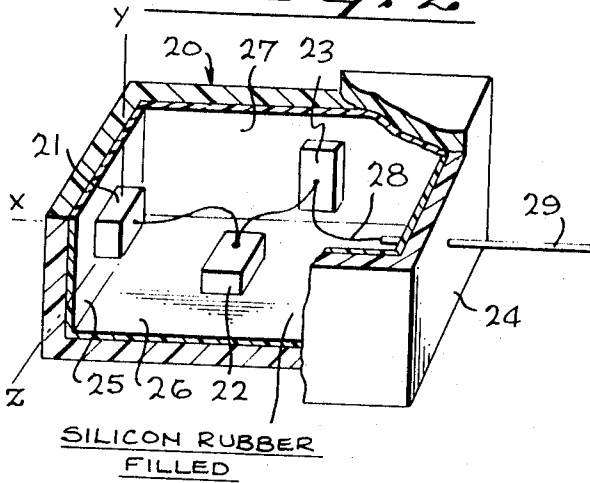


Fig. 3

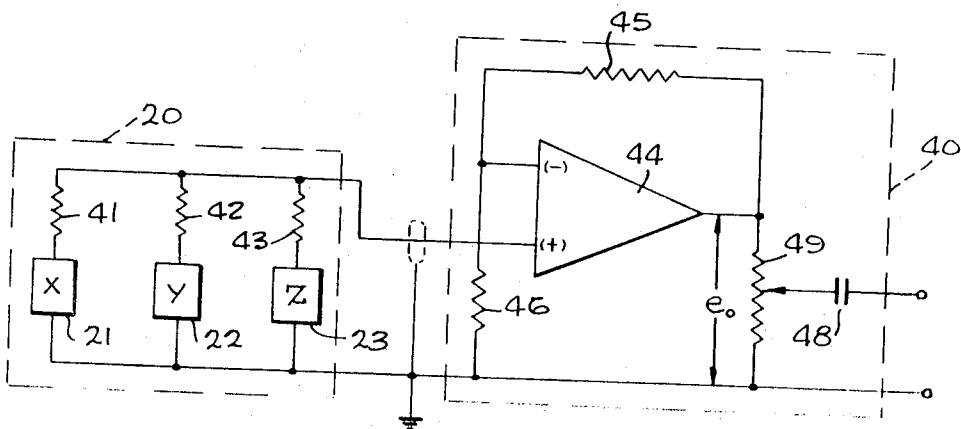
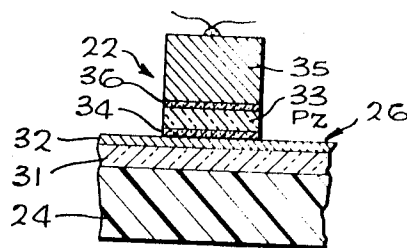


Fig. 4

INVENTOR.
ARNOLD LAZARUS

BY
Lindenberg & Freilich
ATTORNEY

METHOD AND APPARATUS FOR SOUND AND VIBRATION DETECTION

BACKGROUND OF THE INVENTION

This invention relates to a method and apparatus for detecting vibrations, and in particular for converting vibrations from musical instruments, especially ones having a resonant cavity, into high fidelity electrical signals for amplification and reproduction of musical sounds.

A variety of electromechanical transducers have been employed to produce electrical signals from vibrations in general, and of musical instruments in particular. The most common has been a type employing polarized ferroelectric (piezoelectric) ceramics for receiving vibrations, such as from a musical instrument.

While some attention has been given to the nature of mechanical coupling of a transducer to a musical instrument having a resonant cavity, sufficient attention has not been given to the point on the instrument at which attachment should be made, nor to the nature of mechanical motion or vibration produced by the instrument of the point of attachment. For example, it has been standard practice to attach a transducer to a stringed instrument at a point centered under the strings, and near the string bridge. While such a point may be the most effective for producing an electrical signal which corresponds in frequency to the fundamental tone of a given note played, it may not be the most effective point for producing an electrical signal which also corresponds to the overtones that produce the tonal qualities of the musical instrument. Moreover, once such a point of attachment has been selected, it has been standard practice to provide some form of permanent attachment.

An object of this invention is to provide a method of converting a musical sound from an instrument that produces audible sound by vibrations in three orthogonal axes for amplification into an electrical signal which corresponds in frequencies to the tone and the overtones to the musical instrument one hears projected to him through the air.

Still another object is to provide a method of attaching a transducer on a variety of instruments without modification to the transducer or the instrument.

Another object is to provide a transducer on a musical instrument that responds to vibrations in three orthogonal axes for producing an electrical signal to a load that is the sum of separate electrical signals, each proportional to vibrations in a different one of the three axes.

Another object is to provide a transducer on a musical instrument that is effective in producing an electrical signal that includes frequencies of a fundamental tone and overtones created by vibrations in three orthogonal axes of a musical instrument.

OBJECTS AND SUMMARY OF THE INVENTION

These and other objects of the invention are achieved by three vibration detectors mounted on a common base and electrically connected to form a triple-axis transducer adapted to be mechanically coupled to a vibrating object, such as a musical instrument, with adhesive wax. In a musical instrument having a resonant cavity, the point selected is one which reflects the same frequency and tonal qualities of the musical instrument as one hears projected to him from the instrument. That point is determined empirically by mounting the transducer with universal wax that can be readily removed with a solvent. Each of the three vibration detectors is mechanically coupled to the common base and oriented to convert vibrations in a separate one of three orthogonal axes into a proportional electrical signal.

Each of the vibration detectors comprises a piezoelectric (PZ) element held between a conductive film on the common base and an inertia mass with a thin layer of cement. The common base comprises at least three orthogonal walls, one wall for each of the vibration detectors. A given detector is so oriented as to produce an electrical signal in response to the

well-known piezoelectric effect by which an electric charge is produced between the faces of the PZ element when pressure against the faces changes due to vibrational motion of the wall to which attached in a direction normal to the wall. All three of the vibration detectors are electrically connected in parallel with one end of each connected to a summing circuit comprising a high-input impedance operational amplifier.

The novel features that are considered characteristic of this invention are set forth with particularity in the appended claims.

The invention will best be understood from the following description when read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a front view of a musical instrument representative of instruments having a resonant cavity for sound amplification and projection with a transducer attached in accordance with the present invention.

FIG. 2 is an isometric view of a transducer according to the present invention partially broken away to show three detectors mounted for detecting vibrations in three orthogonal axes.

FIG. 3 is an enlarged cross-sectional view of one detector mounted on a wall of a common base according to the present invention.

FIG. 4 is an electrical diagram of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1 of the drawings, there is illustrated a guitar which is representative of musical instruments having resonant cavities for sound amplification and projection. Other instruments which also have a resonant cavity, and therefore may also utilize the present invention for electronically amplifying music more exactly as it sounds than has heretofore been possible, are the violin, cello, bass viol, mandolin, harp, piano and African thumb piano. Still others could acoustically mentioned; the list is given by way of example and not by way of limitation.

The guitar illustrated is a modern music guitar but is similar to any other guitar in that it includes a body portion 10 which is hollow. Openings 11 and 12 on the face of the body portion 10 permit it to function as a resonant cavity for amplification and projection of sound. The term "resonant cavity" is used herein to mean any hollow body having an opening for the purposes of acoustically amplifying and projecting sound.

The guitar includes a fretted neck 13 and six strings held under tension over the neck by tone-adjusting pegs, such as a string 14 held under tension by a peg 15. The other end of each of the strings is tied to a tailpiece 16 anchored to an end 17 of the resonant cavity opposite the neck 13. A bridge 18 serves to hold the strings away from the body 10 and the neck 13 so that they may be free to vibrate when strummed or plucked. The fundamental frequency with which a given string will vibrate is determined by its length from the bridge 18 to a point on the neck 13 against which the string is pressed by the musician.

The face of the resonant cavity will vibrate with the fundamental frequency of a note played. A note is thus amplified by the resonant cavity and, in the process, overtones are created by the interaction of the vibrating string with the resonating cavity. These overtones give the note played a quality which is characteristic of the instrument.

In order to electronically amplify sound from a musical instrument having a resonant cavity, such as the guitar illustrated in FIG. 1, it has been the practice to mechanically couple to the resonant cavity a transducer comprising a vibration detector. The point at which the connection has been customarily made is centered under the strings and near the bridge. In addition, the vibration detector has, in the past, been oriented in a fixed point to detect vibration along a single axis, generally an axis normal to plane tangent to the face of the resonant cavity at the point where the detector is connected.

This prior art arrangement has provided efficient detection of vibration at the frequency of the fundamental note played, but not of vibrations at the frequencies of the overtones. It has been discovered that, to reproduce sound with high fidelity from the electrical signal (as through a loudspeaker), the signal from the transducer must include frequency components of vibrations along three orthogonal axes and not merely along one principal axis. An analogy can be drawn to a ship in a storm. A graph of vertical acceleration will not be nearly as indicative of passenger discomfort as a graph that includes roll and pitch, namely a graph of the sum of acceleration along three orthogonal axes. In the case of a single-axis transducer coupled to the resonant cavity of an instrument, the vibrations along the other two axes may be small, but they contribute significantly to the tonal qualities of the music one hears projected to him directly from the instrument. Therefore, in accordance with the present invention, three orthogonally oriented detectors are provided and their voltage outputs are added directly.

Referring next to FIG. 2, a triple-axis transducer 20 is shown for detecting vibrations along three orthogonal axes in accordance with the present invention. The transducer includes three vibration detectors 21, 22 and 23, each comprising a piezoelectric (PZ) accelerometer for producing a voltage signal proportional to vibrations along one of three orthogonal axes *x*, *y* and *z*, thus converting mechanical energy (sound) into electrical energy suitable for amplification. A housing for the three vibration detectors consists of an epoxy shell 24 having at least three mutually perpendicular walls 25, 26 and 27, each with a copper film on the inside face electrically connected to all other copper films to provide a common support and a common conductor for the vibration detectors.

In practice, five copper-clad boards may be assembled to form an open box. Once the vibration detectors have been cemented to three mutually perpendicular walls as shown, a sixth copper-clad board is electrically connected to the other copper-clad boards and placed as a lid over the box. Alternatively, a single copper-clad board may be cut and folded to form an open box with a lid hinged along one edge. In either case, the copper film is produced on a board of dielectric material, such as epoxy impregnated fiber glass cloth, in the same manner as for conventional circuit boards.

Before placing a lid on the assembly, an inner conductor 28 of a coaxial cable 29 is connected to each of the detectors, and the outer conductor of the cable 29 is electrically connected to the copper film on the walls of the transducer. Then edges of the box, and the opening in the box through which the coaxial cable 29 passes, are sealed with epoxy. Before sealing, the box is filled with silicon rubber, such as Dow Corning 3110 silastic. After sealing, the box assembly is provided with an epoxy shell using conventional epoxy potting techniques. The result is a sensitive, shockproof and waterproof transducer capable of picking up vibrations in three orthogonal axes without electrostatic noise or hum and without acoustic feedback since all of the vibration detectors are shielded and are sensitive to only vibrations of the resonant cavity of the instrument. The silicon rubber fill contributes significantly to the shockproof and waterproof qualities of the transducer without significantly degrading sensitivity.

Before describing the present invention in greater detail with reference to an electrical diagram in FIG. 4, a given vibration detector will be described with reference to FIG. 3. The manner of mechanically coupling the transducer 20 to the musical instrument 10 will also be described first.

Referring now to FIG. 3, which illustrates a cross-sectional view of the vibration detector 22 of FIG. 2, the copper-clad wall 26 inside the epoxy shell 24 is shown as a circuit board 31 having a copper film 32. A PZ element 33 is coupled to the support comprising the epoxy shell 24, circuit board 31 and copper film 32 with a suitable film 34 of cement, such as a cement commercially available under the trade name Eastman 910, or any resin. The cement may be impregnated with conductive particles, such as particles of silver, copper or aluminum to provide a low electrical resistance coupling, but that

is not necessary since the use of a resin having a high dielectric constant simply provides AC coupling of very large capacitance (low impedance).

The PZ element 33 may be made in the form of a disc from a ferroelectric ceramic material, such as a suitable barium titanate of lead titanate zirconate, polarized to exhibit a strong piezoelectric effect in response to stresses and strains in a direction normal to the wall. An inertia mass 35 made of a suitable metal (such as copper) is mechanically coupled to the PZ element 33 with a film 36 of cement of the same material as the film of cement 34. To complete the assembly of the vibration detector 22 in the transducer 24 of FIG. 2, the inertia body 35 is connected to the inner conductor 28 of the coaxial cable 29 as well as the inertia body of the other vibration detectors 21 and 23 as shown in FIG. 2.

Once the transducer 20 has been assembled in the manner illustrated and described with reference to FIGS. 2 and 3, it is mechanically coupled to the resonant cavity of the instrument as shown in FIG. 1 using a universal wax of a type customarily used for vibration testing, such as a wax commercially available under the trade name Cenco Universal Red Wax (Cenco Part No. 11450) described in the CRC handbook of Chemistry and Physics, 40th Edition, at page 3296. A universal wax is preferred for mechanically coupling the transducer to the instrument because it can be readily removed with a suitable solvent, such as xylene, which violin makers use to clean instruments.

It has been discovered that, on instruments having resonant cavities, there is at least one vibration point which reflects the same frequency and tonal qualities of the musical instrument as one hears projected directly to him through the air. The triple-axis transducer 20 is capable of picking up a maximum of overtones created by the fundamental note played on the instrument. These overtones are not governed by the vibration of the string alone, but also by the string interacting with the resonant cavity functioning as an acoustic chamber. In accordance with the present invention, the triple-axis transducer is moved about to find a point on the musical instrument where the overtones detected by the transducer 20 are sufficient to provide the same tonal qualities when the electrical signal produced by the transducer 20 is amplified to drive a loudspeaker or other device adapted to convert electric energy back into acoustic energy. In other words, by moving the triple-axis transducer 20 about the instrument, one can find a vibration point which sounds the same through an electronic amplifier as one hears directly (i.e., unamplified). At each point tested, the transducer 20 is mechanically coupled to the instrument with universal wax.

Operation of the transducer 20, when connected to a summing preamplifier 40 (FIG. 1) will now be described with reference to the schematic diagram of FIG. 4 where the internal impedances of the vibration detectors 21, 22 and 23 are represented by the respective resistors 41, 42 and 43. The internal impedance of a given transducer is very high since it consists of the resistance of its PZ element, inertial mass and a thin film of coupling cement. However, virtually no current flows into the input terminal of an operational amplifier 44 connected as a noninverting high input impedance amplifier having differential inputs (+) and (-) with negative feedback through a voltage dividing network comprising resistors 45 and 46.

Current in the feedback resistors 45 and 46 is the algebraic sum of the currents due to input voltages from the vibration detectors 21, 22 and 23. Thus, each of the vibration detectors contributes to the total feedback current, and therefore the output voltage e_0 . Assuming the voltages produced by the vibration detectors 21, 22 and 23 at a given instant of time are e_1 , e_2 and e_3 , then the output voltage e_0 is given by the following expression:

$$e_0 = \frac{R_0 + R_1}{R_1} (e_1 + e_2 + e_3)$$

where R_0 is the resistance of the feedback resistor 45 and R_1 is the resistance of the bias resistor 46.

It is desirable to employ the operational amplifier 44 as an impedance matching device with an input impedance of over 10^{11} ohms and an output impedance in the order of 150 to 200 ohms, to match the high input impedance of the transducer 20 with the low input impedance of a power amplifier 46 (FIG. 1) adapted to drive a loudspeaker 47, or a standard high fidelity amplifier, tape recorder, studio microphone or the like. To accomplish that, the noninverting operational amplifier configuration shown is preferred with an overall gain of nominally 10, and a 3-db roll off at 5 Hz. established by a filter capacitor 48. The frequency response of the entire system is then from 5 Hz. to an upper limit in order of 100,000 Hz., the upper limit being established by the first resonant point of the ceramic material used in the transducer. A potentiometer 49 is provided at the output of the amplifier 44 as a volume control. Thus, the amplifier 40 not only functions as a summing amplifier but also as an impedance matching preamplifier with volume control.

Although a particular embodiment of the invention has been described and illustrated herein, it is recognized that modifications and variations may readily occur to those skilled in the art. Consequently, it is intended that the claims be interpreted to cover such modifications and equivalents.

What is claimed is:

1. A method of electronically amplifying sound from a vibration point in a musical instrument selected from various points that are subject to vibrations in three orthogonal axes to produce for a given note a fundamental note played and overtones that provide the tonal qualities of said instrument, comprising the steps of:

attaching a transducer to said instrument at one of said various points, said transducer having three vibration detectors, a separate detector for vibrations along each of three orthogonal axes;

adding signals proportional to vibrations in said three axes produced by said three detectors of said transducer in response to vibrations of said instrument at said one vibration point to produce a sum signal;

amplifying said sum signal to produce an amplified signal;

applying said amplified signal to a device for converting said sum signal into audible sound;

moving said transducer about said instrument to said various points and attaching said transducer to said instrument at each point until an optimum vibration point is found where sound produced by said device from said amplified signal sounds the same as unamplified sound directly; and

leaving said transducer at said optimum point for amplification of sound thereafter.

2. A method as defined in claim 1 wherein said instrument has a resonant cavity and said optimum vibration point is on a wall forming said cavity.

3. On a musical instrument, a transducer that responds to vibrations of said instrument in three orthogonal axes for producing across a pair of output terminals of said transducer an electrical signal that is the sum of separate electrical signals, each proportional to vibrations in a different one of said three axes, comprising:

three separate means for detecting vibrations, each adapted to detect vibrations along a different one of said three axes and produce a voltage signal proportional thereto;

a common support means for said detecting means, said support means being adapted to secure each detecting means for detection of vibrations in a different one of said three axes;

means having a pair of input terminals for summing signals applied in parallel across said input terminals to produce a sum signal;

means for connecting said three detecting means in parallel between said input terminals of said summing means; and

means for amplifying said sum signal produced by said summing means.

4. A combination as defined in claim 3 wherein said support means comprises a sealed enclosure filled with silicon rubber.

5. A combination as defined in claim 4 wherein said enclosure is lined with a film of conductive material to form an electrostatic shield, and including a coaxial cable having an outer conductor connected to said film and to one terminal of each of said vibration detecting means to form one output terminal of said pair, and an inner conductor connected to another terminal of each of said vibration detecting means to form a second output terminal of said pair.

6. A combination as defined in claim 5 wherein each vibration detecting means comprises a piezoelectric element having a pair of parallel faces, a first one cemented to said film, and an inertia mass of conductive material cemented to a second one of said pair of parallel faces, whereby an area of said film to which each element is cemented provides one terminal of each of said vibration detecting means and said inertia mass of each of said vibration detecting means provides the other terminal thereof.

7. A combination as defined in claim 6 wherein said summing means comprises a noninverting operational amplifier connected to said detecting means in parallel by said coaxial cable, said noninverting operational amplifier having differential input terminals and an output terminal, a bias resistor connected between one of said differential input terminals and said outer conductor of said coaxial cable, a feedback resistor connected between said amplifier output terminal and said one of said differential input terminals and another of said differential input terminals connected to said inner conductor of said coaxial cable.

8. On a musical instrument, a triple-axis transducer that responds to vibrations of said instrument for producing across a pair of output terminals an output signal that is the sum of three signals, each of said three signals being proportional to vibrations in a different one of three orthogonal axes, comprising:

a common support having three orthogonal conductive walls;

three vibration detectors, each mounted on a unique one of said three walls, and each comprising a piezoelectric element having a pair of parallel faces, a first one of said faces being cemented to a conductive wall, and an inertia mass cemented to a second one of said faces; and

a flexible conductor connecting a first one of said output terminals to said inertia mass of each one of said vibration detectors, and means connecting said conductive walls to a second one of said output terminals.

9. A combination as defined in claim 8, wherein said support is a sealed enclosure filled with silicon rubber.

10. A combination as defined in claim 9, wherein all walls of said sealed enclosure support are conductive to form an electrostatic shield around said detectors.

11. A combination as defined in claim 10, wherein all conductive walls are comprised of a film of conductive material on a board of dielectric material, and all films of all walls are connected together electrically.

12. A combination as defined in claim 11, wherein said first one of said output terminals is connected to an inner conductor of a coaxial cable, and an outer conductor of said coaxial cable is connected to said conductive walls to form said second output terminal.

13. A combination as defined in claim 12, wherein said sealed enclosure support is completely coated on the outside with dielectric and waterproof material to provide an electrical and moisture seal around said outer conductor of said coaxial cable.

* * * * *