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LOW LOSS, BROAD BAND, ULTRASONIC TRANSMISSION SYSTEMS

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FIG. 1

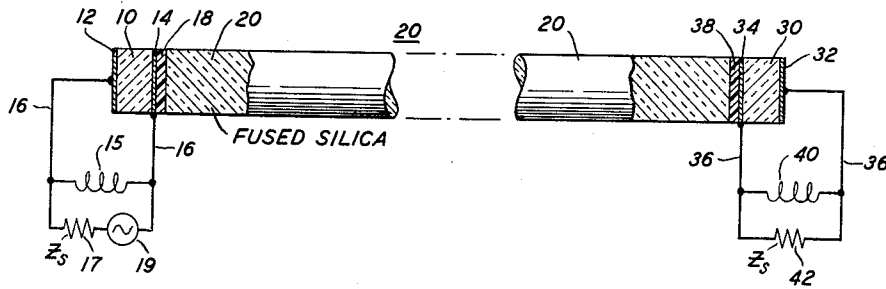
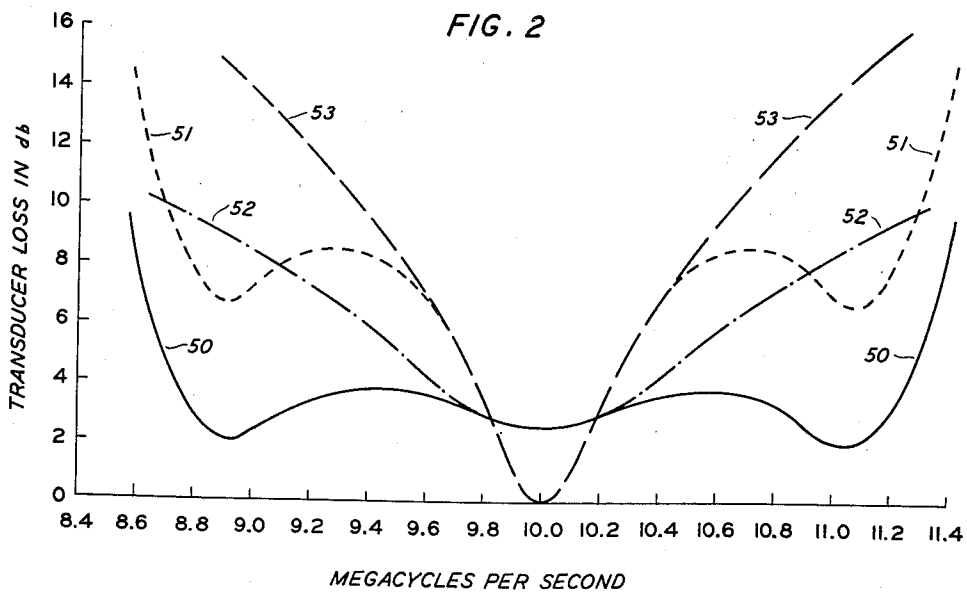


FIG. 2



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7 Claims. (Cl. 333—30)

This invention relates to the "bonding" of electro-mechanical transducers to ultrasonic delay lines. More particularly, it relates to an improved type of "bond" between an electromechanical transducer and an ultrasonic delay line affording a wider frequency transmission band and/or lower loss over the wide frequency band than comparable prior art arrangements.

As is well known to those skilled in the art, one way of expressing "bandwidth" is as a percentage obtained by dividing the width of the band transmitted in cycles per second (or other convenient unit) by the median frequency of that band expressed in the same unit. Throughout this specification "bandwidth" is to be understood as being so defined. For example, a device passing a band of frequencies one thousand cycles wide, centered about a median frequency of ten thousand cycles is said to have a bandwidth of ten percent.

United States Patent No. 2,427,348, granted September 16, 1947, to W. L. Bond and W. P. Mason and United States Patent No. 2,430,013, granted November 4, 1947, to C. W. Hansell, for example, teach the use of an intermediate layer of material or "bond" between a transducer and its associated acoustic (or vibratory energy) transmission medium, the intermediate layer being substantially one quarter wavelength thick and having a characteristic mechanical impedance which is substantially the geometric mean of the characteristic impedances of the crystal and the medium. The "bond" is employed in these patents mainly for the purpose of reducing the reflection of power at the junction between the medium and the transducer, by providing, effectively, a better "impedance match" between the characteristic mechanical impedances of the transducer and the medium.

Applicant's copending application Serial No. 151,175, filed March 22, 1950, Patent No. 2,672,590, granted March 16, 1954, teaches that a solder and foil "bond," one quarter median wavelength thick, between a transducer and a solid acoustic or ultrasonic transmission line will substantially widen the transmission frequency band between the transducer and the medium. Such a "bond" is employed, in accordance with the teaching of the application, to provide a quarter wavelength bond having a characteristic mechanical impedance substantially greater than that of the acoustic or ultrasonic transmission medium.

The present invention teaches that "bonds" substantially one half wavelength at the median frequency of the transmission band of frequencies in length, or thickness, in the direction of energy transmission, and having a characteristic mechanical impedance, which is smaller than the characteristic mechanical impedance of the acoustic or ultrasonic transmission medium, will, when interposed between the transducer and the transmission medium and used in conjunction with suitably chosen electrical terminal circuits provide a considerably wider frequency band of transmission and lower losses in the wider transmission band than any prior art "bond" of which applicant is aware. An additional advantageous

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feature of the "bonds" of the invention is their relative simplicity so that they are easily and economically manufactured and assembled in the over-all acoustic or ultrasonic transmission system.

For the purposes of the present invention the term "bond" will be applied to an intermediate member serving to mechanically interconnect an electromechanical transducer with an acoustic or ultrasonic transmission medium. The half wavelength dimension mentioned above for the thickness of the bond is, of course, determined by the velocity of propagation for the ultrasonic waves transmitted within the bond material.

A principal object of the invention is to improve the operation of arrangements employing electro-mechanical transducers with solid ultrasonic delay lines to transmit and/or receive acoustic or ultrasonic wave energy.

Another object is to provide simple, effective and economical bonds between electromechanical transducers and acoustic or ultrasonic wave transmission media which will, in conjunction with suitably chosen electrical terminal circuits, afford wider frequency band operation with lower losses in the wider frequency band.

Other and further objects will become apparent during the course of the following detailed description of illustrative embodiments of the principles of the present invention and from the appended claims.

The principles of the present invention will be more readily perceived from the following description of various arrangements of the invention described below and from the accompanying drawing in which Fig. 1 illustrates a typical arrangement of the invention; and

Fig. 2 shows curves of transmission loss versus frequency per transducer for a quartz crystal transducer operating with a fused silica delay line, with and without a one half wavelength seal and with particular electrical terminations, respectively.

In more detail in Fig. 1 a typical arrangement of the invention is illustrated and comprises an acoustic or ultrasonic delay line 20, at one end of which are a piezoelectric transducer 10, having electrically conductive terminal platings 12 and 14 to which the pair of electrically conductive leads 16 are connected, respectively, as shown. An inductance 15 is connected in shunt across leads 16 and a source of electrical energy 19 having an impedance 17 of value Z_s is connected to leads 16 as shown. A bond 18 is provided to interconnect the transducer 10 and the acoustic or ultrasonic delay line 20 for the transfer of mechanical vibratory energy between transducer 10 and line 20. At the other end of delay line 20, a second transducer 30 having terminal platings 32 and 34 to which are respectively connected the conductive leads 36, as shown, is similarly connected mechanically to line 20 by bond 38. An inductance 40 and a resistive termination 42 having an impedance Z_s are connected across leads 36, as shown.

Of the presently known materials which exhibit piezoelectric properties to any substantial degree, the single crystal of quartz and the class of ceramics consisting mainly of barium titanate but preferably including minor percentages of lead, calcium or other titanates, for example 80 percent barium titanate, 12 percent lead titanate and 8 percent calcium titanate, have been found most practicable for use as piezoelectric electromechanical transducers in acoustic and ultrasonic arrangements. For lower frequency systems, below one megacycle, for example, magnetostrictive or other electromechanical types of transducers, not employing piezoelectric properties, can be employed to advantage in accordance with the principles of the present invention.

Of the above mentioned two piezoelectric materials, the ceramic has, as is well known to those skilled in the art, a considerably higher electromechanical coupling

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and is therefore, in general, capable of yielding larger frequency bandwidths for a given loss.

The use of quartz may be indicated, however, for some applications, particularly in view of the higher electrical impedance level afforded and its superior performance at extremely high frequencies, for example, at frequencies in the order of 30 to 60 megacycles, or more.

In a particular instance, by way of example, the electrical impedance of a quartz transducer was found to be several thousand ohms as compared to approximately 100 ohms for a ceramic transducer.

In electromechanical arrangements designed to be interconnected between a circuit of high electrical impedance and a circuit of low electrical impedance, the use of a quartz transducer at the high impedance end and a ceramic transducer at the low impedance end may often prove advantageous.

One preferred material for the bonds 18 and 38 of Fig. 1 is polystyrene, which may, if necessary, be "loaded" with particles of other materials to increase its effective characteristic mechanical impedance. Alternative bond materials and constructions will be described hereinafter. Bonds 18 and 38 are cemented to their respective transducers 10 and 30 and to the delay line 20 at its respective ends by means of a polymerizing bonding resin, for example, or other strong adhesive of which only a thin film is required to provide a mechanically strong union. The bonds are made substantially one half wavelength long (including the adhesive), at the median frequency of the band to be transmitted. Their cross sections are of substantially the same dimensions as for the transducers 10 and 30 and the delay line 20.

The delay line 20 of Fig. 1 is preferably of fused silica, alternative materials being various types of glass and perhaps magnesium, though in general the variable grain structures usually encountered in metals make it extremely difficult to obtain consistent results if metal delay lines are used.

The delay line 20 can conveniently be a round rod and its length is proportioned to provide the desired delay. For example, a fused silica rod three quarters of an inch in diameter and eight inches long will provide a delay of substantially 54 microseconds when shear waves are used.

In general, Y-cut piezoelectric quartz transducers will vibrate in the shear mode, whereas X-cut quartz and ceramic transducers of the above mentioned type (principally of barium titanate) will produce simple longitudinal vibration giving rise to longitudinal waves in the delay line. Since the velocity of the latter waves is usually about twice that of the shear waves the characteristic mechanical impedances of the various materials such as polystyrene will be substantially double the values mentioned hereinafter for shear waves. When longitudinal waves are used the delay will, of course, be substantially one half of that for shear waves for a specific delay line. It should be noted that the above mentioned patents to Bond and Mason and to Hansell employ longitudinal waves and therefore the characteristic mechanical impedances referred to in said patents are substantially double the characteristic mechanical impedances assigned to the same materials in instances where the transmission of shear waves is contemplated.

As mentioned above, transducers 10 and 30 may both be of the single crystal quartz type where the over-all delay line is to be connected to high impedance electrical circuits at both ends or where the over-all device is to be operated at very high frequencies.

Where both circuits to which the over-all device is to be connected are of low electrical impedance, transducers of the ceramic type, above described, may prove preferable to the quartz type. Also where extremely broad frequency band operation is desired at appropriate fre-

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quencies the ceramic type of transducer may be preferable.

Where one circuit is of high impedance and the other of low, it may be preferable to employ a quartz crystal transducer at the high impedance end and a ceramic type transducer at the low impedance end.

Alternatively, electrical impedance matching can, of course, be effected by using appropriately designed transformers between the transducers and the electrical circuits to which they are to be connected.

The delay line of Fig. 1 is of the simple straight-through transmission type, but the principles of the invention are obviously also directly applicable with delay lines employing multiple paths and reflecting the wave one or more times to obtain increased delay from a line of moderate dimensions, as is done, for example, in the wedge-shaped delay lines disclosed in applicant's copending application Serial No. 331,299, filed January 14, 1953. This application matured into Patent 2,839,731 granted June 17, 1958.

An alternative use of a portion of the structure illustrated in Fig. 1 of the drawing, by way of example, could be based upon omitting bond 38 and transducer 30 at the far end of line 20. With such a structure a relatively short duration signal such as a pulse could be introduced by transducer 10 and bond 18 into line 20 which upon reaching the far end of line 20 would be reflected back to the near end and emerge from leads 16 with a delay double that for the straight-through transmission from transducer 10 to transducer 30. As is well known to those skilled in the art, successive echoes of a single pulse are sometimes employed to provide a series of pulses the spacing of which is the delay introduced by traversing the delay line twice.

One illustrative combination of the invention, by way of example, employs shear waves and comprises Y-cut quartz piezoelectric transducers having a characteristic mechanical impedance Z_x of 10.4×10^5 mechanical ohms per square centimeter (centimeter-gram-second), bonds of polystyrene having a characteristic mechanical impedance Z_0 of 1.19×10^5 and a fused silica delay rod or line having a characteristic mechanical impedance Z_q of 8.27×10^5 , the bond thicknesses in the direction of transmission each being substantially one half wavelength at the median frequency (10 megacycles) of the transmitted band of frequencies. This combination has a bandwidth in the order of 25 percent and involves a loss varying between approximately 2.0 and 3.8 decibels per transducer throughout the pass band. The generator impedance 17 of Fig. 1 having a value Z_s and the far end terminating impedance 42 also having a value of Z_s , (specified in equivalent mechanical units in the manner discussed on page 403 of W. P. Mason's book entitled "Electro-Mechanical Transducers and Wave Filters," published by D. Van Nostrand Co., Inc., New York, second edition, October 1948), are both made substantially two-tenths of the value of Z_q for optimum performance. Inductances 15 and 40 as shown in Fig. 1 are, in each instance, given values such that they each anti-resonate with the capacitance of their respective associated transducers at the median frequency of the transmitted frequency band.

While the value of Z_s (impedances 17 and 42) for optimum performance can be calculated by the application of conventional wave filter design techniques, it can also be readily determined experimentally by employing variable potentiometers as part or all of the impedances 17 and 42, respectively, of Fig. 1. A few trial adjustments and corresponding transmission measurements in the pass band will soon indicate the value of Z_s which should be used for optimum performance.

It should be borne in mind that, as is well understood by those skilled in the art, a composite electro-mechanical system can be readily converted either to an equivalent all-electrical system or, alternatively, to an equivalent all-

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mechanical system, the principles involved in either case being fully explained, for example, in the above mentioned book by W. P. Mason.

By increasing the characteristic mechanical impedance of the one half wavelength bonds 18 and 38 of Fig. 1 to $2.5 \times 10^5 (Z_0)$, by, for example, using "loaded" or laminated bonds of the types described in the above mentioned patent to Bond and Mason, a flatter band in the order of 32 percent can be obtained but at an increase in the loss per transducer which varies between approximately 4.2 and 5.6 decibels throughout the pass band. The electrical input and output impedances Z_s are, for optimum performance with this combination, adjusted to substantially .12 Z_q as described for the illustrative combination mentioned above.

Similarly by increasing the mechanical impedance of the one half wavelength bonds to approximately $5 \times 10^5 (Z_0)$ a still flatter pass band with a bandwidth in the order of 50 percent can be obtained but with the loss per transducer increased to substantially 8.4 decibels throughout the passband. The electrical input and output impedances Z_s are, for optimum performance with this combination, adjusted to substantially .04 Z_q , as above described.

The curves 50 through 53, inclusive, of Fig. 2, illustrate graphically the improved operation accorded by a specific combination of the invention of the general type illustrated in Fig. 1.

The curve 50 shows the transmission loss per transducer versus frequency for a combination as illustrated in Fig. 1, using quartz crystal transducers, one half wavelength bonds and a fused silica delay line, the impedances of the electrical circuits having been adjusted for optimum performance, in the manner indicated above, to substantially two-tenths of the characteristic mechanical impedance Z_q of the delay line 20.

The curve 52 shows the transmission loss per transducer versus frequency for the same combination as described above for curve 50 except that the one half wavelength bonds have been omitted and the quartz crystal transducers have been cemented directly to the ends of the delay line.

The curve 51 shows the transmission loss per transducer versus frequency for the same combination as described above for curve 50 except that the impedances of the electrical circuits have been adjusted, in the manner indicated above, to substantially equal the characteristic mechanical impedance Z_q of the delay line 20.

Finally the curve 53 shows the transmission loss per transducer versus frequency for the same combination as described above for curve 52 except that the impedances of the electrical circuits have been adjusted in the manner indicated above, to substantially equal the characteristic mechanical impedance Z_q of delay line 20.

A further combination of the invention comprises ceramic transducers of the above described type (mainly of barium titanate) having a characteristic mechanical impedance Z_x for longitudinal waves of 28×10^5 , "loaded" polystyrene or laminated bonds one half wavelength thick at the median frequency having a characteristic mechanical impedance Z_0 of 4×10^5 and a fused silica delay rod or line having a characteristic mechanical impedance Z_q of 13.1×10^5 . The electrical input and output impedances Z_s , 17 and 42, are adjusted in the manner indicated above to substantially 1.7 Z_q , for optimum performance. This combination provides a frequency bandwidth in the order of 37 percent with a loss of approximately .34 decibel throughout the transmitted band.

A still further combination of the invention comprises ceramic transducers (mainly of barium titanate, as above

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described) having a characteristic mechanical impedance Z_x of 28×10^5 , "loaded" polystyrene or laminated bonds one half wavelength thick at the median frequency having a mechanical impedance Z_0 of 7.5×10^5 and a fused silica delay rod or line 20 having a mechanical impedance Z_q of 13.1×10^5 . The electrical input and output impedances Z_s , 17 and 42, are adjusted in the manner indicated above, to substantially .64 Z_q , for optimum performance. This combination provides a frequency bandwidth in the order of 46 percent with an essentially flat or uniform loss throughout the frequency band of approximately .2 decibel.

The above combinations, employing ceramic transducers, compare with a 30 percent bandwidth with negligible loss throughout the band for a ceramic transducer (mainly barium titanate, as above described) cemented directly to a fused silica delay line.

Numerous and varied other combinations of transducers, bonds and delay lines can be readily devised by those skilled in the art within the spirit and scope of the principles of the present invention. No attempt to exhaustively cover all possible such combinations has been made.

What is claimed is:

1. In combination, an electromechanical transducer, an ultrasonic transmission medium and a bond of ultrasonic transmitting material mechanically interconnecting said transducer and said medium, said bond having a thickness, in the direction of transmission, of substantially one half wavelength at the median frequency to be transmitted and a uniform characteristic mechanical impedance less than that of either of said medium or said transducer whereby a broad frequency band may be transmitted between said transducer and said medium with low transmission loss throughout said broad band.
2. The combination of claim 1 in which said transducer is a piezoelectric quartz crystal type of transducer, said bond is of polystyrene and said transmission medium is a fused silica rod.
3. The combination of claim 2 in which said bond is of polystyrene having metal particles embedded therein.
4. The combination of claim 1 in which said transducer is a ceramic comprising mainly barium titanate with minor percentages of other titanates, said bond is of polystyrene and said transmission medium is a rod of glass.
5. The combination of claim 4 in which said bond is of polystyrene having metal particles embedded therein.
6. The combination of claim 1 in which said transducer is a ceramic comprising mainly barium titanate, said bond is of polystyrene having metal particles embedded therein and said transmission medium is a fused silica rod.
7. In combination a rod of material having low transmission loss for ultrasonic waves; first and second electromechanical transducers and first and second bonds mechanically interconnecting the ends of said rod to said first and said second transducers, respectively, said bonds each having a thickness in the direction of transmission of substantially one half wavelength at the median frequency to be transmitted and a uniform characteristic mechanical impedance smaller than the characteristic mechanical impedance of either said rod or said transducers.

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