

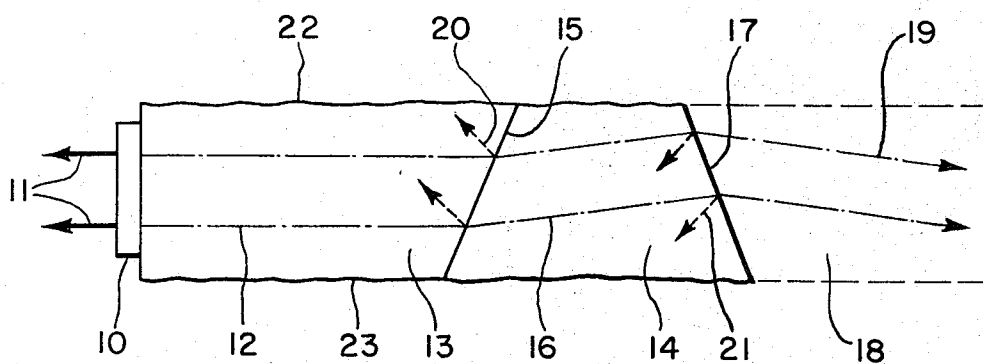
May 14, 1968

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3,383,631

ACOUSTIC IMPEDANCE MATCHING

Filed Sept. 16, 1965



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ACOUSTIC IMPEDANCE MATCHING

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Continuation-in-part of application Ser. No. 476,875, Aug. 3, 1965. This application Sept. 16, 1965, Ser. No. 490,160

4 Claims. (Cl. 333—30)

ABSTRACT OF THE DISCLOSURE

Improved coupling of sound between a transducer and a low-effective-transfer-impedance medium such as water is obtained by an impedance matching system interposing one or more solid media. The medium coupled to the transducer is selected to have the impedance preferred by the transducer to attain a desired bandwidth. Other media impedance relationships provide maximum power transmission between the transducer and the water. The common boundary between the different media are oriented relative to the path of sound waves in one material to effect dispersion of the reflected energy.

The present application is a continuation-in-part of co-pending application Ser. No. 476,875, filed Aug. 3, 1965, by Adrianus Korpel for Impedance Matching and assigned to the same assignee as the present application.

This invention pertains to signal translating apparatus. More particularly it relates to sound propagation systems in which sound waves are propagated through a plurality of media in succession. The term "sound" is utilized herein generically to embrace wave energy not only at audible frequencies but which may be at frequencies extending even into the microwave region.

When a transducer is used to drive a medium of considerably lower acoustic impedance, it usually is difficult to obtain both a good efficiency of power transfer and a wide bandwidth. One approach has been to use a quarter-wave transformer; however, if only one such transformer is employed the bandwidth is severely limited. This particular limitation can be overcome by using several quarter-wave transformers in cascade. For example, if two transformers are used, they should have impedances of $Z_w n^4$ and $Z_w n^4$, respectively, where nZ_w is that load impedance which provides the desired transducer loading, and Z_w is the final load impedance to which transformation is to be made. In practice, between a piezoelectric element and water, the impedance ratio n has a value between 10 and 20. Thus, the value of n^4 (for a single quarter-wave section) is between 3 and 5 and n^4 and n^4 are about 2 and 8, respectively. The corresponding impedances of the transformers are about 6 for n^4 , 3 for n^4 and 12 for n^4 , all expressed in terms of 10^6 kilogram-meter⁻²-seconds⁻¹.

It is not easy to obtain practical materials for a single quarter-wave matching section; materials of appropriate impedance have been synthesized by filling an epoxy with metal powder, but such a mixture does not lead itself well to being formed into thin sheets. The thicknesses involved often are of the order of 0.001 inch as a result of which the fabrication of such structures is at best difficult. Suitable materials have been found to exist for double, cascaded quarter-wave sections. However, such arrangements also are inconvenient because of the necessity of cementing together several precise layers of materials having widely different properties. In the usual operation, all of the layers, including the transducer, are extremely thin and even flimsy. For this reason, piezoelectric half-wave transducers operative in the range of 30–100 mega-

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cycles are difficult to obtain, particularly if they are to be made from ceramic materials.

It is accordingly a general object of the present invention to provide an improved system for coupling sound waves between different media.

Another object of the present invention is to provide such a system wherein a transducer, which may be extremely thin, is attached to a substrate of much greater substance.

A further object of the present invention is to provide a sound transducing system having improved qualities of impedance match.

In accordance with the present invention, signal translating apparatus includes a first medium having a boundary toward which waves of sound energy are propagated together with means for developing those sound waves. A second medium has a first boundary common with that of the first medium and is responsive to the sound waves from the first medium for propagating waves of the sound energy toward a second boundary. In a preferred embodiment, a third medium has one boundary common with the aforesaid second boundary of the second medium and is responsive to the sound waves from that second medium for propagating the sound energy. The first and second boundaries are oriented relative to the path of the sound waves in the first and second media to effect dispersal of sound waves reflected therefrom away from the paths of the sound waves so as not to effect the impedance seen from the transducer.

The features of the present invention which are believed to be novel are set forth with particularity in the appended claims. The organization and manner of operation of the invention together with further objects and advantages thereof, may best be taken by reference to the following description taken in conjunction with the accompanying drawing in which the single figure is a schematic diagram of sound propagating apparatus constructed in accordance with the invention.

As illustrated in the invention, a piezoelectric transducer 10, which may be a quartz crystal, is driven by a source coupled to terminals 11 to develop waves of sound energy which are propagated along a path 12 in a first medium 13 on one end of which transducer 10 is affixed.

A second medium 14 has a first boundary 15 in common with the boundary of medium 13 toward which the sound waves are propagated. Medium 14 is responsive to the sound waves propagated along path 12 in medium 13 and propagates waves of the sound energy along a path 16 in medium 14 toward a second boundary 17. A third medium 18 has one boundary common with boundary 17 and responds to the sound waves from medium 14 propagated along path 16 to propagate the sound energy along a path 19 in medium 18.

Common boundaries 15 and 17 are oriented relative to paths 12 and 16 to effect dispersal of sound waves reflected from those boundaries away from the paths 12, 16 of the sound waves in media 13 and 14. Thus, waves reflected from boundary 15 are directed backwardly along path 20 literally away from the primary sound path; similarly in medium 14, waves reflected from boundary 17 are directed along a path 21 also away from the primary sound path. As embodied, the external surfaces 22 and 23 of the composite of the first two media are rough and irregular in order to effect maximum dispersion of the reflected waves in paths 20 and 21.

In this embodiment, medium 18 is the ultimate load or final utilization region for the sound waves. Hence, its boundary has been shown in dashed lines since it may take whatever shape and be of whatever form is appropriate with respect to the ultimate use of the sound waves. In one example, it is simply a clear plastic con-

tainer filled with medium 18 which is water, while media 13 and 14 are solids. In that case, medium 13 may be selected, for the purpose of obtaining flat response over a wide band, to have a characteristic impedance to the sound waves approximately the same as the characteristic impedance of transducer 10 while medium 14 has a characteristic impedance to the sound waves intermediate the comparatively high characteristic impedance of medium 13 and the much lower characteristic impedance to the sound waves of medium 18. More particularly, the characteristic impedance Z_2 of medium 14 is selected in accordance with the relationship:

$$Z_2 = (Z_1 Z_3)^{1/2} \quad (1)$$

where Z_1 and Z_3 are the characteristic impedances of media 13 and 18, respectively.

To afford a fuller appreciation of the advantages available from the illustrated arrangement, assume first that the arrangement was not used and that transducer 10 was made to radiate directly into medium 18. With that arrangement, transducer 10 would behave like a simple resonant circuit having a Q equal to $\pi/2 \cdot n_t$, where n_t is the ratio of characteristic impedances of transducer 10 and medium 18. For transformation from a ceramic piezoelectric transducer to water, n_t has a value of about 20 so that Q is approximately equal to 31, resulting in a bandwidth of only 3%.

Proceeding now to an arrangement according to the invention, assume the insertion of medium 13 between transducer 10 and medium 18; medium 13 is chosen so that the desired bandwidth is obtained at the transducer. For instance, the characteristic impedance Z_1 of medium 13 may be made equal to the transducer impedance Z_t ; this is accomplished conveniently by also using the ceramic piezoelectric material for medium 13. With this arrangement, the bandwidth is much larger. The reflection at the boundary between media 13 and 18 in this example is in accordance with the relationship for the reflection coefficient r as follows:

$$r = \frac{n_t - 1}{n_t + 1} \quad (2)$$

The fractional reflected power is:

$$r^2 = \left(\frac{n_t - 1}{n_t + 1} \right)^2 \quad (3)$$

The fractional remaining or transmitted power p is equal to:

$$p = \frac{4n_t}{(n_t + 1)^2} \quad (4)$$

For a value of $n_t \gg 1$, the power is similar to $4/n_t$. Hence, for the aforementioned materials with $n_t = 20$, the transmitted power is approximately 0.18, or there is about a 7.4 db loss.

In the example just given, the matching of impedance between transducer 10 and medium 13 is based upon the desire to obtain maximum bandwidth. However, the selection of impedance with bandwidth as the objective is not the same as is made to obtain maximum power transmission. Better power transfer is obtained by utilizing a relatively lower characteristic impedance of medium 13. For an appropriate compromise between maximum bandwidth and maximum power transfer, the characteristic impedance of medium 13 is selected to have a value intermediate that of the characteristic impedance of transducer 10 and one-half the latter value. With that arrangement, the mismatch between medium 13 and medium 18 is correspondingly reduced.

Turning attention next to the full arrangement shown in the drawing, the impedance of medium 13 is again assumed to be matched to that of the transducer and the impedance of medium 14 is selected in accordance with Equation 1. Thus, for insertion between a ceramic piezoelectric medium 13 and water, as medium 18, medium 14

is selected to have a characteristic impedance approximately 4.5 times that of the water. Such an impedance is conveniently obtained with the above-mentioned epoxy filled with metal powder. For example, it is known that the epoxy has a characteristic impedance about twice that of water while that of aluminum is approximately twelve times that of water. Accordingly, the epoxy and aluminum are mixed in proportionate ratio so that the resulting synthesized material exhibits the desired characteristic impedance value of about 4.5. The bandwidth of this arrangement is again large as in the case just described. However, there are now reflections both at boundaries 15 and 17. These have respective reflection coefficients r_{15} and r_{17} which are expressed in accordance with the relationship:

$$r_{15} = r_{17} = \frac{n_t^{1/2} - 1}{n_t^{1/2} + 1} \quad (5)$$

The fractional power p_{14} transmitted into medium 14 may be expressed:

$$p_{14} = \frac{4n_t^{1/2}}{(n_t^{1/2} + 1)^2} \quad (6)$$

In medium 18, the fractional power p_{18} is equal to the square of the power in medium 14, or:

$$p_{18} = \frac{16n_t}{(n_t^{1/2} + 1)^4} \quad (7)$$

For a very large value of n_t , the power in the final medium approximates the value $16/n_t$, or about four times the power available, as shown in Equation 4, without intermediate medium 14. For the aforementioned materials, Equation 7 results in an overall loss of only about 4.4 db.

From the foregoing, it is evident that the bandwidth is determined only by the impedance ratio of transducer 10 and first medium 13. All other transitions are aperiodic, and a very large bandwidth is available. Additionally, there is an important mechanical advantage in enabling permanent affixation of the transducer to the rugged base of the substrate of similar material which is medium 13. Consequently, transducer 10 may be lapped to its ultimate dimension in situ. Moreover, there is no requirement for any special length of any of media 13, 14 or 18; they may be many wavelengths long, rather than fractions of a wavelength. The extremely large bandwidth is obtained at only a comparatively small sacrifice in efficiency, such as the 4.4 db loss encountered in the embodiment illustrated.

Numerous devices call for the development of sound waves propagating in a particular direction through a load material. One example of such devices are the piezoelectric-semi-conductive amplifiers in which electric and sound waves interact to provide amplification in a manner analogous to the operation of a traveling-wave tube. The principles of the present invention permit launching of the sound waves into the body of the device at a desired direction, with proper matching of impedances, and over wide bandwidths.

Another highly interesting application utilizes sound waves propagated across a beam of coherent light in order to diffract the light. By modulating or scanning the frequency of the sound waves, the diffraction angle of the light is correspondingly varied so that the light energy may in turn be scanned across a light-responsive material; this results in the formation of an image reproduction system analogous to cathode-ray-tube operation except that light beams are used instead of electron beams. Here again, good matching and wide bandwidth often are important.

While particular embodiments of the present invention have been shown and described, it will be obvious to those skilled in the art that changes and modifications may be made without departing from the invention in its broader aspects. Accordingly, the aim in the appended claims is to

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cover all such changes and modifications as followed in the true spirit and scope of the invention.

I claim:

1. Signal translating apparatus comprising:
 - means for developing sound waves of a predeterminable frequency, said means requiring a specific impedance termination for optimum bandwidth; 5
 - a first medium of a characteristic impedance at said frequency selected in accordance with the bandwidth obtained at said means, having a boundary and being responsive to said means for propagating sound waves toward said boundary; 10
 - and a second medium having a boundary common with that of said first medium and responsive to said sound waves from said first medium for propagating them, said second medium having a characteristic impedance substantially different than said means and said first medium, and said first medium having its impedance intermediate that of said means and said second medium to provide optimum power transmission at the bandwidth obtained. 15 20
2. Signal translating apparatus comprising:
 - transducer means for developing sound waves at a predetermined frequency range, said means requiring a specific impedance termination for optimum bandwidth transmission; 25
 - a first medium having a boundary toward which sound waves are propagated by said transducer means and having the required specific impedance;
 - a second medium having a first boundary common with 30

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that of said first medium and responsive to said sound waves from said first medium for propagating sound waves toward a second boundary thereof;

and a third medium having one boundary common with said second boundary and responsive to sound waves from said second medium for propagating said sound waves, said third medium having an impedance substantially different than said first medium with said second medium having an impedance intermediate to the impedances of said first and third media.

3. Signal translating apparatus according to claim 1, in which said first and second boundaries are oriented relative to the path of sound waves to effect dispersal of reflected sound waves therefrom.

4. Signal translating apparatus according to claim 1, in which the impedance Z_2 of said second medium is selected to substantially satisfy the relationship $Z_2 = \sqrt{Z_1 Z_3}$ wherein Z_1 and Z_3 are the impedances of said first and third media, respectively.

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