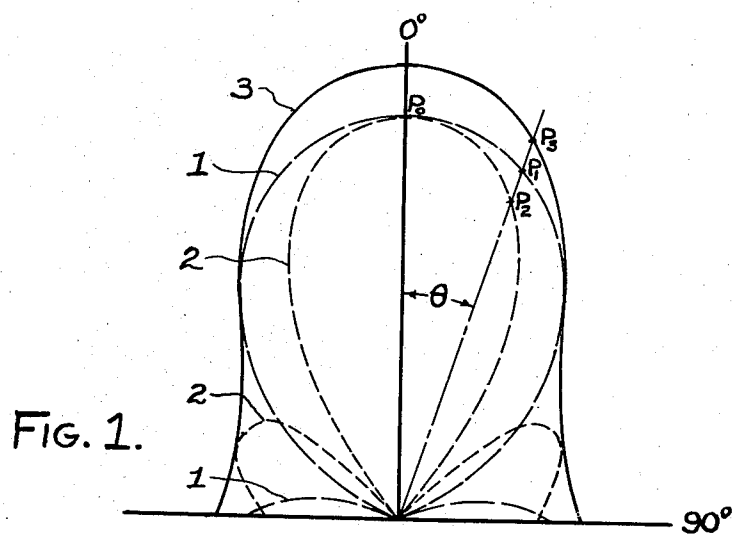
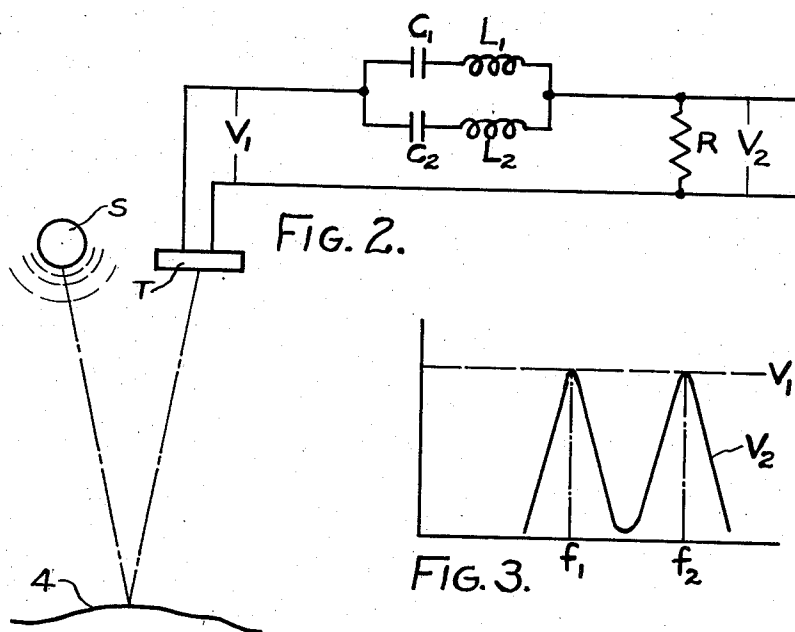


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F. MASSA  
DIRECTIONAL CHARACTERISTICS OF ELECTRO-ACOUSTIC  
TRANSDUCERS AND METHOD FOR  
UTILIZING THE SAME  
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Frank Massa

Inventor

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## DIRECTIONAL CHARACTERISTICS OF ELECTRO-ACOUSTIC TRANSDUCERS AND METHOD FOR UTILIZING THE SAME

Frank Massa, Cleveland Heights, Ohio

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8 Claims. (Cl. 340—8)

My invention is concerned with directional sound generating and receiving systems and, more particularly, with means for obtaining directional patterns that have predetermined spatial characteristics. For example, it is well-known that in conventional direction electro-acoustic transducers, such as, for example, vibrating circular pistons or rings whose diameters are large compared with the wavelength of the generated or received sound vibration frequency, that the directional characteristic of the transducer consists of a main lobe whose maximum is on the normal axis of the transducer, and a number of secondary lobes spaced away from the normal axis of the piston or ring. In some applications, the large variation in sensitivity which results in such a conventional transducer as a function of angle from the normal axis is very objectionable. A directional pattern having a gradual change in sensitivity with angle instead of the violent variation of maximum and minimum sensitivities as occur in the above-cited conventional examples is, in many instances, very desirable. In previous attempts to minimize these objectionable variations in the directional characteristics of transducers, it has been the practice to design vibrating structures in which different portions of the vibrating surface of the transducer operate with varying amplitudes or phase. Besides being very costly to manufacture such composite structures, the variation between the maximum and minimum sensitivities with angle is usually only reduced by this procedure and not actually eliminated.

It is the major object of my invention to provide directional patterns having smooth, gradually varying sensitivities as a function of angle in transducers that are basically very simple structures.

A further object of my invention is to "tailor make" directional patterns of an electro-acoustic transducer by the simple expedient of designing a given frequency selectivity into the electrical circuit associated with the unit.

A still further object of my invention is to improve the directional patterns of electro-acoustic transducers without changing the mechanical design of the basic transducer element.

Another object of my invention is to provide a method for the directional sending and receiving of sound energy in which the radiation pattern in the medium is free of the violent fluctuations in angular sensitivities which are inherently present in the basic transducers employed in the system when operating at single frequencies.

The novel features that I consider characteristic of my invention are set forth with particularity in the appended claims. The invention, itself, however, both as to its organization and method of operation, as well as its advantages thereof, will best be understood from the following description of several embodiments thereof, when read in connection with the accompanying drawings, in which:

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Fig. 1 is a polar diagram showing the directional radiation characteristic of a transducer at two discrete frequencies and also the resultant directional radiation characteristic of the transducer when it is operated in a circuit which utilizes the basic principle of my invention.

Fig. 2 is a schematic representation of an echo-ranging system in which a conventional transducer is employed as a receiver and frequency selective circuit elements are employed in the output circuit of the transducer which causes the elimination of the sharp variations in the directional radiation pattern of the transducer in accordance with the teachings of my invention.

Fig. 3 is a graph illustrating the change which is caused in the frequency response characteristic of the transducer illustrated in Fig. 2 due to the tuned circuit elements shown incorporated in the output connection of the transducer in Fig. 2.

Referring more particularly to Fig. 1, there are shown three curves, labelled 1, 2, and 3, each representing the directional characteristic of the transducer as a function of angle  $\theta$  under different conditions. The curve 1 has actually been computed for a plane piston surface operating at a frequency  $f_1$  in which the wavelength of sound in the medium is approximately three-fourths the diameter of the piston. The curve 2 shows the directional characteristic of the same piston as a function of angle for a higher frequency  $f_2$  in which the wavelength of sound in the medium is approximately one-half the diameter of the piston. The solid curve 3 shows the resultant directional characteristic of the same piston when it simultaneously is allowed to respond to the two frequencies  $f_1 + f_2$ . The axis labelled  $0^\circ$  represents a line normal to the surface of the piston which comprises the active face of the transducer. The curves in Fig. 1 show the relative sensitivity of the transducer in decibels as a function of the angle  $\theta$  removed from the normal axis labelled  $0^\circ$ . Although the curves shown in Fig. 1 were expressly worked out for a plane piston surface, they are equally illustrative of the directional radiation pattern of a transducer whose active area comprises only an annular portion of a piston which might be in the form of a thin ring, the vibrating surface of the ring being parallel to the polar axis of symmetry drawn normal to the plane containing the ring. For the case of the ring type transducer, the relative magnitudes, as a function of angle  $\theta$ , on the directional characteristics would be actually different than shown in Fig. 1, as will be indicated below, but the principle of achieving an improved directional pattern by the application of the teachings of my invention are the same. The directional characteristics illustrated in Fig. 1 could also represent the directional patterns of a long line, in which case the relative magnitudes would be again different than either those of the piston or the ring but, again, the principle of the application of the teachings of my invention remain the same. A line type transducer is well known to those skilled in the art and consists of a one-dimensional array of a number of transducer elements such as shown in Figs. 10 and 11 of U. S. Patent 2,613,261 and further described in the paragraph beginning on line 39 of column 7 in said patent. The patterns indicated in Fig. 1, if illustrative of a line type transducer, would be the characteristics in a plane containing the line of which the axis labelled  $0^\circ$  would be the perpendicular bisector of the line. In this case, however, as already mentioned, the relative magnitudes of the response as a function of angle would be different than the relative response as a function of angle for either the case of the piston surface or the ring surface, as will be shown by the equations below. In the case of either the piston or the ring type trans-

ducer, the curves shown in Fig. 1 would be symmetrical about the axis labelled  $0^\circ$ , while for the case of a line type transducer, the curves would be symmetrical about axis labelled  $90^\circ$  which contains the normal axis of the line.

Still referring to Fig. 1, the curve 1 indicates the directional characteristic of a plane piston operating at a frequency  $f_1$ . The ratio of the response  $P_1$  at an angle  $\theta$  to the response  $P_0$  on the normal axis of the piston is given by the well-known expression:

$$P_1/P_0 = \frac{2J_1[(\pi D/\lambda_1) \sin \theta]}{(\pi D/\lambda_1) \sin \theta} \quad (1)$$

where:

$P_1$ =response at angle  $\theta$

$P_0$ =response along the normal axis ( $\theta=0$ )

$J_1$ =Bessel function of first order

$D$ =diameter of the piston in inches

$\lambda_1$ =wavelength of sound in the medium in inches, corresponding to the frequency  $f_1$

$\theta$ =angle removed from normal axis in degrees

If curve 1 in Fig. 1 is to be plotted for the case of a thin ring whose active surface moves parallel to the direction of its normal axis of symmetry labelled  $0^\circ$ , the ratio of the response  $P_1$  at angle  $\theta$  to the response  $P_0$  on the normal axis of the ring is given by another well-known expression:

$$P_1/P_0 = J_0[(\pi D/\lambda_1) \sin \theta] \quad (2)$$

where:

$D$ =diameter of the ring in inches

$J_0$ =Bessel function of zero order and the other symbols are the same as in Equation 1.

For the case of a thin line, the ratio of the response  $P_1$  at an angle  $\theta$  to the response  $P_0$  along the perpendicular bisector of the line would give the following shape to curve 1:

$$P_1/P_0 = \sin[(\pi L/\lambda_1) \sin \theta] / (\pi L/\lambda_1) \sin \theta \quad (3)$$

where:

$L$ =length of line in inches and the other symbols are the same as in Equation 1.

The curve 2 in Fig. 1 is the directional pattern for the same piston for which curve 1 was computed except that the frequency has been increased to  $f_2$ . This curve is given by Equation 1 above by substituting  $\lambda_2$  for  $\lambda_1$  in which  $\lambda_2$  corresponds to the wavelength of the sound in inches at the operating frequency  $f_2$ . Similarly, the corresponding curve 2 for a ring or a line may be obtained by substituting  $\lambda_2$  for  $\lambda_1$  in Equations 2 and 3 above.

The curve 3 in Fig. 1 is the sum of curves 1 and 2 and represents the directional characteristic of a simple circular flat piston when operating simultaneously and at equal sensitivity at both frequencies  $f_1$  and  $f_2$ . By allowing the transducer to respond simultaneously to the two separate frequencies, I am able to achieve a smooth directional characteristic as illustrated by curve 3 in Fig. 1. The basic reason why this curve is free from sharp null points is that I have added the curves 1 and 2 vectorially. This is permissible only because I have employed two separate different frequencies for the component curves 1 and 2 in the determination of the overall characteristic 3 and it is this principle of combining two different frequency directional characteristics which is the basic part of my present invention.

In previous attempts at improving the directional characteristics of transducers, two curves similar to 1 and 2 of Fig. 1 were obtained by using a composite piston in which different portions operated at different amplitudes. These curves, being of the same frequency, however, had to be combined algebraically, which resulted in the retention of sharp nulls in the overall characteristic as shown, for example, in U. S. Patent 2,427,062 issued

to Frank Massa on September 9, 1947. The algebraic addition of two directional patterns such as curves 1 and 2 when they would be of the same frequency must take cognizance of the alternate phase reversals of the successive secondary lobes in each of the curves. This would mean that at the point at which the main lobe of curve 1 crosses the secondary lobe of curve 2, the two response components would be of equal magnitude and of opposite phase (were the curves representing the same frequency as in the case of a composite piston surface operating at different amplitudes) and thus the combined sensitivity would be zero. For the actual case in this present invention, however, curves 1 and 2 represent different frequencies so that phase relations have no significance and the resultant curve 3 is always the root mean square sum of the individual components. Thus, by employing this new concept, I am able to achieve a smooth directional characteristic without sharp nulls as is actually shown by the curve 3 in Fig. 1.

One large advantage of my invention is that existing transducers may be made to yield smooth directional characteristics without change in design of the transducer structure but by making a relatively simple circuit modification in which the circuit is selectively sensitive to two separated frequencies which are desired to be reproduced by the transducer. Figs. 2 and 3 illustrate my new method for the directional sending or receiving of a sound wave through an elastic medium for the purpose of improving the directional response characteristic of the transducer. In Fig. 2, T represents a conventional transducer which may be a flat circular piston which is facing down toward the bottom of the sheet in the drawing. In Fig. 2, S represents a sound generator which may be electrically, mechanically, or chemically excited and which generates more than a single frequency of vibration. The source S may generate a band of frequencies or only the frequencies  $f_1$  and  $f_2$  which are going to be selectively received by the electrical circuit connected to the transducer. When the arrangement schematically illustrated in Fig. 2 is used as an echo-ranging system, for example, a burst or a pulse of sound of short duration is caused to be discharged from the source S. The sound is reflected from the distant surface 4 and the returned echo is picked up by the transducer T. The voltage  $V_1$  generated by the transducer is passed through the series tuned circuits  $C_1L_1$  and  $C_2L_2$  connected as shown in Fig. 2 and a voltage  $V_2$  appears across the output resistance R.

A graph showing the circuit response and its selectivity to the transducer generated voltage is plotted in Fig. 3. The abscissa in Fig. 3 represents frequency and the ordinate indicates magnitude of the response. At the transducer terminals, a voltage  $V_1$  is generated by the received echo which is uniformly flat with respect to frequency. This assumes that the source S has generated sound having a uniform spectral distribution of energy and also that the receiving transducer T is uniformly sensitive over the frequency spectrum. The effect of the two series tuned circuits  $L_1C_1$  and  $L_2C_2$  is to cause only the frequencies  $f_1$  and  $f_2$ , representing their respective series resonant frequencies, to be present in the output voltage  $V_2$ . If the frequency  $f_1$  is chosen to correspond to the directional characteristic of the transducer T as is shown by curve 1 in Fig. 1 and if the frequency  $f_2$  is chosen to correspond to the characteristic shown by curve 2, then the end result of the method illustrated in Fig. 2 is to cause the transducer T to have the effective directional characteristic as illustrated by curve 3 in Fig. 1. The advantage of not having any sharp nulls in the directional characteristic of the transducer by employing the teachings of this invention is obvious in that there will be no "blind spots" in which an echo may fail to be received such as might occur when employing conventional transducers in conventional prior art receiving circuits.

The schematic arrangement of Fig. 2 has illustrated the principle of my invention by having the receiving transducer pick up wide band sound which was generated by a separate source. Another equally satisfactory method of using my invention is to use the transducer T for both sending and receiving. When sending, the transducer may be either excited with a pulse having a band width including the frequencies  $f_1$  and  $f_2$  or the transducer may be excited to generate only the frequencies  $f_1$  and  $f_2$ . In either case, after the sound pulse is emitted and the circuit is switched to receiving position, the reflected signal picked up by the transducer will be applied to the selective circuit schematically shown in Fig. 2 to cause the results already described for the effective smoothing of the directional characteristic of the receiving system.

I have found that optimum results can be obtained in correcting the directional characteristic of simple transducers, in accordance with the teachings of my invention, if the two selected frequencies  $f_1$  and  $f_2$  are chosen so that the lower frequency  $f_1$  lies in the range from 10% to 50% below the frequency  $f_2$ . If single frequencies are not used, the individual frequency regions are each preferably less than  $\frac{1}{4}$  octave in band width.

Although I have chosen only a few specific examples to illustrate the basic principles of my invention, it will be obvious to those skilled in the art that numerous departures may be made from the details shown, and I, therefore, desire that my invention shall not be limited except insofar as is made necessary by the prior art and by the spirit of the appended claims.

I claim as my invention:

1. In combination, in a directional system for the reproduction of sound waves, an electro-acoustic transducer for the conversion of sound vibrations to electric signals, said transducer being characterized in that its directional response characteristic is different for each of two separated frequency regions of operation, an electric circuit connected to said transducer, frequency selective means associated with said electric circuit, said frequency selective means being characterized in that two separated frequency regions are selectively passed by said electric circuit, and means for combining signals from each of the said two separated frequency regions whereby said combined signal from said transducer results in a directional response characteristic which is a combination of the two different directional response characteristics displayed by the transducer for each of the two separated frequency regions of operation.

2. The invention set forth in claim 1, further characterized in that the lower of said two separated frequency regions lies in the range from 10% to 50% below the higher of said frequency regions.

3. The invention set forth in claim 1, further characterized in that the active portion of said electro-acoustic transducer comprises a plane surface having at least one dimension greater than the wavelength of sound at the highest frequency which is selectively passed by said electric circuit.

4. The invention set forth in claim 1, characterized in that said electro-acoustic transducer is of the line type and further characterized in that the length of the line is greater than the wavelength of the sound at the highest frequency which is selectively passed by said electric circuit.

5. In combination, in a directional system for the reproduction of sound, an electro-acoustic transducer, said transducer being characterized in that its directional response characteristic is different for each of two separated frequency regions of operation, an electric circuit connected to said transducer, two tuned circuit elements associated with said electric circuit, each tuned circuit element tuned to a different frequency, said tuned circuit elements being adapted to permit said electric circuit to be selectively sensitive to each of said different tuned frequencies, and means for combining signals from each of the said two different frequencies whereby said combined signal from said transducer results in a directional response characteristic which is a combination of the two different directional response characteristics displayed by the transducer for each of the two different frequencies.

6. The invention set forth in claim 5, further characterized in that the lower of said two separated frequency regions lies in the range from 10% to 50% below the higher of said frequency regions.

7. The invention set forth in claim 5, further characterized in that the active portion of said electro-acoustic transducer comprises a plane surface having at least one dimension greater than the wavelength of sound at the highest frequency which is selectively passed by said electric circuit.

8. The invention set forth in claim 5, characterized in that said electro-acoustic transducer is of the line type and further characterized in that the length of the line is greater than the wavelength of the sound at the highest frequency which is selectively passed by said electric circuit.

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