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*GENERATIONS AHEAD IN SONAR & ULTRASONIC TECHNOLOGY*

## *An Overview of Electroacoustic Transducers*

*by*

*Donald P. Massa*

## An Overview of Electroacoustic Transducers

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### 1.0 Introduction and Historical Overview

The purpose of this article is to provide a brief overview of the very extensive topic of electroacoustic transducers. Transducers are devices that transform one form of energy into another. A few acoustic transducers, such as whistles or musical instruments, transform mechanical energy into sound, but the following discussion will be primarily concerned with electroacoustic transducers. They are classified as either transmitters that convert electricity to sound, or receivers that change acoustic energy into electrical signals.

The invention of the telephone in the late 1800's resulted in the first widespread use of electroacoustic transducers. The microphone in the telephone converted the acoustical energy of the human voice into electrical signals. The earpiece in the telephone converted the electrical signals back into acoustic energy so the voice of the person at the other end of the line can be heard.

New requirements for different types of electroacoustic transducers were created by the development of the phonograph at the turn of the last century, followed by increased consumer use of radio in the 1920's and the advent of sound motion pictures in the 1930's. Improved loudspeakers and microphones were required to meet the demands of these new industries, and the science of sound was transformed into the applied science of electroacoustics.

During the 1920's, electrical engineers began applying the concepts of "equivalent circuits" to characterize acoustic transducers. The mechanical and acoustical portions of the transducer were modeled by converting them to equivalent electric circuit components of inductors, capacitors and resistors. These equivalent circuit elements of the acoustic portions were coupled to the pure electrical portions of the transducer by means of an electromechanical transformer. This modeling allowed the pioneering generation of electroacoustic engineers to not only better understand how transducers operated, but also to optimize transducer designs by using the well known methods of electric circuit analysis. In 1929 the Acoustical Society of America was formed, and in 1934 the first engineering-based textbook on transducers, entitled *Applied Acoustics*, was published by Olson and Massa.

While significant improvement in the design of electroacoustic transducers for use in the audible frequency band in air were achieved during the first three decades of the last century, a new requirement for electroacoustic transducers to operate underwater for sonar applications was only in its infancy. However, the military threat of submarines during World War II caused sonar transducer development to rapidly advance during the 1940's.

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Following World War II, new types of electroacoustic transducers designed to operate in the ultrasonic frequency range were developed for a wide variety of new industrial applications, such as non-contact distance or level measurement, collision avoidance, communication, remote control, intrusion alarms, ultrasonic cleaning, ultrasonic welding, ultrasonic flow detection, and ultrasonic imaging. Different transducers were designed to operate at frequencies as low as 20kHz, the upper frequency limit of human hearing, to 10 MHz and higher [1,2,3].

### 2.0 Fundamentals of Electroacoustic Transducers

There are many factors that affect the design of an electroacoustic transducer. For example, a transducer designed to operate in a gaseous medium, such as air, is very different from one designed to operate in a liquid medium, such as water. Likewise, differences in acoustical requirements, such as frequency of operation or radiation pattern will influence the design. It is, therefore, necessary to first understand some basic acoustical principles in order to properly understand how electroacoustic transducers operate.

#### 2.1 Generation of Sound

Sound is a transfer of energy caused by the vibration of particles in the transmission medium. The particles vibrate back and forth a small distance which causes a longitudinal wave to travel in the same direction as the vibrating particles.

An electroacoustic transmitting transducer produces sound by vibrating a portion of its surface, which therefore affects the molecules in the transmission medium. When the radiating surface moves forward the molecules are pushed closer together, thus increasing the instantaneous pressure (condensation). When the radiating surface moves back, the molecules expand, thus decreasing the instantaneous pressure (rarefaction). The vibrating molecules near the transducer push against their neighbors, causing them to also vibrate. This process continues, creating a propagating wave in which the instantaneous pressures oscillate between condensation and rarefaction as it progresses outward from the transducer. This is illustrated in Figure 1, which shows two moments of time of a piston moving back and forth pushing against the molecules in a transmission medium contained in a pipe. The first picture shows the molecules when the piston is moving forward creating condensation, while the second shows the piston moving backwards, causing rarefaction.

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**2.2 Differences in the Characteristics of Sound Propagation In Gaseous and Liquid Mediums**

There are fundamental differences in many of the properties of sound radiating in a liquid as compared to sound propagating in a gas, but there are typically only minor variations in the acoustic properties of sound radiating among various gasses or among various liquids. Since the applications of most sound transmissions in gasses occur in air, and in liquids occur in water, the characteristics of these two media will be used to illustrate the difference between acoustic radiation in liquids and in gasses.

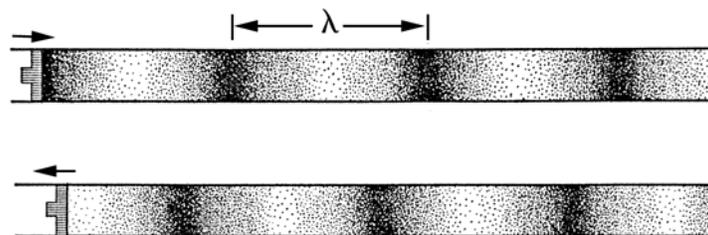


FIGURE 1

Illustration Showing How a Piston Moving Forward (*top*) Compresses the Molecules in the Transmission Medium in a Pipe Creating Condensation, and Moving Backward (*bottom*) Expands the Molecules Creating Rarefaction

**2.2.1 Speed of Sound**

The velocity that the sound waves travel through a transmission medium is called the speed of sound, *c*. The nominal value of *c* is primarily a function of the composition of the particular medium, but slight changes occur for each medium because of variations in parameters such as temperature or pressure. However, the velocity of sound is much greater in liquids than in gasses. As an example, in air at 20°C the speed of sound is 343 m/sec, and in fresh water at 20°C it is 1483 m/sec (4).

**2.2.2 Wavelengths of Sound**

The wavelength of sound traveling in a medium is the distance between condensation peaks, as shown in Figure 1, and is a function of both the frequency and the speed of the sound wave. The wavelength is

$$\lambda = \frac{c}{f} \tag{1}$$

where:  $\lambda$  is the wavelength  
 $c$  is the speed of sound  
 $f$  is the frequency

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Figure 2 shows a plot of the wavelength of sound in air and water at room temperature as a function of frequency. As can be seen from the curve, since the speed of sound in water is approximately 4.3 times greater than in air, the wavelength for a given frequency in water is approximately 4.3 times longer than in air.

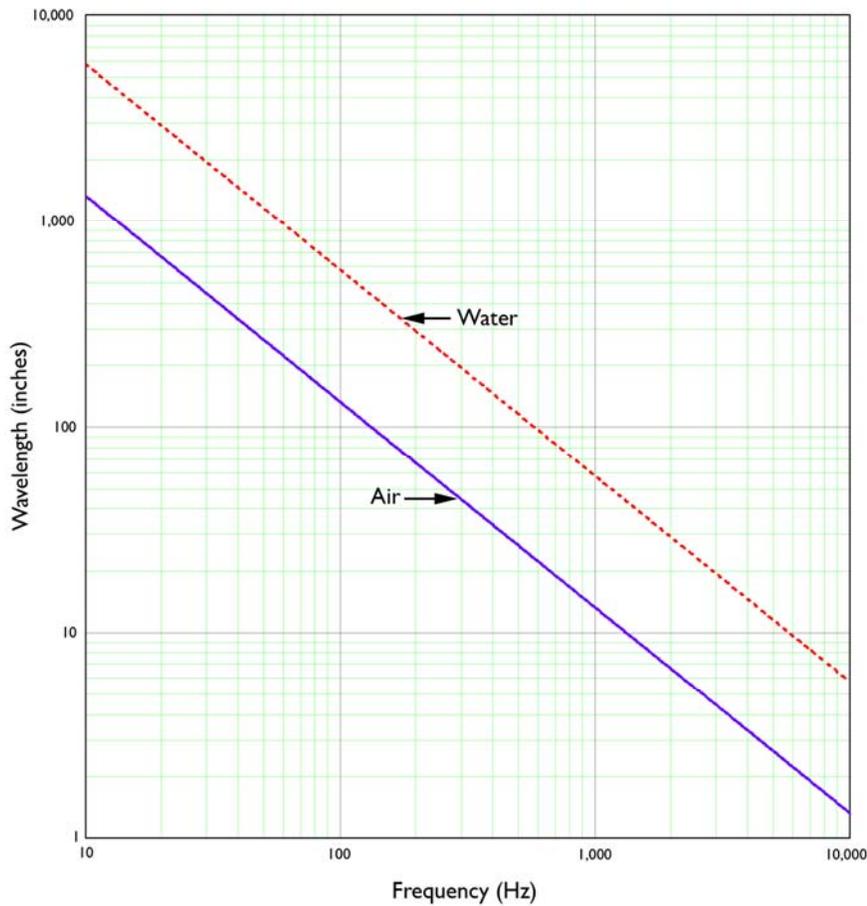


FIGURE 2

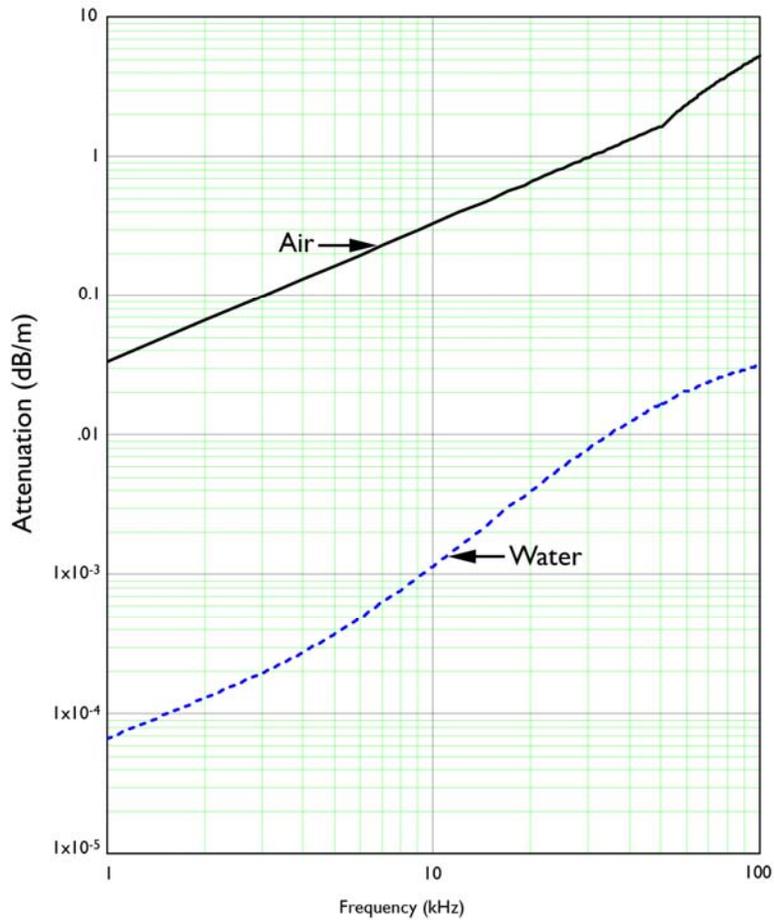
Plot of the wavelength,  $\lambda$ , as a Function of Frequency for Sound in Air and Water

2.2.3 Attenuation of Sound

The attenuation of sound traveling through a medium increases as the frequency increases, and the attenuation in a gas at a given frequency is much greater than in a liquid. Figure 3 on the following page shows plots of typical attenuations for sound in both air and water as a function of frequency (5,6). Because the attenuation is much less in water than in air, objects can be detected at much greater ranges using echo location in water than in air. Table 1 compares propagation distances and wavelengths for sound at different frequencies in air and water.

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**FIGURE 3**

Plot of the Attenuation,  $\alpha$ , as a Function of Frequency for Sound in Air and Water

**TABLE 1**

Comparisons of Propagation Distances and Wavelength for Sound at Different Frequencies in Air and Water

Frequency	Propagation Distance for Planar Sound Wave to Attenuate to Half Its Initial Pressure (No Spreading Loss)		Wavelength	
	Air	Water	Air	Water
0.5 kHz	375 m	330,000 m	0.68 m	3 m
1.0 kHz	180 m	130,000 m	0.34 m	1.5 m
5.0 kHz	40 m	20,000 m	.068 m	0.3 m
10 kHz	18 m	7,000 m	.034 m	0.15 m
50 kHz	3.8 m	330 m	.0068 m	.03 m
100 kHz	1.2 m	160 m	.0034 m	.015 m

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**2.2.4 Density**

Gasses are much less dense than liquids. The density,  $\rho_o$ , of air is only 1.2 kg/m<sup>3</sup>. The density of water is 1000 kg/m<sup>3</sup>, which is over 800 times greater [4].

**2.2.5 Analogies Between Acoustical Properties of a Transmission Medium and the Electrical Properties of a Circuit**

Most people are familiar with Ohms' Law in electricity. This Law states that for a given voltage E applied across an electrical component which has an impedance Z, the electrical current I flowing through the component will be directly proportioned to the value of the electrical impedance Z. Ohms' Law can be written as

$$E = IZ \tag{2}$$

where:  $E$  is the voltage in volts  
 $I$  is the current in amps  
 $Z$  is the electrical impedance in Ohms

Acoustic transmission media have properties analogous to electrical properties in circuits. In acoustics, the sound pressure  $p$  of the acoustic wave is equivalent to voltage in an electric circuit, and the particle velocity  $u$  is analogous to current. The acoustical impedance of a transmission medium is the product of the density times the speed of sound. It is written as  $\rho_o c$ , and the units are acoustic Ohms or rayls (after Lord Rayleigh). Ohms' Law in acoustics is

$$p = u \rho_o c \tag{3}$$

where:  $p$  is the pressure of the sound wave in Pa  
 $u$  is the particle velocity in m/sec  
 $\rho_o c$  is the acoustic impedance in rayls

Because gasses have much slower sound velocities and lower densities than liquids, their acoustic impedances are much less. For example, the acoustic impedance of air is nominally 415 rayls, while  $\rho_o c$  for water is approximately 1.48 x 10<sup>6</sup> rayls. This large disparity causes the fundamental design concepts to be much different than those for use in water. Table 2 on the following page summarizes the analogies between acoustical and electrical properties.

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TABLE 2

Ohm's Law Analogies Between Electrical and Acoustic Properties

ELECTRICAL			ACOUSTICAL		
Quantity	Symbol	Units	Quantity	Symbol	Units
Voltage	$E$	Volts	Pressure	$p$	$\mu\text{Pa}$
Charge	$q$	Coulomb	Particle Displacement	$\xi$	m
Current	$I$	Amperes	Particle Velocity	$u$	m/sec
Impedance	$Z$	Ohms	Acoustic Impedance	$\rho_0 c$	rayls

2.2.6 Relationship Among Sound Pressure, Particle Displacement and Partial Velocity

As was previously discussed, sound is transmitted in a wave caused by the particles in the medium vibrating back and forth. In a plane acoustic wave traveling in the x direction, the particle velocity is the real part of

$$\xi = |\xi| e^{j\left(\omega t - \frac{\omega}{c} x\right)} \tag{4}$$

which is

$$\xi = |\xi| \cos\left(\omega t - \frac{\omega}{c} x\right) \tag{4a}$$

where:  $\xi$  is the particle displacement in m  
 $\omega$  is the frequency of the sound wave in rad/sec  
 $c$  is the speed of sound in the medium in m/sec

The particle velocity is the derivative of the displacement, therefore

$$u = -\omega |\xi| \sin\left(\omega t - \frac{\omega}{c} x\right) \tag{5}$$

where:  $u$  is the particle velocity in m/sec

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Substituting Equation 5 into Equation 3, the sound pressure becomes

$$p = -\rho_o c \omega |\xi| \sin\left(\omega t - \frac{\omega}{c} x\right) \tag{6}$$

where:  $p$  is the sound pressure of the acoustic wave in Pa  
 $\rho_o c$  is the acoustic impedance in rayls

From Equation 6, it can be seen that the magnitude of the sound pressure of an acoustic wave is directly proportional to the acoustic impedance, the frequency, and the magnitude of the particle displacement. To transmit sound at a specific pressure and frequency, an acoustical transducer must vibrate with an amplitude equal to the particle displacement required for the particular medium. Because the acoustic impedance of water is 3,600 times greater than that of air, the particle displacement in air must be 3,600 times larger than the particle displacement in water to produce the same sound pressure at the same frequency. For either medium, the particle displacement required to produce a constant sound pressure will decrease as the frequency increases.

Because of these relationships, transducer designs are different for operation in fluids than in gasses, or for operation at high frequencies than low frequencies. The radiating surfaces in underwater sonar transducers only have to move small displacements to generate large sound pressures. However, they must generate a relatively large amount of force to compress the dense water. Transducers that operate in air have to vibrate over much larger displacements to generate high sound pressures, but very little force is necessary to compress the gas.

Transducers that radiate at low frequencies in either medium must vibrate larger distances than those that operate at high frequencies, which can be verified by observing loudspeakers in a typical stereo system. The low frequency woofer can be seen moving large amplitudes when base notes are played, while the motion of the high frequency tweeters appears to be negligible.

**2.3 Sound Pressure Levels**

Because sound pressures vary more than 10 orders of magnitude, they are expressed by acoustical engineers as logarithmic ratios, which are called sound pressure levels (SPLs). The SPL in decibels for a sound pressure  $p$  is calculated as  $20 \log (p/p_{ref})$ , where  $p_{ref}$  is a standard

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reference sound pressure. Some confusion can occur because several different reference pressures are in use, which results in a given sound pressure being expressed with several different possible sound pressure levels.

Most of the early work in acoustical engineering was associated with the development of audio equipment, so it was natural to use the threshold of human hearing for the reference pressure. In the cgs system, that sound pressure is .0002 dynes/cm<sup>2</sup> [.0002 μbars], so sound pressure levels were expressed in terms of dB // .0002 μbar [SPL=20 log (p/.0002) dB // .0002 μbar, where p is the pressure in μbar].

During World War II, there were major advances in the development of sonar for detecting submarines. Since the sounds produced by sonar systems are not heard directly by people, sonar engineers began using 1 μbar as a more logical standard reference pressure. Sound pressure levels therefore began being expressed in terms of dB // 1 μbar [SPL=20 log (p/1) dB // 1 μbar, where p is pressure in μbar].

In the early 1970's, the SI system of units was adopted in acoustical engineering, so the μPa, which is equal to 10<sup>-6</sup> N/m<sup>2</sup>, became the reference pressure. Sound pressure levels therefore began to be expressed in terms of dB // 1 μPa [SPL=20 log (p/1) dB // 1 μPa, where p is pressure in μPa]. This is now the most often used reference pressure for acoustic measurements, but it is not unusual to encounter data using any of these three standard reference pressures. To add to the confusion, sometimes the SPL will be improperly stated in terms of dB only, without indicating the reference pressure used to compute the ratio. It is obviously important to know which reference pressure was used whenever an SPL is expressed, and when comparing transducer responses, all sound pressure levels should be converted to the same reference pressure. It is quite simple to convert sound pressure levels among the three reference pressures by using Table 3.

TABLE 3

Sound Pressure Level Conversion Table

To Convert SPL in:	To SPL in:	
dB // .0002 μbar	dB // 1 μbar	Subtract 74 dB
dB // .0002 μbar	dB // 1 μPa	Add 26 dB
dB // 1 μPa	dB // .0002 μbar	Subtract 26 dB
dB // 1 μPa	dB // 1 μbar	Subtract 100 dB
dB // 1 μbar	dB // .0002 μbar	Add 74 dB
dB // 1 μbar	dB // 1 μPa	Add 100 dB

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### 2.4 Radiation Patterns of Transducers

The acoustic radiation pattern, or beam pattern, is the relative sensitivity of a transducer as a function of spatial angle. This pattern is determined by factors such as the frequency of operation and the size, shape and acoustic phase characteristics of the vibrating surface. The beam patterns of transducers are reciprocal, which means that the beam will be the same whether the transducer is used as a transmitter or as a receiver.

Transducers can be designed to radiate sound in many different types of patterns, from omnidirectional to very narrow beams. The beam pattern of a transducer is usually calculated and graphed showing the relative reduction in sensitivity as a function of angle, with the maximum sensitivity of the transducer along the main acoustic axis set to equal 0 dB. The beam angle of the transducer is equal to the total arch encompassed by the beam between the angles when the pressure has fallen to a level of -3 dB on either side of the main acoustic axis.

For a transducer with a circular radiating surface vibrating in phase, the narrowness of the beam pattern is a function of the ratio  $D/\lambda$ , the diameter of the radiating surface over the wavelength of sound at the operating frequency. The larger the diameter of the transducer as compared to a wavelength of sound, the narrower the sound beam. For example, if the diameter is twice the dimension of the wavelength, the total beam angle will be approximately  $30^\circ$ , but if either the diameter or frequency is changed so that the ratio becomes 10, the total beam angle will be reduced to approximately  $6^\circ$ . Since the wavelength of sound at a given frequency in water is approximately 4.3 times larger than in air, the diameter of an underwater transducer must be approximately 4.3 times larger than an air transducer to produce the same beam angle at the same frequency.

A transducer large in size compared to a wavelength not only produces a narrow main beam, but it also produces secondary lobes separated by nulls. Figure 4 on the following page is a representation of the beam pattern produced by a transducer with a radiating diameter that is large compared to a wavelength. As can be seen, each secondary lobe is sequentially lower in amplitude than the previous one. The equation for the radiation pattern of a circular rigid piston in an infinite baffle as a function of spatial angle is (7).

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$$P(\theta) = \left[ \frac{2J_1\left(\pi \frac{D}{\lambda} \sin \theta\right)}{\pi \frac{D}{\lambda} \sin \theta} \right]^2 \tag{7}$$

where:  $P(\theta)$  is the relative sound pressure as a function of angle

$\theta$  is the angle of the sound pressure from an axis perpendicular to the center of the piston

$D$  is the diameter of the piston

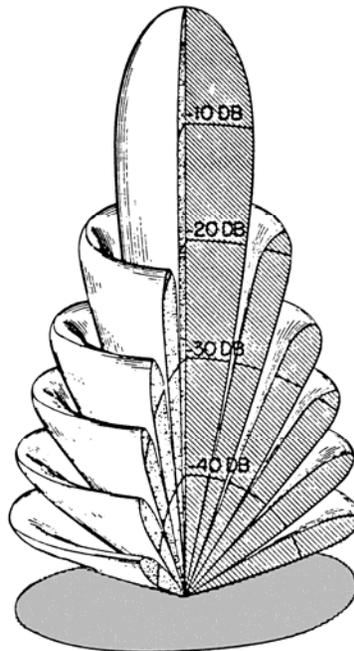
$\lambda$  is the wavelength of the sound

$J_1$  is the first order Bessel function

Beam patterns are usually plotted on a decibel scale where the sound pressure as a function of spatial angle is

$$P_{dB}(\theta) = 20 \log \left[ \frac{2J_1\left(\pi \frac{D}{\lambda} \sin \theta\right)}{\pi \frac{D}{\lambda} \sin \theta} \right] \tag{7a}$$

where:  $P_{dB}(\theta)$  is the relative sound pressure as a function of spatial angle in dB



**FIGURE 4**

3D Representation of a Beam Pattern Produced by a Transducer with a Radiating Diameter That is Large Compared to a Wavelength

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The beam angle is usually defined as the measurement of the total angle where the sound pressure level of the main beam has been reduced by 3dB on both sides from the peak that occurs along the axis perpendicular to the piston. When describing transducer beam patterns, 2D plots are most commonly used. These show the relative sensitivity of the transducer vs. angle in a single plane cut through the axis perpendicular to the center of the piston in the 3D beam pattern. Figure 5 shows 2D plots on rectilinear coordinates of the beam patterns of circular piston radiators for several different values of  $D/\lambda$ .

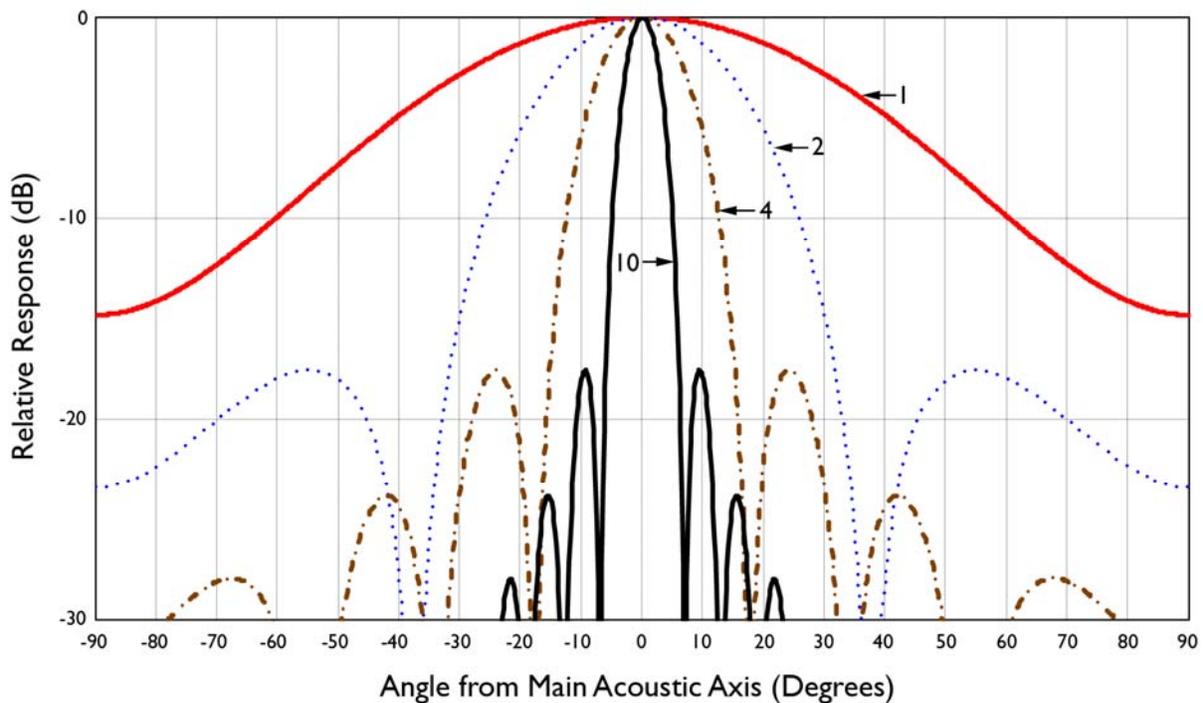


FIGURE 5

2D Plots on Rectilinear Coordinates Showing the Beam Patterns of Four Different Circular Piston Radiators in an Infinite Baffle Having Diameter to Wavelength Ratios,  $D/\lambda$ , of 1, 2, 4 and 10

2.5 Resonance

Many electroacoustic transducers are designed to operate at resonance, which is the natural frequency of vibration of the transducer structure. Transducers will produce a much greater displacement for a given drive voltage when operated at frequencies in the vicinity of resonance. Likewise, when used as receivers they will produce a larger electrical signal for a given sound pressure.

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The Quality Factor,  $Q$ , of a transducer is a value that indicates the width of the frequency band in the vicinity of resonance over which it can operate with high output. The  $Q$  is calculated by dividing the resonant frequency by the bandwidth, which is defined as the frequency band over which the response of the transducer is within 3 dB of the peak response.

The receiving response of transducers is usually constant at frequencies well below resonance, so the output voltage will be constant for a given sound pressure, and proportional to changing sound pressures at all frequencies in this region. Transducers that are only used for receiving (microphones in air, and hydrophones in water) are often operated well below resonance to take advantage of this broadband flat response.

### 3.0 Transduction

Electroacoustic transducers operate by using a variety of different transduction materials or mechanisms to transform electrical energy into sound and vice versa. For example, in transducers that employ magnetics, an alternating electrical current flowing through a coil of wire produces a varying magnetic force that causes the transducer structure to vibrate. In like manner, a sound wave will vibrate the transducer, which moves the coil in a magnetic field, thus generating an electrical signal.

Transducers can also be designed using magnetostrictive materials for transduction. When these materials are placed in a magnetic field, their mechanical dimensions change as a function of the strength of the magnetic field, which in turn can be used to generate sound.

Other transducers employ piezoelectric crystals, such as Quartz, Rochelle Salt, or Ammonium Dihydrogen Phosphate (ADP) for transduction. They develop an electric charge between two surfaces when the crystal is mechanically compressed, and they expand and contract in size in the presence of an applied electrical field.

The most commonly used transduction materials for transducers are electrostrictive ceramics. These ceramic materials, such as Barium Titanate and Lead Zirconate Titanate, are often referred to as piezoelectric ceramics and also produce an electric charge when a mechanical stress is applied, and vice versa. However, they must have an internal polarizing electric field established in order for transduction to occur. Their popularity is due to relatively low cost, coupled with the ability to be fabricated into a wide variety of shapes and sizes.

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4.0 A Few Examples of Some Electroacoustic Transducers

The following sections contain a short description of the construction of a few electroacoustic transducers. Since there are such a wide variety of different types of electroacoustic transducers, it is not possible to provide a description of most of them in this brief overview. Some of the publications in the reading list at the end of this article contain detailed information on many specific types of transducers.

4.1 Moving Coil Electrodynamic Loud Speaker

The most common loudspeakers used in stereo or public address systems are electrodynamic transducers, which contain a coil of wire suspended in a magnetic field. When an alternating electrical current is passed through the coil, mechanical forces are developed between the coil's electromagnetic field and the field in which it is mounted.

Figure 6 is a cross sectional sketch illustrating the schematic construction of an electrodynamic speaker [8]. As can be seen, the voice coil 5 is a coil of wire fashioned into a cylindrical tube. It is rigidly connected to a radiating diaphragm 1, which is resiliently mounted to an enclosure 3. This holds the coil within the magnetic field produced by the permanent magnet 4, but allows it to freely vibrate within this field. The magnet is shaped like a disk with a circular groove cut into the surface facing the diaphragm. The tubular voice coil is mounted so that it is held within this groove. A varying electrical current in the coil produces proportional changes in its electromagnetic field, which in turn modulates the magnetic forces between the coil and the permanent magnet. This causes the coil to move back and forth, thus vibrating the diaphragm and generating sound.

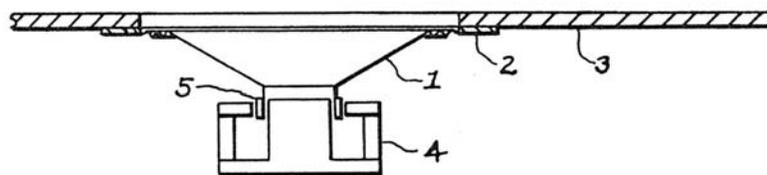


FIGURE 6

Illustration Showing the Construction of an Electrodynamic Speaker

Figure 1 of U.S. Patent 2,445,276 [8]

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**4.2 Condenser Microphone**

The condenser microphone produces a variation in its electrical capacitance in the presence of an acoustic wave. Figure 7 illustrates the construction of such a transducer. The stretched thin metallic membrane is separated from the rigid back plate by a small air gap. When a sound wave vibrates the membrane, it causes the air gap to change in thickness, producing a variation in the electrical capacitance between it and the back plate. This varying capacitance is converted into an electrical signal that is proportional to the sound pressure wave.

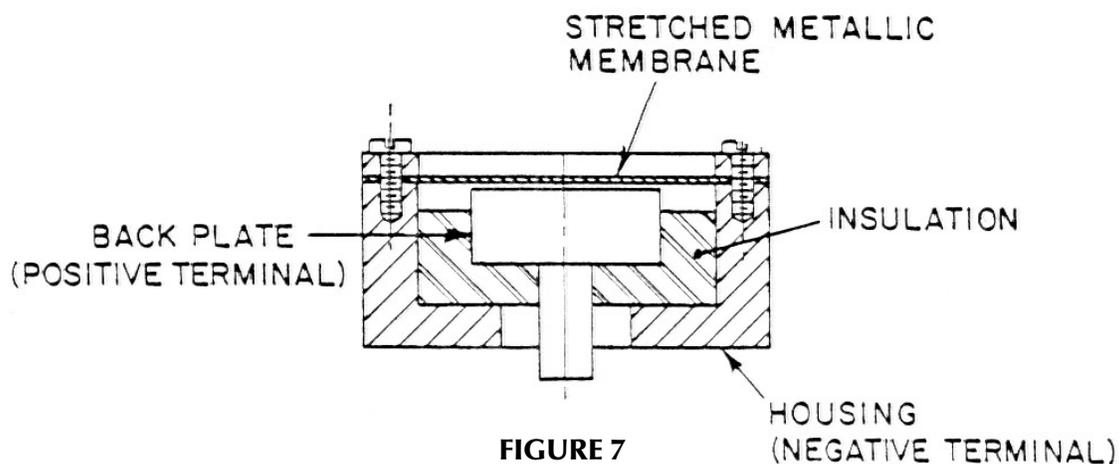


Illustration Showing the Construction of a Condenser Microphone

**4.3 Flexural Air Ultrasonic Transducer Using Electrostrictive Ceramics**

Flexural ultrasonic transducers use the resonance of a mechanical diaphragm to produce the motion required to generate the required sound pressure. Figure 8 on the following page shows a cross-sectional illustration of a typical flexural ultrasonic transducer [9]. The housing is an aluminum cup consisting of an outer cylindrical shell 1 with relatively thick sides and a thin circular diaphragm. This produces a rigid clamped circular disk in which the resonant frequency is primarily controlled by its diameter and stiffness. A thin ceramic disc 5 is cemented to the radiating diaphragm.

As a receiver, the diaphragm is mechanically vibrated by sound pressure, causing it to buckle up and down. Since the ceramic is rigidly attached to the diaphragm, it stretches as the diaphragm buckles, which produces an electrical voltage across it. In like manner, when the ceramic is excited by an electrical voltage it will stretch, causing the diaphragm to vibrate and transmit sound. Because the diaphragm can move large displacements while creating only minor strains in the ceramic, this design allows for generation of large sound pressures without over stressing and cracking the ceramic.

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This particular transducer design operates at an overtone of the fundamental resonant frequency of the clamped diaphragm. The frequency of operation can be adjusted by varying the diaphragm thickness.

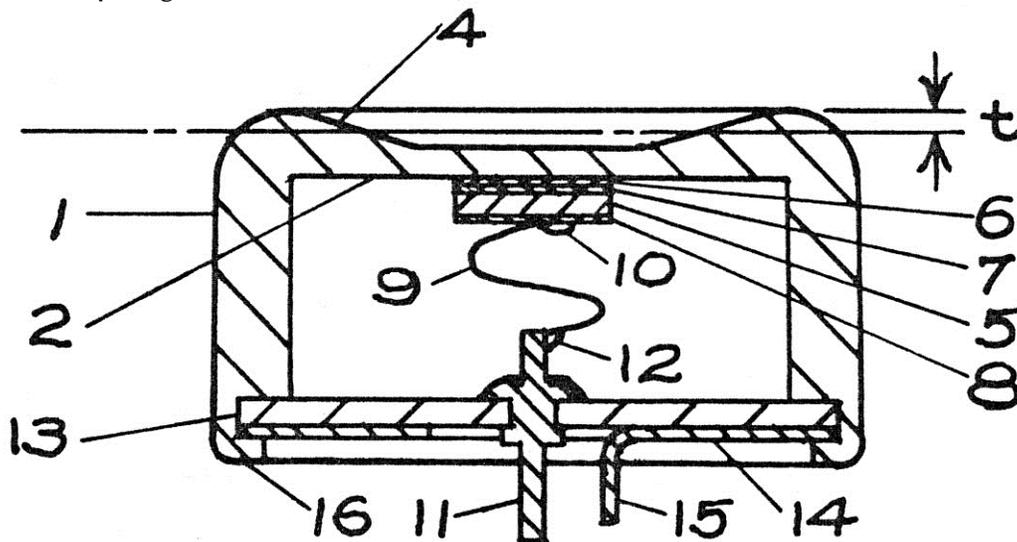


FIGURE 8

Illustration Showing the Construction of a Flexural Ultrasonic Transducer Designed for Operation in Air Using an Electrostrictive Ceramic for Transduction

Figure 1 of U.S. Patent 3,943,388 [9]

#### 4.4 Tonpilz Sonar Transducer

A mass loaded vibratile transducer (Tonpilz Transducer) is a common design used in Sonar. A typical example is shown in Figure 9 on the following page (10). A ceramic cylinder **12**, is cemented between a light aluminum head mass **11**, and a heavy steel tail mass **15**. The ceramic has electrodes on its two ends. This transducer resonates in much the same way as a large mass attached to a spring. If the mass is reduced, the resonant frequency will lower. If the stiffness of the spring increases, the resonant frequency will be higher.

In the transducer of Figure 9, the ceramic cylinder is the spring connected to the head mass and the tail mass. If it is made more compliant, for example, by reducing the wall thickness or increasing the length, the resonant frequency will lower. If the head and tail masses are made smaller, the resonant frequency will increase. At resonance, the length of the ceramic will increase and decrease relatively large amounts, causing the head and tail masses to vibrate. Because the head mass is much lighter than the tail mass, it vibrates at much larger amplitude.

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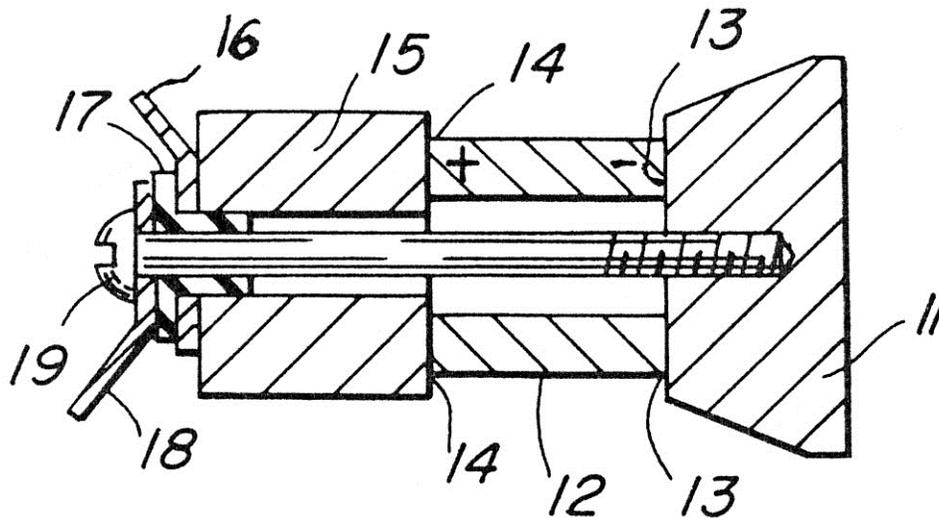


FIGURE 9

Illustration Showing the Construction of a Tonpliz Sonar Transducer

Figure 1 of U.S. Patent 3,739,327 [10]

In operation the structure is encapsulated in waterproof material, such as rubber, and the radiating head is acoustically coupled to the water. When used as a transmitter, an oscillating electrical voltage is connected across the electrodes of the ceramic causing it to alternately lengthen and contract. This in turn causes the head mass, which is coupled to the water, to vibrate large amplitudes and produce a sound pressure wave. As a receiver, a sound pressure wave pushes the head mass, causing the transducer structure to vibrate. This in turn causes the length of the ceramic tube to alternately contract and expand, which generates a voltage across the ceramic stack.

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