

An Overview of Some Fundamentals of Electroacoustics

by

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ACOUSTIC TRANSMISSION MEDIA

Electroacoustic transducers operate as transmitters or receivers of sound. When operating as transmitters, they transform electrical energy into acoustic energy that propagates through a medium, which is usually air or water. When operating as receivers, they transform the acoustical energy into electrical energy.

The fundamental equations for sound transmission are the same for all transmission media. However, because many of the acoustical properties are vastly different between fluid media such as water and gaseous media such as air, there are many fundamental differences between transducers and systems that are designed to operate in each of them. Massa is one of the few organizations that design and manufacture electroacoustic transducers and systems for both underwater (sonar) applications and specialized industrial ultrasonic application in air. A comparison of some of the acoustic properties of air and water are contained in Table I.

TABLE I

	Temperature (°C)	Density (kg/m³)	Velocity (m/sec)	Impedance (MKS Rayls)
Fresh Water	20	1000	1480	1.48 x 10 ⁶
Sea Water (35 ppt salinity)	13	1026	1500	1.54 x 10 ⁶
Air	0	1.29	332	428
Air	20	1.21	343	415

GENERAL PROPERTIES

Wavelength of Sound as a Function of Sound Speed and Frequency

The wavelength of sound changes as a function of both speed of sound and frequency, as shown by the expression:

$$\lambda = \frac{c}{f} \quad (1)$$

where: λ is the wavelength

c is the speed of sound

f is the frequency

Figure 1 shows a plot of the wavelength of sound from Equation (1) in air and water at room temperature as a function of frequency.

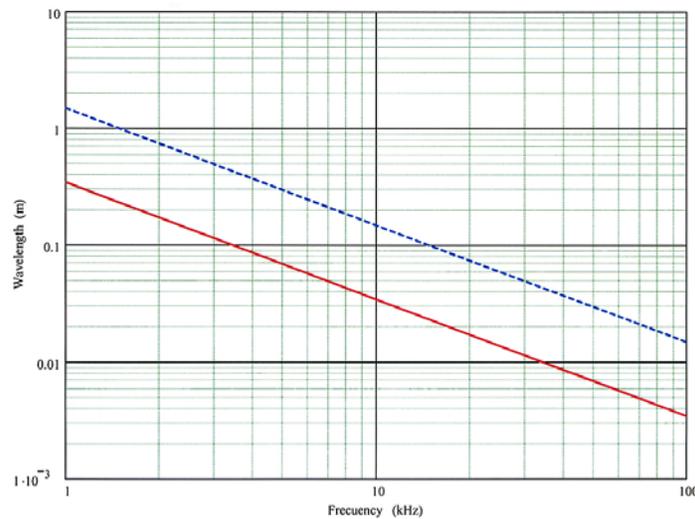


FIGURE 1

Plot of the Wavelength as a Function of Frequency for Sound in Air and in Water at Room Temperature

Transducer Beam Patterns

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. It is important to note that the system beam pattern is not the same as the transmitting or receiving beam pattern of the transducers, as will be explained in a later section.

Transducers can be designed to radiate sound in many different types of patterns, from omnidirectional to very narrow beams. For a transducer with a circular radiating surface vibrating in phase, as is most commonly used in ultrasonic sensor applications, the narrowness of the beam pattern is a function of the ratio of the diameter of the radiating surface to 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.

Figure 2 on the following page shows a three-dimensional representation of the beam pattern produced by a transducer with a diameter that is large compared to a wavelength. As can be seen, it produces a narrow conical beam and a number of secondary lobes of reduced amplitude separated by nulls. Even though the beam is called conical, it does not have straight sides and a flat top as the word "conical" may imply. 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 3 dB on both sides of the on-axis peak. However, the transducer still has the sensitivity at greater angles, both in the main beam and in the secondary lobes.

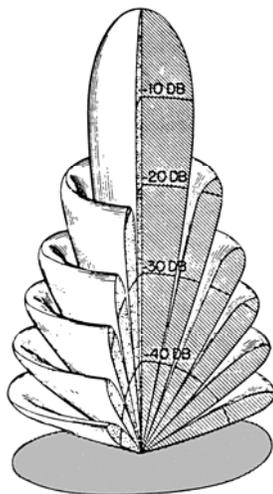


FIGURE 2

Three Dimensional Representation of the Beam Pattern Produced by a Transducer with a Diameter Large Compared to a Wavelength

When describing the beam patterns of transducers, two-dimensional plots are most commonly used. They show the relative sensitivity of the transducer vs. angle in a single plane cut through the three-dimensional beam pattern. For a symmetrical conical pattern, such as that shown in Figure 2, a simple two-dimensional plot will describe the entire three-dimensional pattern. Figure 3 shows a two-dimensional polar plot from -90° to $+90^\circ$ of the beam of a circular radiating piston mounted in an infinite baffle with a diameter equal to two wavelengths of sound. As can be seen, the pattern is smooth as a function of angle, and the -3 dB points are at $+15^\circ$ and -15° off axis, producing a total beam angle of 30° . However, the total angle of the major radiating lobe between the first two nulls is approximately 70° , and the side lobes peak at approximately $+55^\circ$ and -55° .

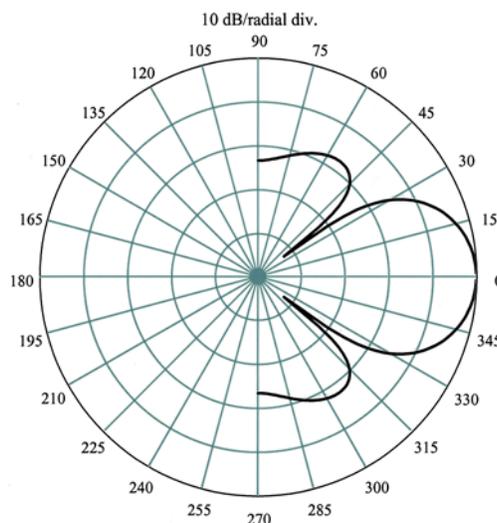


FIGURE 3

A Two Dimensional Polar Plot is Shown which Represents the Beam Pattern of a Transducer Mounted in an Infinite Baffle with a Circular Disk Radiator (Diameter/Wavelength = 2)

When using transducers, it is important to be aware that nearby unwanted targets that are beyond the beam angle can inadvertently be detected, because the transducers are still sensitive at angles greater than the beam angle. Some transducers used in sensing applications are specially designed to minimize or eliminate the secondary lobes to avoid detecting unwanted targets.

System Beam Patterns

In the operation of an echo ranging system, the transmitting transducer sends out sound at reduced amplitudes at different angles, as described by the beam pattern of the transmitting transducer. The receiving transducer has less sensitivity to echoes received at angles off axis, as described by the beam pattern of the receiving transducer. The system beam pattern is the sum in dB of the beam patterns of the transmitter and the receiver.

The solid curve of Figure 4 shows a plot of the beam pattern of Figure 3 on rectilinear coordinates for angles from 0° to 30° off axis. This beam pattern is the same for the transducer whether it is transmitting or receiving. The dotted curve shows the system beam pattern when the same transducer is used first to transmit a sound pulse and then to receive the reflected echo. As can be seen, the system beam pattern is narrower than the pattern of the transducer alone.

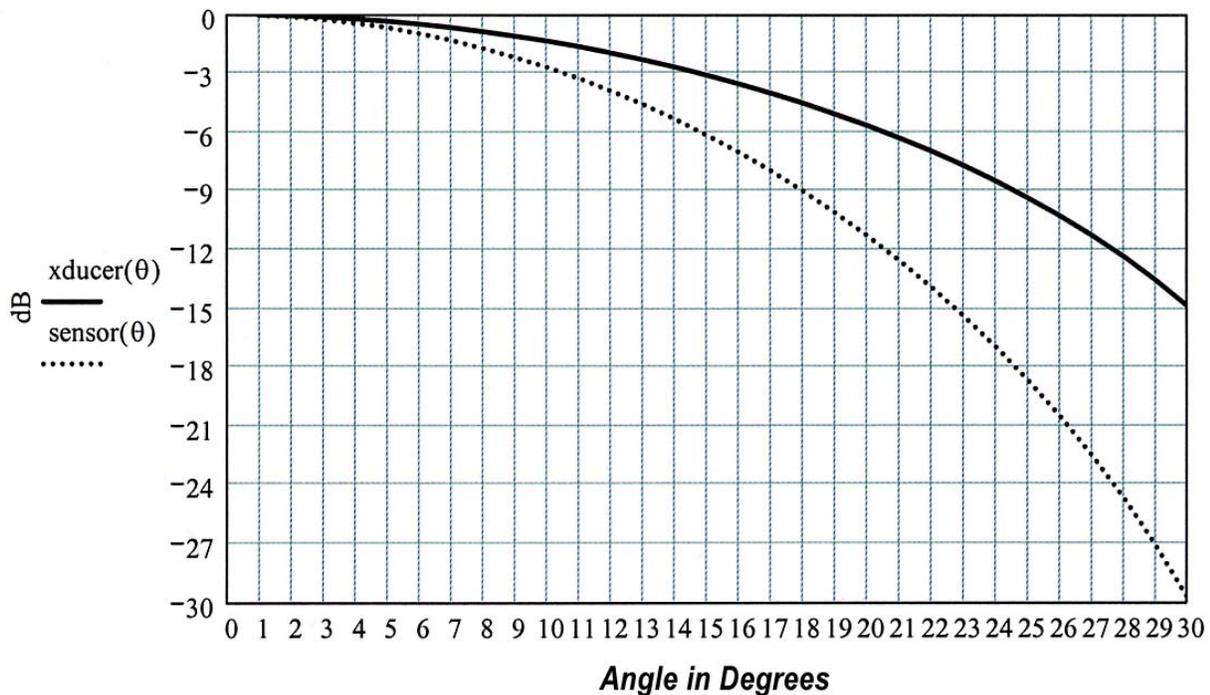


FIGURE 4

The Transducer Beam Pattern of Figure 3 is Plotted on Rectilinear Coordinates as the Solid Curve, and the System Beam Pattern for a Sensor Using the Transducer to Both Transmit and Receive is Plotted as the Dotted Curve

ULTRASONIC TRANSDUCERS AND SYSTEMS OPERATING IN A GASEOUS MEDIUM

Ultrasonic sound is a vibration at a frequency above the range of human hearing, usually greater than 20 kHz. The microphones and loudspeakers used to receive and transmit ultrasonic sound are called transducers. Most ultrasonic sensors are echo ranging systems that use a single transducer to both transmit the sound pulse and receive the reflected echo, typically operating at frequencies between 40 kHz and 250 kHz. A variety of different types of transducers can be used in these systems. For a more detailed discussions of this subject, view the two-part article by Donald P. Massa entitled “*Choosing An Ultrasonic Sensor For Proximity Or Distance Measurement; Part 1: Acoustic Considerations; Part 2: Optimizing Sensor Selection*” that was published in the February and March 1999 editions of **Sensors**, which is located in “Articles” in the “Press” section of the Massa web site, www.massa.com.

Speed of Sound in Air as a Function of Temperature

The speed of sound in air varies as a function of temperature by the relationship:

$$c(T) = 13,044 \sqrt{1 + \frac{T}{273}} \tag{2}$$

where: $c(T)$ is the speed of sound in air a function of temperature in inches/sec.
 T is the temperature of air in °C

Attenuation of Ultrasonic Sound in Air as a Function of Frequency and Humidity

As the sound travels, the amplitude of the sound pressure is reduced due to friction losses in the transmission medium. The attenuation of sound in air increases as the frequency increases, and at any given frequency the attenuation varies as a function of humidity. The value of humidity that produces the maximum attenuation is not the same for all frequencies. For example, above 125 kHz the maximum attenuation occurs at 100% relative humidity; however, at 40 kHz the maximum attenuation occurs at 50% relative humidity.

Since an ultrasonic sensor usually is required to operate at all possible humidities, maximum target range calculations should use the largest value of attenuation. A good estimate for the maximum attenuation in air at room temperature over all humidities for frequencies up to 50 kHz is given by:

$$\alpha(f) = .01f \tag{3a}$$

where: $\alpha(f)$ is the maximum attenuation in dB/ft.
 f is the frequency of sound in kHz

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For frequencies between 50 kHz and 300 kHz, the maximum attenuation over all humidities is:

$$\alpha(f) = .022f - 0.6 \tag{3b}$$

Figure 5 is a plot showing the maximum attenuation of sound as a function of frequency in air at room temperature over all humidities for frequencies between 40 kHz and 250 kHz. Figure 6 shows a family of curves that plot the variations in the attenuation of sound in air at room temperature as a function of humidity for various frequencies between 40 kHz and 200 kHz.

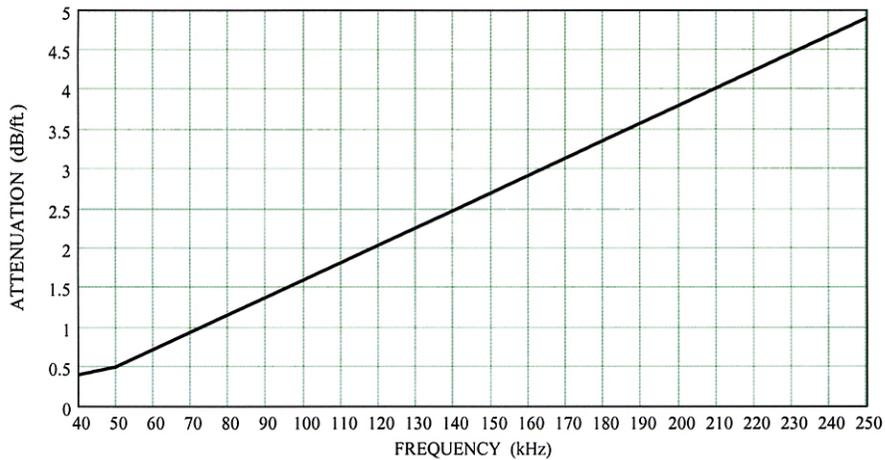


FIGURE 5
Maximum Attenuation of Sound vs. Frequency
in Air for All Humidities

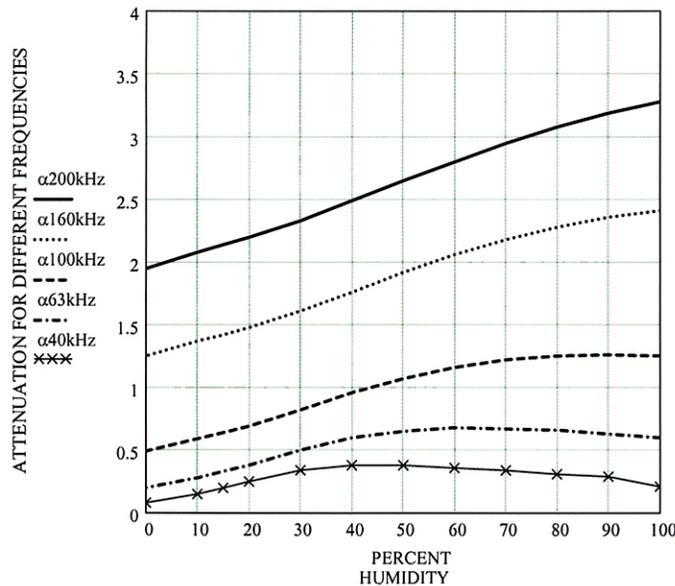


FIGURE 6
Attenuation of Sound in Air vs. Humidity
for Different Frequencies