Chapter 11
Piezoelectric Transducer Designs for Sonar Applications

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11.1 Introduction

An electroacoustic transducer is a device that converts acoustic energy (sound) into electrical energy (voltage or current) or vice versa. When the transducer is used to generate sound, it is called a projector, transmitter, or source. When it is used to detect sound, it is called a receiver. Furthermore, when the receiver is employed underwater, it is referred to as a hydrophone. An underwater sonar system consists of projectors, hydrophones, and associated electronics such as amplifiers and data acquisition systems. This chapter, however, will only cover the description and operational principles of the projector and hydrophone components. More specifically, the chapter will focus on piezoelectric ceramic-based transducer designs intended for underwater use that operate in the frequency band spanning from 1 kHz to 1 MHz. This span covers weapons sonar (1–100 kHz) and imaging sonar (100 kHz to 1 MHz) applications.

Section 11.2 describes the fundamental parameters and measurement techniques necessary to characterize transducers both in air and in water. The piezoelectric ceramic materials that are most commonly used in sonar transducers and their relevant materials properties are discussed in Sect. 11.3. The most common piezoelectric ceramic-based projector designs for sonar applications are described in Sect. 11.4, where they are grouped according to their operational frequency range. A single transducer cannot operate efficiently over the entire 1-kHz to 1-MHz frequency band – primarily due to impedance matching issues with the associated amplifiers. Consequently, a variety of transducer designs have been developed and optimized for different frequency ranges. The chapter concludes with hydrophone characterization, designs, and some performance results in Sect. 11.5.
11.2 Transducer Characterization

11.2.1 In-Air Characterization

Piezoelectric transducers designed for underwater use are initially characterized in air, preferably before being either potted in polyurethane or filled with oil. With modern impedance analyzers, electrical immitance (i.e., impedance or admittance) as a function of frequency, both in terms of real and imaginary components, is a simple measurement to perform and provide a wealth of information to the transducer designer.

A very informative way to plot admittance data is shown in Fig. 11.1. Here, the in-air admittance is plotted as a vector in the conductance–susceptance plane, where frequency increases along the loop as shown in the figure. The circle describes the admittance behavior in the neighborhood of the transducer fundamental resonance frequency. It should be noted that this particular plot is representative of a lightly-loaded (such as air) transducer with a strong resonance.

The noteworthy frequencies obtained from this plot are as follows:

- $f_s$ is the series resonance frequency and is the frequency of maximum conductance. It is the frequency at which the motional power is a maximum for a constant applied voltage (Stansfield 1991).
- $f_p$ is the parallel resonance frequency and is the frequency of maximum motional resistance.
- $f_m$ is the frequency of maximum admittance.
- $f_n$ is the frequency of minimum admittance.
- $f_r$ is the electrical resonance frequency (susceptance is zero).
- $f_a$ is the electrical antiresonance frequency (susceptance is also zero).

The “sharpness” of the resonance of a transducer is known as the \textit{mechanical quality factor}, or simply $Q_m$. It is found from the electrical conductance vs. frequency curve as

$$Q_m = \frac{f_s}{f_2 - f_1},$$

(11.1)

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{admittance_circle.png}
\caption{Admittance circle of a lightly-loaded piezoelectric transducer}
\end{figure}