ACOUSTICS LABORATORY

EXPERIMENT 6 - Transducer Calibration I

OBJECTIVES

The overall response of acoustic transducer systems is investigated in this experiment. Two types of transducers are used: one is a high frequency piezoelectric type, resonant in the vicinity of 26 kHz, another is an audio frequency speaker. These transducers will be used in later experiments, and the calibration data obtained here will be useful then. For each type, a pair of units is used; thus, the measured response is always a combined receiver/transmitter response. Two aspects of the response characteristics are considered. One is the overall on-axis response, the second is the directional pattern. The purpose of the experiment is to determine the frequency limitations for transmission through the transducer systems and also to compare the directional pattern with that computed from an idealized model of a piston radiator.

THEORY

The transducers used in this experiment are circular piston radiators; the transducer vibrates in-phase over its entire face, creating compressional acoustic waves in the air at the boundary. If the diameter of the piston is on the order of, or larger, than the wavelength of sound in air, the pattern of radiation from the transducer will have a directional character. For the circular piston in an infinite baffle the directivity pattern, that is, the sound intensity as a function of angle from the normal to the transducer face, normalized to unity maximum response (on axis) is:

$$\beta(\theta) = \left[ \left( \frac{2 J_1(ka \sin(\theta))}{ka \sin(\theta)} \right) \right]^2$$  

where \( k \) is the wavenumber, \( a \) is the radius of the piston and \( J_1 \) is the ordinary Bessel function of order 1. The derivation of this is given in Kinsler et al. (2000: 182).

The measurement results will be expressed as a system response or gain in decibels (usually negative),

$$G = 20 \log_{10}[\text{voltage out / voltage in}]$$  

As described below, the measurement will use pulse techniques. Data will be taken either from the face of an oscilloscope which displays received voltage versus time or from a computer controlled Analog-to-Digital convertor that will read the voltage after a prescribed time delay. For these measurements it is most convenient to observe the peak-to-peak amplitude of the deflection. As long as the same measurement method is used for both the input and output voltages, the gain ratio remains the same. The \( G \) expressed above is usually the on-axis response, that is, the response in the direction of maximum sensitivity.
Directional pattern responses are conveniently referenced to this on-axis response as the 0 dB level. Thus, rotating one transducer and maintaining the input voltage constant,

$$\beta(\theta) = 20 \log_{10} \left[ \frac{\{\text{voltage out at } \theta\}}{\{\text{voltage out at } 0\}} \right]$$

(6.3)

For both of these measurements, $G$ and $\beta$ are frequency dependent and are defined as steady-state responses. This means that the amplitude must be measured after the excitation has persisted long enough for the transient response of the system to die out to an acceptable level.

PROCEDURE NOTES

The calibration measurements are conducted in a pulsed mode to discriminate against the reflections from the boundaries of the room. Thus, the signal source for this experiment is a signal generator operating in a tone-burst mode, generating a sinusoidal wave-train of finite duration which is amplified by a power amplifier to drive the transducer. The receiving transducer is coupled through a preamplifier and an adjustable band-pass filter to an oscilloscope where the resulting output is displayed. To minimize noise pick-up, use a short coaxial cable between the receiving transducer and the preamplifier. The signal output can be measured from the face of the oscilloscope or with the GPIB instrumentation system. A timing pulse for the repetition rate is obtained from either a pulse generator or from the control computer which triggers both the oscilloscope time base and the tone-burst signal generator, and, in the GPIB system, the sampling Analog-to-Digital convertor. See Figure 6.1 for a block diagram of the experimental set up.

The calibration measurement sequence is as follows. Starting with the two high-frequency transducers, connect one as the transmitter, the other as the receiver and set up a 0.5 ms long pulse at about a 20 pps repetition rate. Stand the two transducers on their pivoting bases facing each other at a separation of 1 meter. Scan through the frequency range of 20 to 30 kHz to find the frequency of maximum response. Setting the frequency at the maximum response value, check the orientation of each transducer to be sure that they are set on the 0 degree mark and also are aligned to the direction of maximum response.

To establish the maximum useable pulse length, rotate one of the transducers 90 degrees to reduce the received level for the direct path. Increase the preamplifier and/or the oscilloscope gain until the pulse is observed on the CRT. Now adjust the pulse length so that it ends at the beginning of the first interfering arrival. The first interference should be a reflection from the floor. Check the arrival time to see if it corresponds to that determined from the geometry. A low level of interference within the pulse can be observed by watching its envelope as the frequency is slowly varied. The envelope in the region where interference is present will fluctuate as the interfering signal's phase alternates between constructive and destructive interference.

There are two types of interference of concern, one originates within a pulse repetition interval, the other consists of echoes from previous pulses. These latter are identified by
changing the pulse repetition rate -- this will change the relative phases and again cause the envelope to fluctuate as the phase changes between constructive and destructive interference. Reduce the repetition rate until there is no evidence of any reverberation energy proceeding or during the direct pulse.

After these adjustments and settings have been carried out, return the transducer to the 0 degree, on-axis orientation so that the on-axis frequency response of the transducer pair can be measured. The band-pass filter cutoff frequencies should be set for a low cutoff one octave below the resonant frequency and a high cutoff one octave above resonance. A frequency range of \( \pm \) one half octave around the frequency of maximum response (resonant frequency) should be covered in the measurement. As pointed out previously, to approximate the steady-state response, the amplitude measurement should be made near the end of the direct pulse just before the first interference so the transient response from the start of the pulse has the maximum time to decay.

Next, the directional response (beam pattern) for the transducer should be measured. The beam pattern is, of course, dependent on the operating frequency, so a complete family of response curves is required to fully describe the transducer response. In the interest of conserving time, effort, and patience, only the beam pattern at the resonant frequency will be measured. With the pulse carrier frequency at the resonant frequency, measure the response as was done above, varying the angle in increments fine enough to resolve the structure of the directional pattern, leaving the frequency fixed. During these measurements it may be necessary to narrow the band-pass filter response to reduce noise pickup. The filter settings should remain the same over the full range of angle measurement to avoid artifacts in the response caused by a change in circuit gain introduced by the filter settings. Be sure to make the measurements at the appropriate time delay because you could easily be mislead by spurious reflected paths when measuring the very low sidelobe levels.

After completing these measurements with the high frequency transducers, make an on-axis frequency response measurement for the audio speakers. Cover the frequency range from 2 kHz to 20 kHz using the set-up and technique described above. In this case use a close spacing, about 20 cm so that the direct sound will be enough higher in level that reflections and reverberation can be ignored. The pulse length will have to be longer for this calibration because several cycles (say five) at 2 kHz will have to be transmitted in order to define the frequency. This results in a pulse length that is longer than the floor reflected path between the source and receiver, so the direct path and the floor reflection will overlap. Measurement with the GPIB system will require positioning the sampling point at the correct time within the received pulse.

ANALYSIS

Plot the responses on a decibel scale, (10 dB to the inch). For the beam pattern plots, use a polar plot. Reference the response to 0 dB on the main lobe.
Compare the beam pattern with the theoretical pattern for a piston radiator in a plane baffle (Equation 6.1). What reasons can you give for differences between the theoretical and experimental patterns?

REFERENCE


Figure 6.1 Block diagram for experiment 6.