Transducer Characterization
Learning Objectives

Pulse-echo experimental determination of impedance, sensitivity of commercial transducers

Experimental determination of effective radii and focal lengths of commercial transducers
Transducer impedance, sensitivity

\[
\begin{align*}
t_G(\omega) &= \frac{F_t(\omega)}{V_i(\omega)} = \frac{Z_r^{A;a} S_{vl}^A}{(Z_{in}^{A:e} T_{11} + T_{12}) + (Z_{in}^{A:e} T_{21} + T_{22}) Z_i^e} \\
t_R(\omega) &= \frac{V_R(\omega)}{F_B(\omega)} = \frac{K Z_o^e S_{vl}^B}{(Z_{in}^{B:e} R_{11} + R_{12}) + (Z_{in}^{B:e} R_{21} + R_{22}) Z_o^e}
\end{align*}
\]

To fully characterize these generation and reception transfer functions, we need to be able to obtain the transducers input electrical impedance and their sensitivities.
Transducer impedance

Measurement of the transducer input impedance, $Z_{in}$:

$$Z_{in} = \frac{V}{I}$$
Transducer impedance

Example impedance measurements of two 5 MHz transducers:

transducer 1
Transducer impedance

transducer 2

Amplitude (Ω)

Frequency (MHz)

Phase (Deg)
Transducer impedance

Impedance of a capacitor, \( Z = \frac{1}{-i\omega C} \)
Transducer sensitivity

Pulse-echo measurement setup for determining sensitivity

pulser/receiver

$\rho_1, c_{p1}$

$D$

solid
Transducer sensitivity

1. measure voltage and current when transducer is radiating into the fluid but before any reflected waves have arrived
2. do FFT of the measured voltage and current and relate to the voltage and current at the transducer by compensating for the cabling

\[
\begin{bmatrix} V_{in} \\ I_{in} \end{bmatrix} = \frac{1}{\det[T]} \begin{bmatrix} T_{22} & -T_{12} \\ -T_{21} & T_{11} \end{bmatrix} \begin{bmatrix} V_1 \\ I_1 \end{bmatrix}
\]

Note: then the impedance of the transducer is just

\[
Z_{in}^{A;e} = \frac{V_{in}}{I_{in}}
\]
Transducer sensitivity

3. measure voltage and current generated by the waves reflected from the surface of the block:
Transducer sensitivity

4. do FFT of the measured voltage and current and relate to the voltage and current at the transducer electrical port by compensating for the cabling

\[
\begin{align*}
\begin{bmatrix} V_T \\ -I_T \end{bmatrix} &= \frac{1}{\det[T]} \begin{bmatrix} T_{22} & -T_{12} \\ -T_{21} & T_{11} \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix}
\end{align*}
\]
5. From these measurements and a knowledge of the acoustic/elastic transfer function for this setup we can obtain the sensitivity of the transducer from:

\[ S_{vl}^A = \sqrt{\frac{V_{in}I_T + V_TI_{in}}{t_AZ_r^A,a I_{in}^2}} \]

[Note: in all these division processes in the frequency domain, a Wiener filter is used to desensitize the process to noise]
Example sensitivity calculated for a 5MHz planar transducer:
Cabling effects need to be accounted for in determining the sensitivity:
Use of manufacturer specifications for parameters such as transducer radius and focal length in transducer models do not always lead to good agreement with experimental measurements.

Thus, we need to determine experimentally "effective" values for these parameters.
Transducer Effective Parameters

Effective radius for an unfocused (piston) immersion probe

\[ a_{\text{eff}} = \sqrt{2\frac{\lambda}{z_{\text{min}}}} \]

Diagram showing: sample, FFT, plot 5 MHz component versus \( z \), find \( z_{\text{min}} \), determine \( a_{\text{eff}} \), effective radius calculation.
Transducer Effective Parameters

Effective radius and focal length for a spherically focused probe

\[ a_{\text{eff}} = \sqrt{\frac{2\lambda z_{\text{min}} (R_0)_{\text{eff}}}{(R_0)_{\text{eff}} - z_{\text{min}}}} \]

\[ (R_0)_{\text{eff}} = z_{\text{max}} \left\{ \frac{\pi - x}{\pi - x(z_{\text{max}}/z_{\text{min}})} \right\} \]

where \( x \) is the root of:

\[ x \cos(x) = \frac{\pi - x(z_{\text{max}}/z_{\text{min}})}{\pi - x}\sin(x) \]
Effective transducer parameters determined experimentally:

<table>
<thead>
<tr>
<th>Probes</th>
<th>Manufacturers Specs</th>
<th>Estimated Parameters</th>
<th>Center Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>focal length (cm)</td>
<td>focal length (cm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>radius (cm)</td>
<td>radius (cm)</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>7.62</td>
<td>13.47</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>0.476</td>
<td>0.451</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>7.62</td>
<td>20.74</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>0.635</td>
<td>0.556</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>7.62</td>
<td>7.45</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>0.476</td>
<td>0.469</td>
<td></td>
</tr>
</tbody>
</table>

These values should be independent of frequency but in practice they do vary somewhat with the frequency component used in their determination.