Measuring Acoustic Attenuation in Solids

Introduction

In addition to measuring sound velocity, the Iowa Doppler Products sound calipers can be used to measure attenuation in solids. The method is similar to that used by J. F. Guess and J. S. Campbell (1) in their article "Acoustic properties of some biocompatible polymers at body temperature".

The procedure is as follows:

1. With the Sound Heads in a water bath, and the Pulser Box used to drive one of the Sound Heads, the received waveform from the other Sound Head is recorded.
2. The sample to be measured is placed in the sound path between the two Sound Heads, and again the received waveform is recorded.
3. The Fourier transform of both waveforms is calculated.
4. The magnitude of the transformed signal is expressed in deciBels relative to 1 Volt. DeciBels = 20 log(magnitude (in Volts))
5. The attenuation versus frequency is the difference between these two deciBel curves less the signal lost by reflections. Reflection loss will be treated in the next section.

In this document, we will show an example of results using the procedure outlined above. Then we will compare it to a direct measurement of attenuation versus frequency.

The speed of sound can also be measured by two methods, one a direct time-of-flight method as described in the manual (2) for the Speed of Sound kit, and the second a Fourier transform method described in reference 1. Examples of both of these will be given.

Attenuation

Following the procedure in the introduction with a block of polycarbonate as the sample, the two recorded waveforms are shown in figure 1.

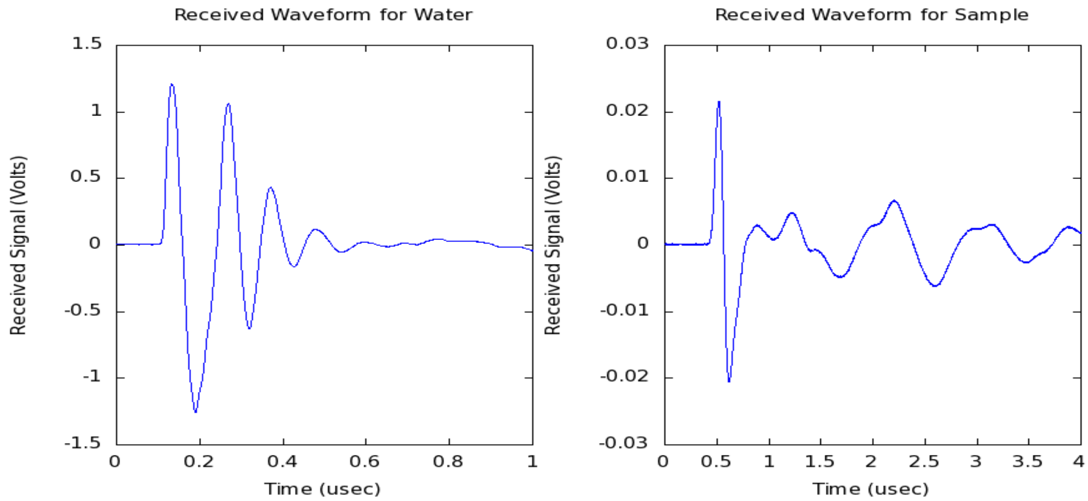

Figure 1. Received waveforms without and with the sample in the sound path.

The Fourier transforms of these two signals are calculated; and, from the transforms, the logs of the magnitudes are calculated. These are shown in figure 2.

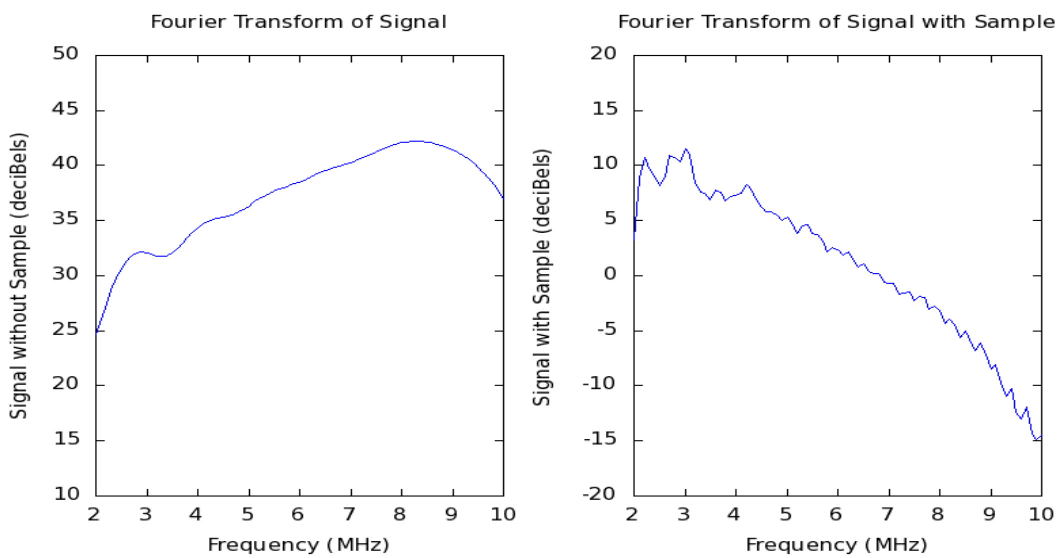

Figure 2. Fourier transforms of the two signals, expressed in deciBels.

The signal lost by reflections is calculated as follows. In the absence of attenuation, the transmission factor for the sample is

$$T=\frac{4Z_sZ_w}{(Z_s+Z_w)^2} \tag{1}$$

where Z_s and Z_w are the acoustical impedances of the sample material and water respectively. These impedances are equal to the sound speed multiplied by the density of the material in question. In deciBels, the transmission is 20*log(T), and this quantity is added to the difference of the two curves in figure 2 to get the bulk attenuation of the sample. The result is shown as the blue line in figure 3.

To compare this with a direct measurement of attenuation, a burst generator is used to drive one Sound Head. The burst length is set to 10 cycles and measurements of received amplitude, with and without the sample, are made in the frequency range from 2 to 10 MHz. Bulk attenuation is calculated as before and the result is shown as the red line in figure 3.

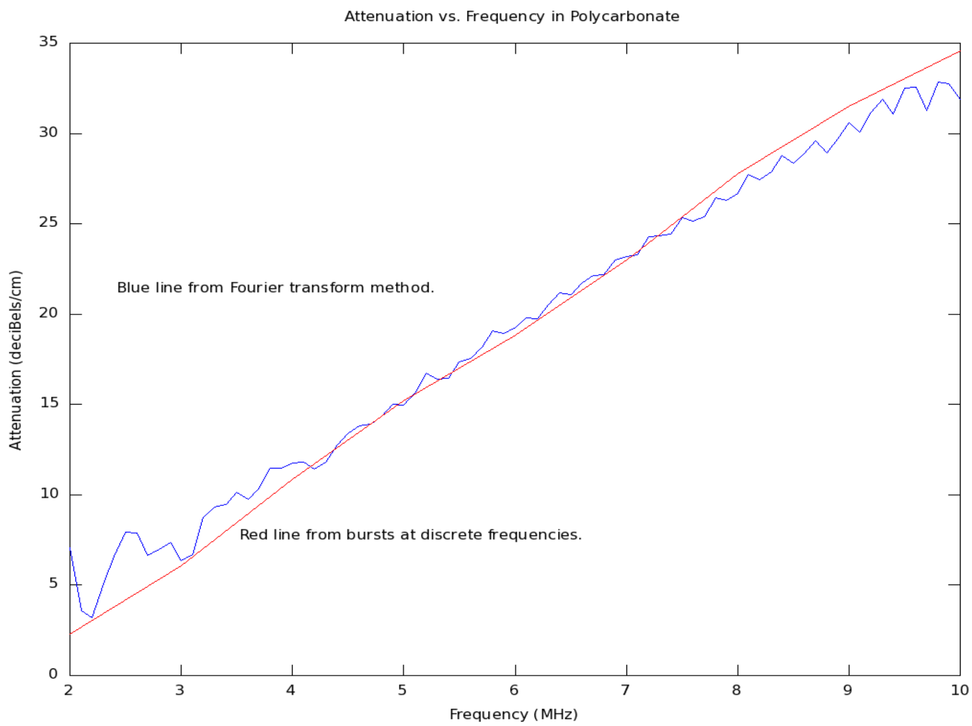

Figure 3. Acoustic attenuation in polycarbonate. The red line is from measurements at discrete frequencies from 2 to 10 MHz. The blue line is from the Fourier transform method described in the introduction.

Sound Speed

The time-of-flight method for measuring sound speed in a solid sample is explained in the Speed-of-Sound manual (2), available on this web page. The speed of sound in the polycarbonate sample by this method is 2.423 km/sec, which would be the group velocity of sound.

The speed of sound can also be calculated by Fourier transform techniques as follows. The time delay in the Sound Head setup is

$$\tau = \frac{-\theta}{2\pi f} \tag{2}$$

where f is the frequency corresponding to the phase delay, θ . In reference (1), the gross time delay is calculated from the centroid of energy of the received pulses, and the small variations are calculated from equation (2), which would also give a value close to the group velocity of sound. Here we will unwrap the phase versus frequency curve to calculate time delay, which will give us the phase velocity. Phase velocity is related to the difference of time delay with and without the sample, Δt , by

$$V_s = \frac{1}{\frac{1}{V_w} + \frac{\Delta t}{d}} \tag{3}$$

where V_s is the phase velocity in the sample, V_w is the speed of sound in water, and d is the sample thickness. Figure 4 shows the speed of sound versus frequency by this method and the value calculated from the time of flight method.

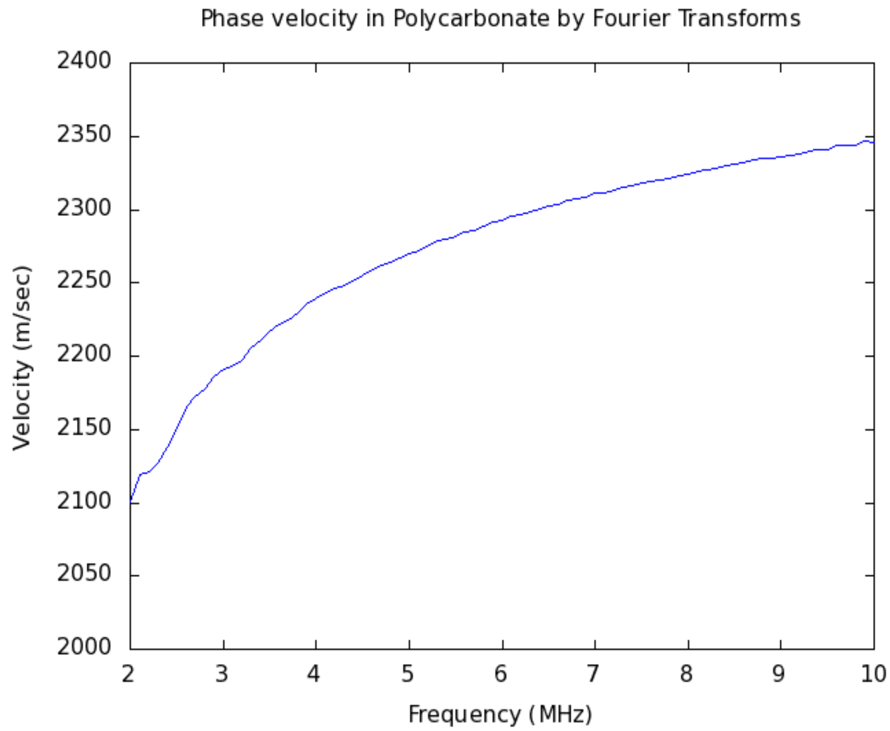

Figure 4. Phase velocity of sound in Polycarbonate. By comparison, the group velocity, as measured by the time of flight method, is 2423 m/sec.

Bibliography

1. Guess, J. F. and Campbell, J. S. Acoustic properties of some biocompatible polymers at body temperature. Ultrasound in Med. & Biol. Vol. 21, No. 2, pp273-277, 1995. A theory for the frequency dependence of sound speed and attenuation is given by one of the references (3) in this article.
2. Speed of Sound Manual, Iowa Doppler Products web page. http://www.iowadoppler.com/educational.html#literature
3. O'Donnell, M.; Jaynes, E. T.; Miller, J. G. Kramers-Kronig relationship between ultrasonic attenuation and phase velocity. J. Acoust. Soc. Am. Vol. 69, pp696-701; 1981.