

Understanding Logging-While-Drilling Transducers with

COMSOL

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Introduction: Logging-while-drilling (LWD) acoustic transducers provide real-time data about geologic and geophysical properties of the borehole that ensure safety margins and optimize completion [1], thus the acoustic transducers (transmitter and receiver) design is important in the modern oil drilling project. An FEM simulation with COMSOL Piezoelectric Device and Acoustic-Piezoelectric Interaction modules is presented and adopted for investigation of LWD transducers design. Various transmitter aspects were studied: displacement resonance response, acoustic field distribution, absolute acoustic pressure frequency response, transmitting voltage response and directivity. Receiving sensitivity and signal to noise ratio (SNR) were also studied based on a receiver design.

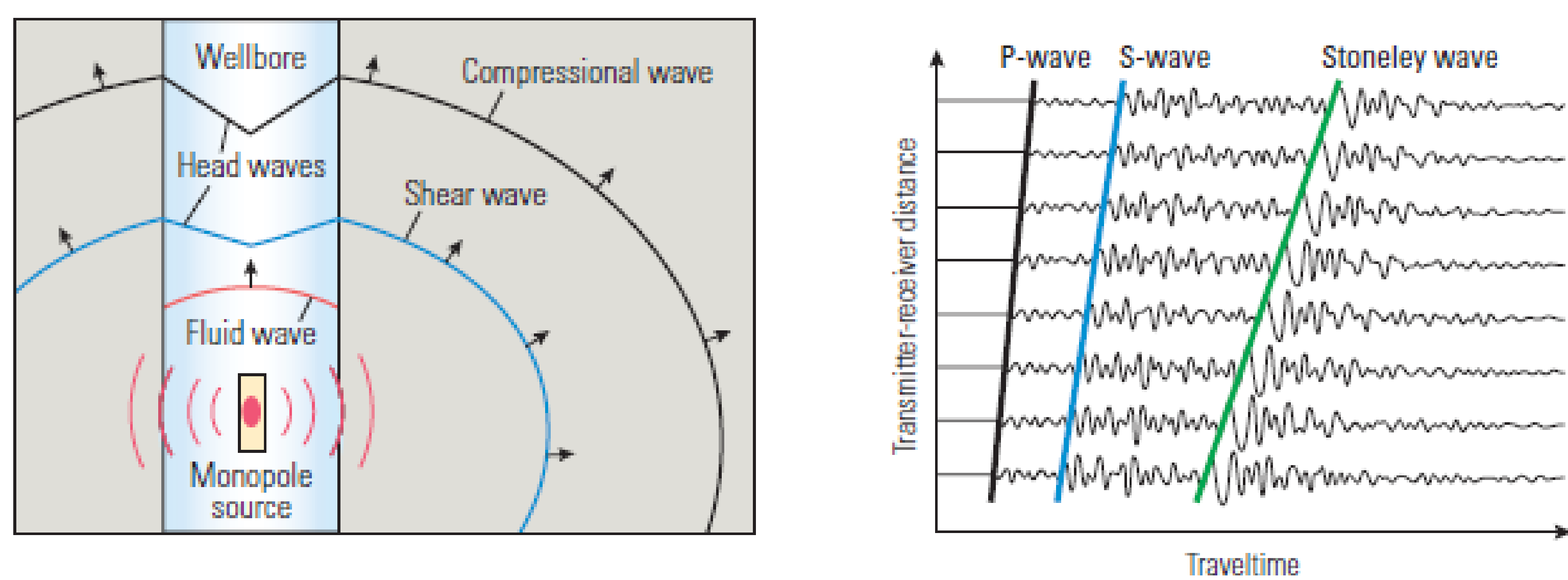


Figure 1. Sonic waves from monopole sources, the sonic signal arrives later as the transmitter-receiver distance increases [2].

Computational Methods: The entire design of the receiver was completed in the Piezoelectric Devices (pzd) module under Structural Mechanics. The displacement analysis part of the design of the transmitter was also conducted in this module. The acoustic response part of the design of the transmitter was done in the Acoustic-Piezoelectric Interaction, Frequency Domain (acpz) module under Acoustics, Acoustic-Structure Interaction. All of them were studied in the frequency domain.

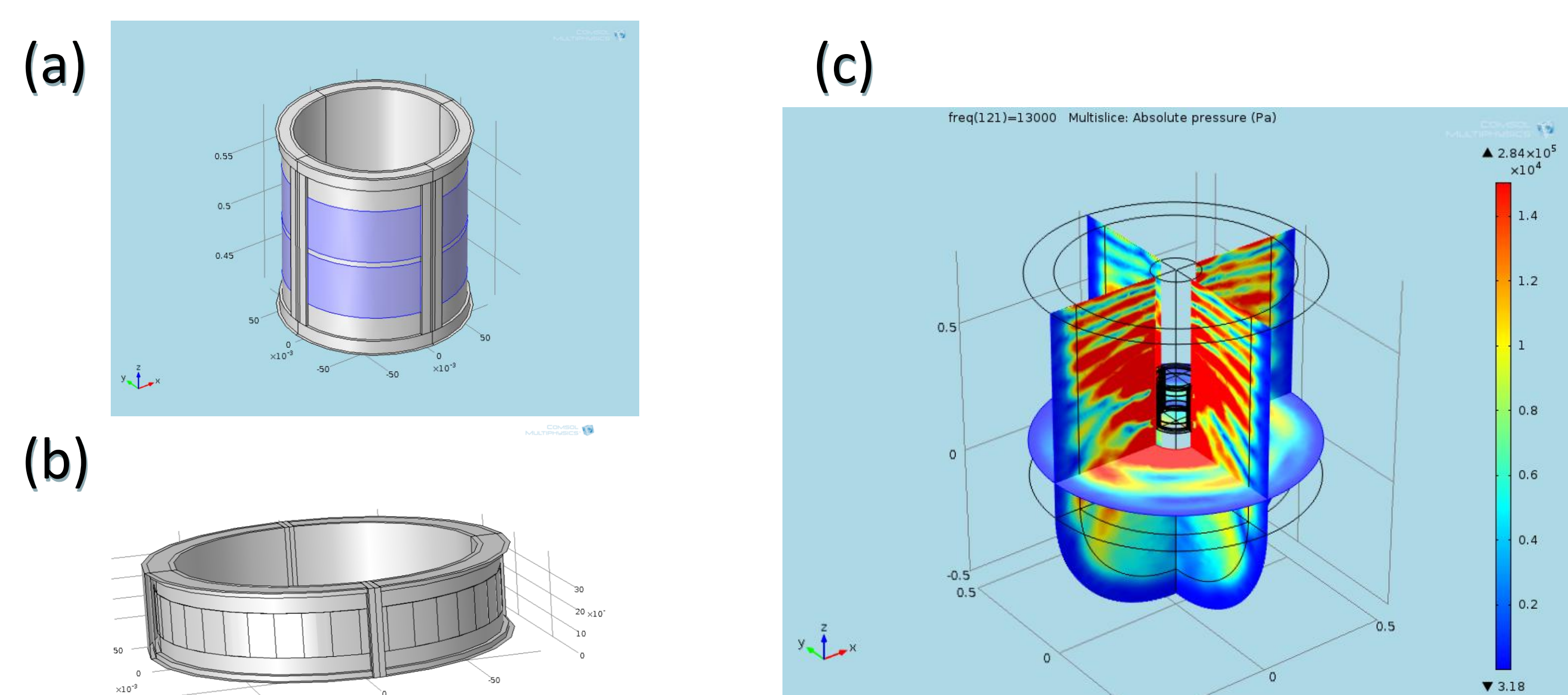


Figure 2. (a) Geometry of transmitter; (b) Geometry of receiver; (c) Acoustic pressure field plot for the transmitter.

The transmitting voltage response (TVR) definition of transmitter for 1 m down the center of the steel shaft is:

$$\begin{cases} p_{\text{rms}} = \sqrt{0.5 \cdot \text{pfar}(0,0,-1) \cdot \text{conj}(\text{pfar}(0,0,-1))} \text{ [Pa]} \\ \text{TVR} = 20 \cdot \log_{10}(p_{\text{rms}} / V_{\text{rms}} / 1[\mu\text{Pa/V}]) \end{cases}$$

For the receiving sensitivity (RS), receiving voltage (RV) is obtained by

$$\text{RV} = \text{intop1}(\text{pzd.normJ}) / (\text{pzd.omega} \cdot \text{C})$$

$$\text{RS} = 20 \cdot \log_{10}(\text{RV} / (P \cdot 1 [\text{V}/\mu\text{Pa}]))$$

Results: The transmitting voltage response (TVR) plot shows how effective the transmitter is to convert electrical energy into detectable acoustic energy as shown in Figure. 3. which has such peaks as caused by half ring resonance around 5 kHz, height resonance around 8 kHz, PZT arc length resonance around 11.5 kHz, and collective third harmonic resonance around 15 kHz. The directivity of the transmitter is also a very important criterion because information in all directions is sought. The directivity is characterized by sound pressure level (SPL) in the azimuthal view (Figure.4).

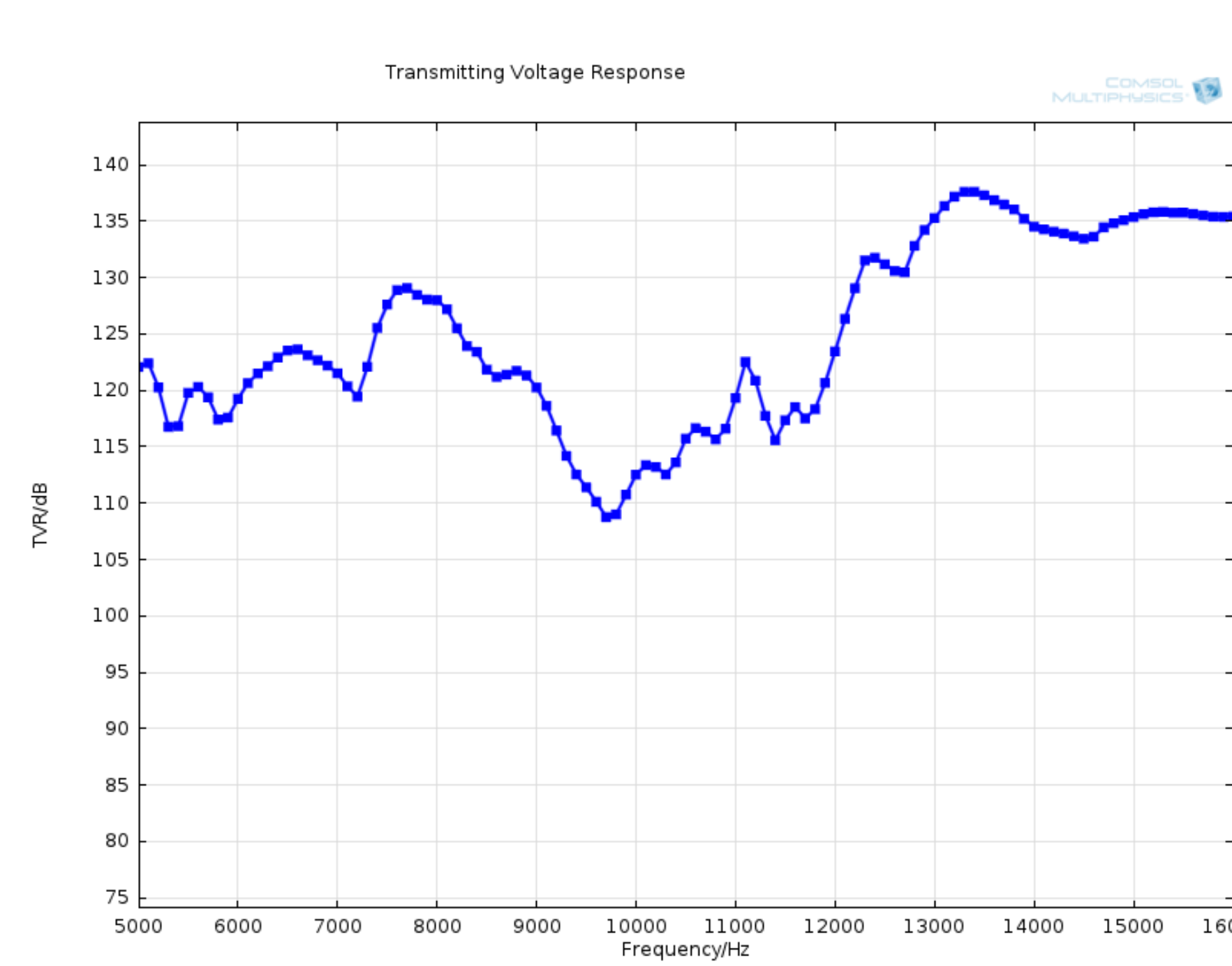


Figure 3. TVR w.r.t. frequency. TVR peaks appear at resonance peaks.

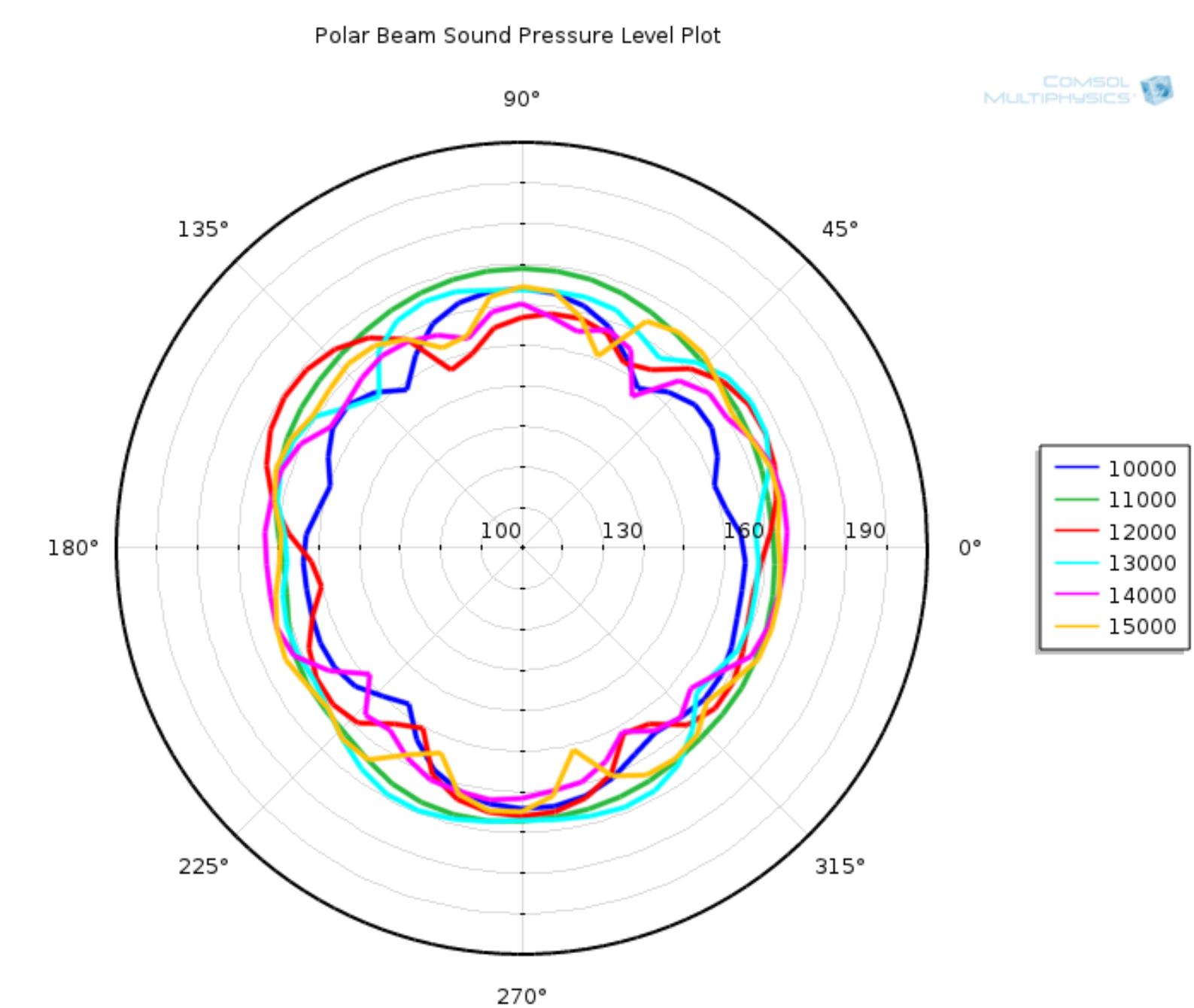


Figure 4. Polar beam pattern of SPL for different frequencies to show directivity.

For the receiver, two most important design parameters are receiving sensitivity and signal to noise ratio. Figure.5 is the equivalent circuit of piezo receiver, Figure.6 is the receiving sensitivity of current design. Good receivers should have a relatively flat receiving sensitivity. However, since this receiver has the half ring resonance and other resonances, there are some fluctuations in the receiving sensitivity curve.

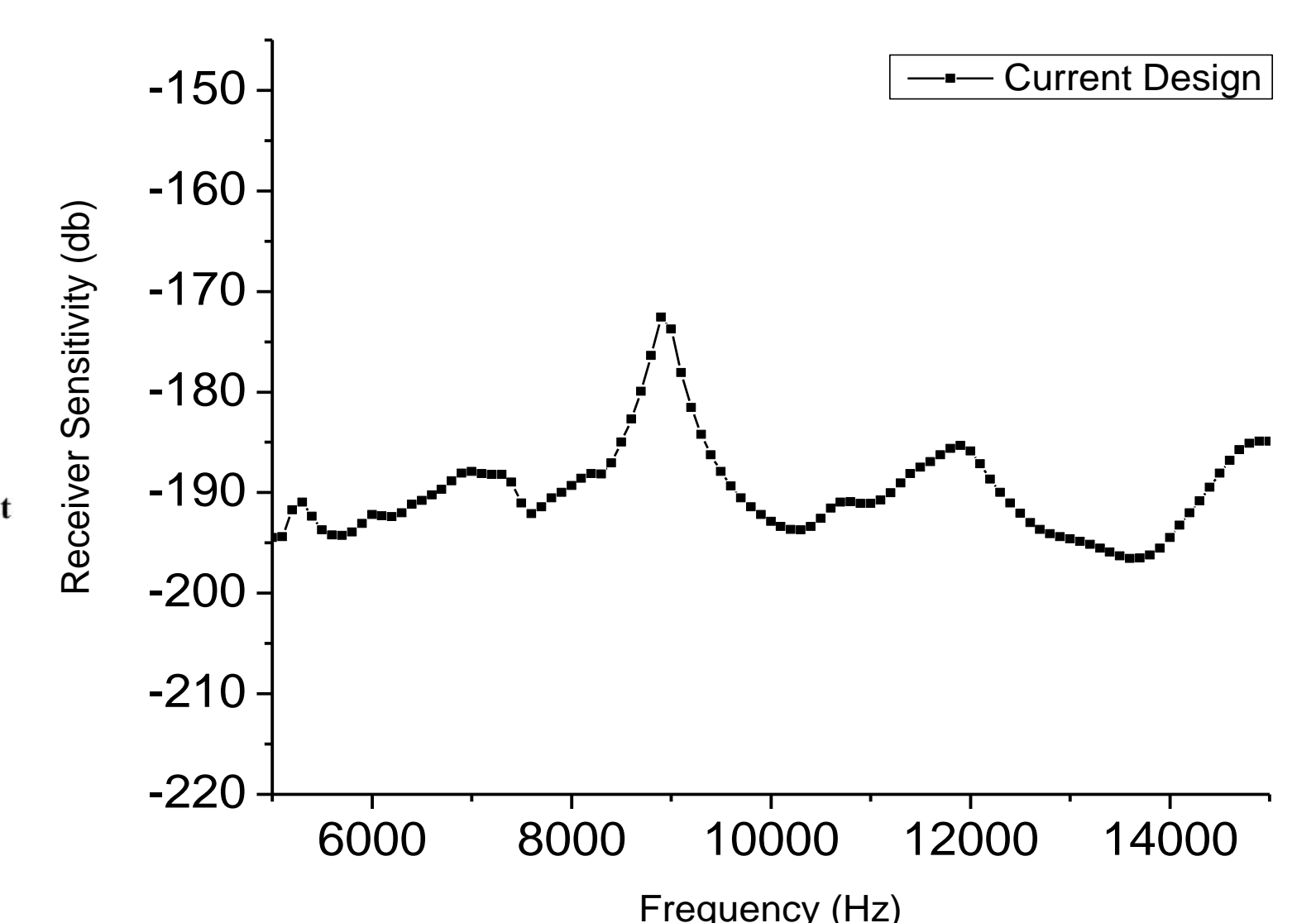
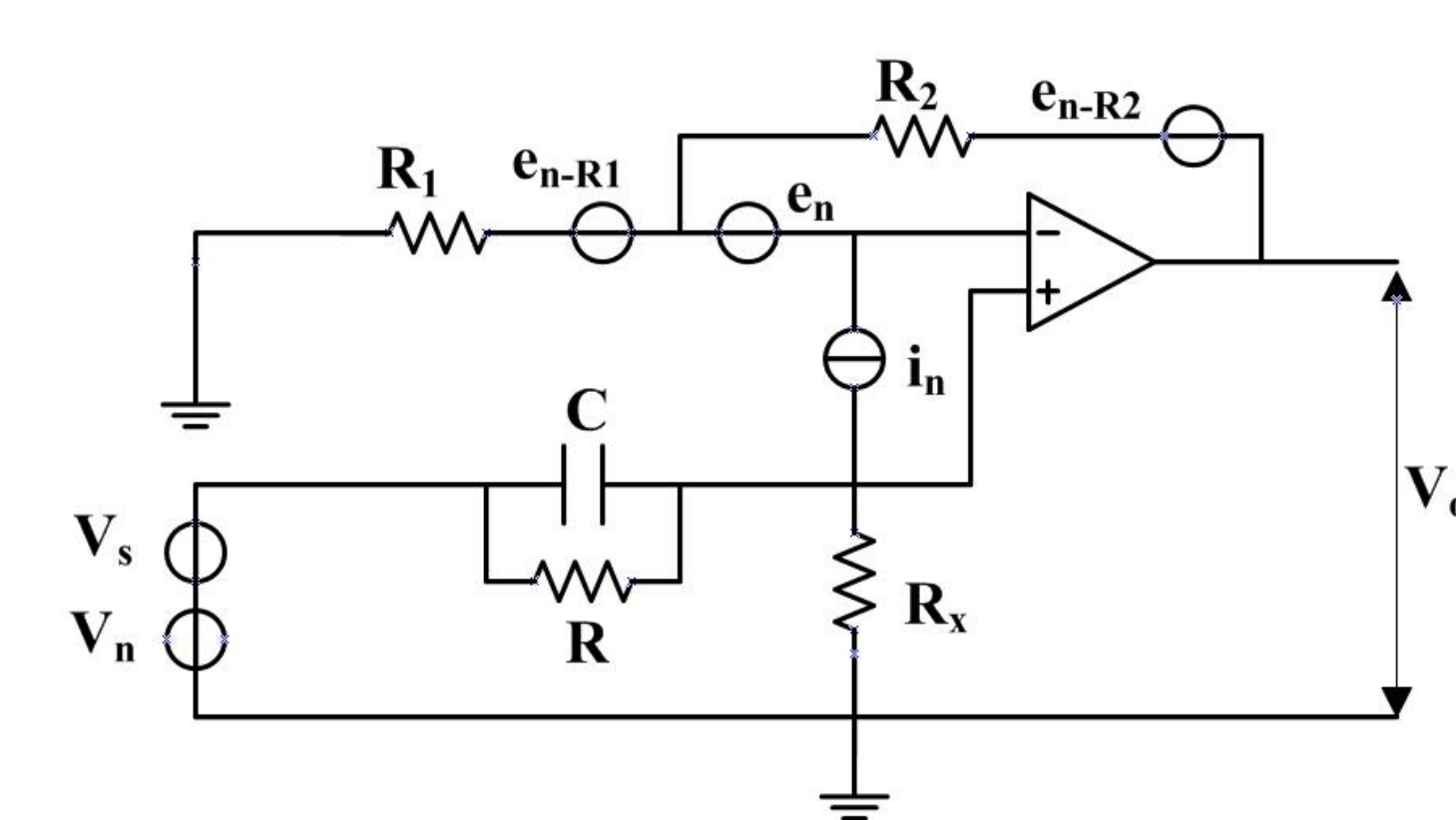


Figure 5. Equivalent circuit of Piezo receiver and OP AMP

Figure 6. Receiving sensitivity of current design.

Conclusions: Detailed COMSOL simulations give a trustworthy guideline what transmitter and receiver designs meet requirements for the LWD acoustic applications. Acoustic response analysis gave much information for applying the transmitter in practice such as acoustic field distribution, absolute acoustic pressure frequency response, transmitting voltage response, and directivity. For the receiver, the receiving sensitivity was given and explained. COMSOL results are useful in understanding the devices and they give guidance for their in-field applications.

References:

1. Darwin V. Ellis, and Julian M. Singer, Well Logging for Earth Scientists, Springer: Dordrecht, The Netherlands (2008)
2. Jeff Alford, et al., Sonic Logging While Drilling - Shear Answers, Oilfield Review, Spring, 4-15 (2012)