Monix Energy Solutions, Inc

PennState Department of Electrical Engineering

Understanding Logging-While-Drilling Transducers

With COMSOL Multiphysics® Software

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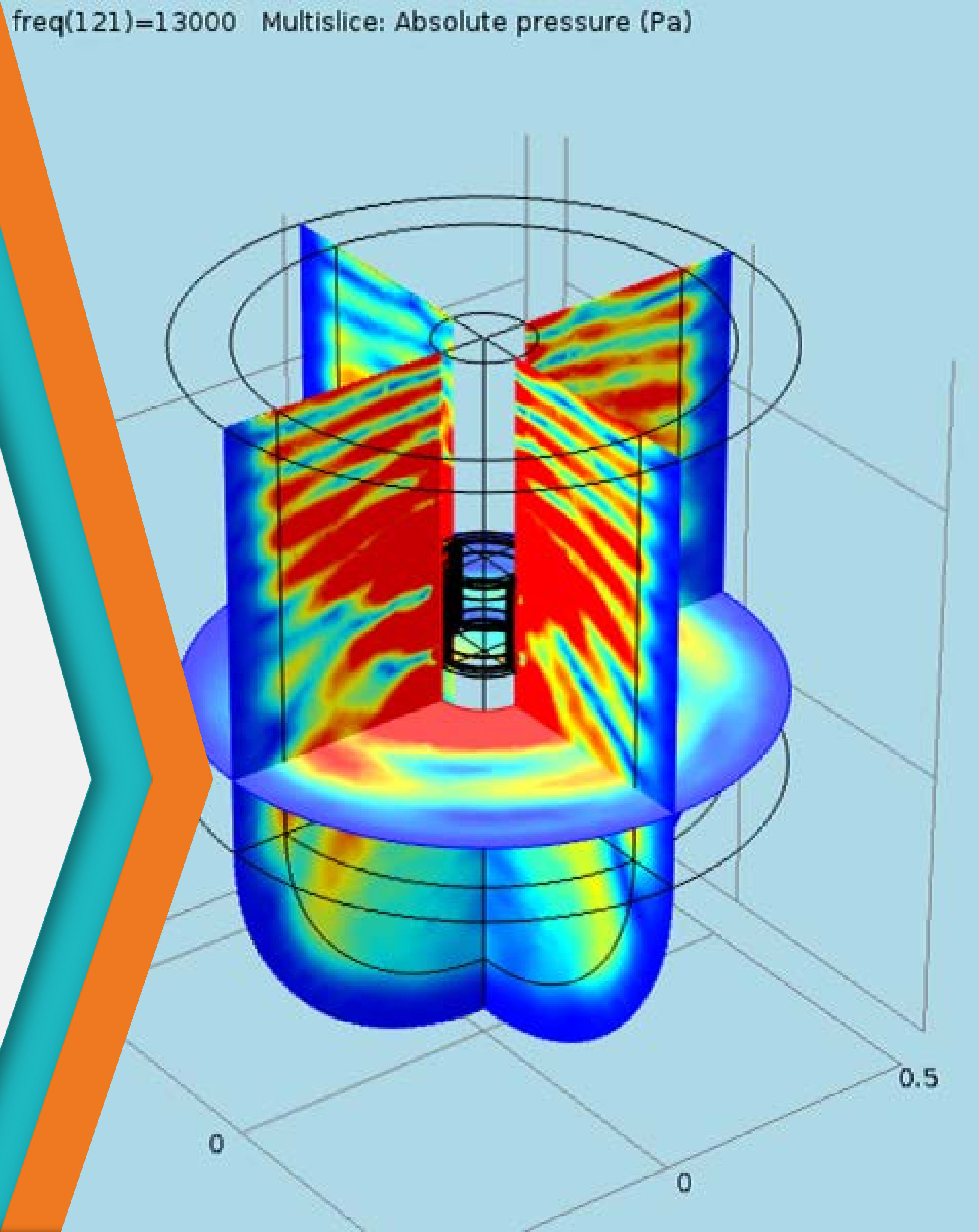

Outline

- Background
- Motivation and Objective
- Transmitter Analysis
  - Displacement Resonance Frequency Response
  - Acoustic Pressure and TVR Frequency Response
  - Acoustic Pressure Field Distribution and Directivity
- Receiver Analysis
  - Receiving Sensitivity
  - Signal-to-Noise Ratio
- Summary

Oil Drilling

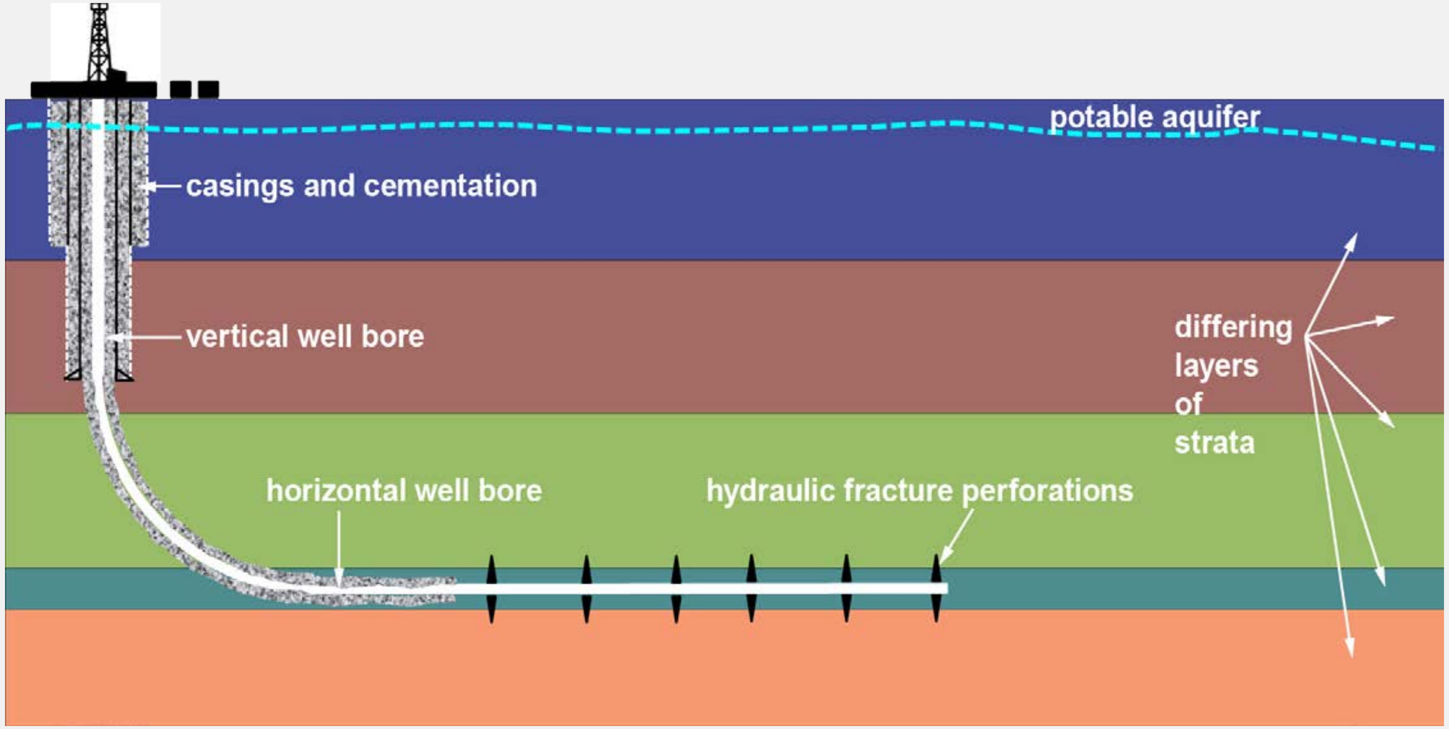

Fig. 1. Schematic oil well structure [1].

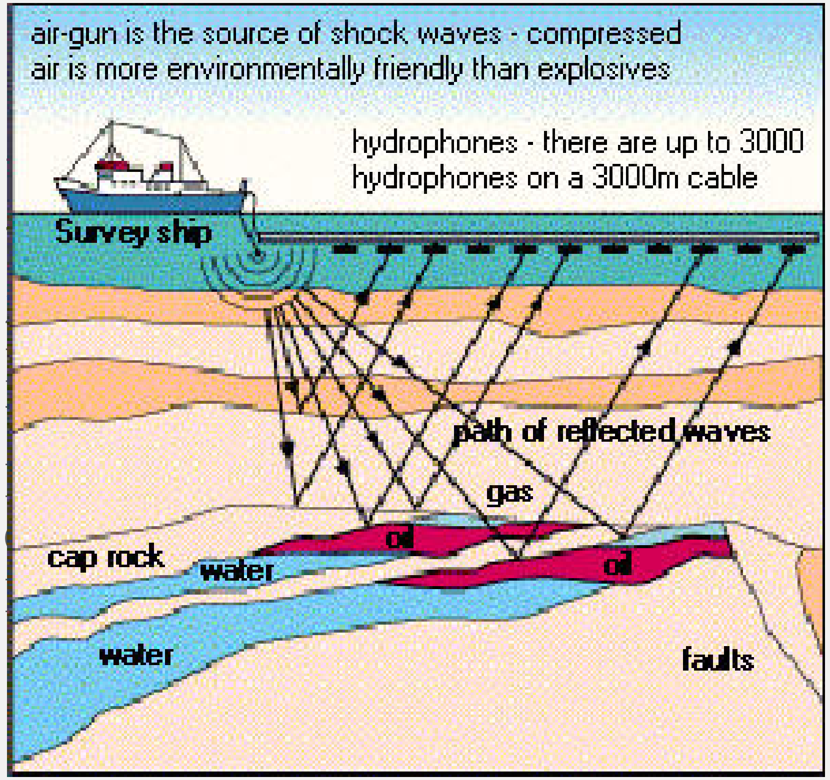

Fig. 2. Searching for oil with seismology [1].

Two major considerations:

1. Cost: A deep water well of duration of 100 days costs around US$100 million [2].
2. Safety: The fatality rate among oil and gas workers is eight times higher than the all-industry rate of 3.2 deaths for every 100,000 workers [2].

Logging-While-Drilling

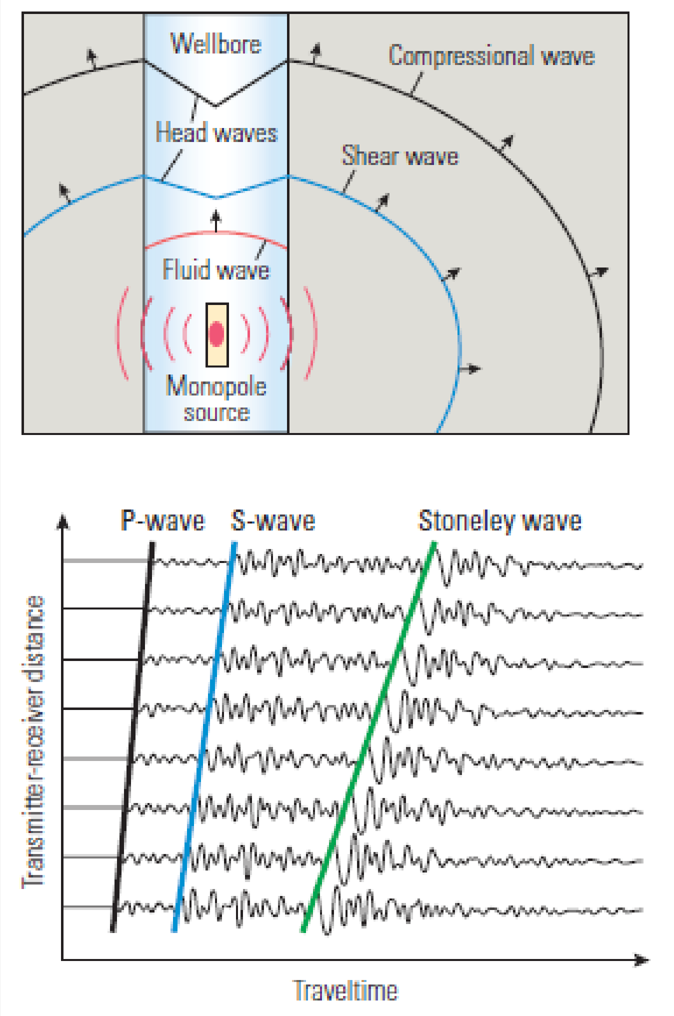

Fig. 3. Monopole source LWD [4].

Material	Compressional Slowness Time Δt_c, µs/m [µs/ft]	Shear Slowness Time Δt_s, µs/m [µs/ft]
Steel	187 [57]	338 [103]
Sandstone	182 [55.5]	289 [88]
Limestone	155 [47.3]	290 [88.4]
Dolomite	143 [43.5]	236 [72]
Shale	200 to 300 [61 to 91]	varies
Freshwater	715 [218]	Not applicable
Brine	620 [189]	Not applicable

Fig. 4. Characteristic values for compressional wave slowness and shear wave slowness.

Real-time information [4]:

1. Formation attributes that include pore pressure and overburden gradients, lithology and mechanical properties
2. Gas detection, fracture evaluation and seismic calibration

Understanding and Improving

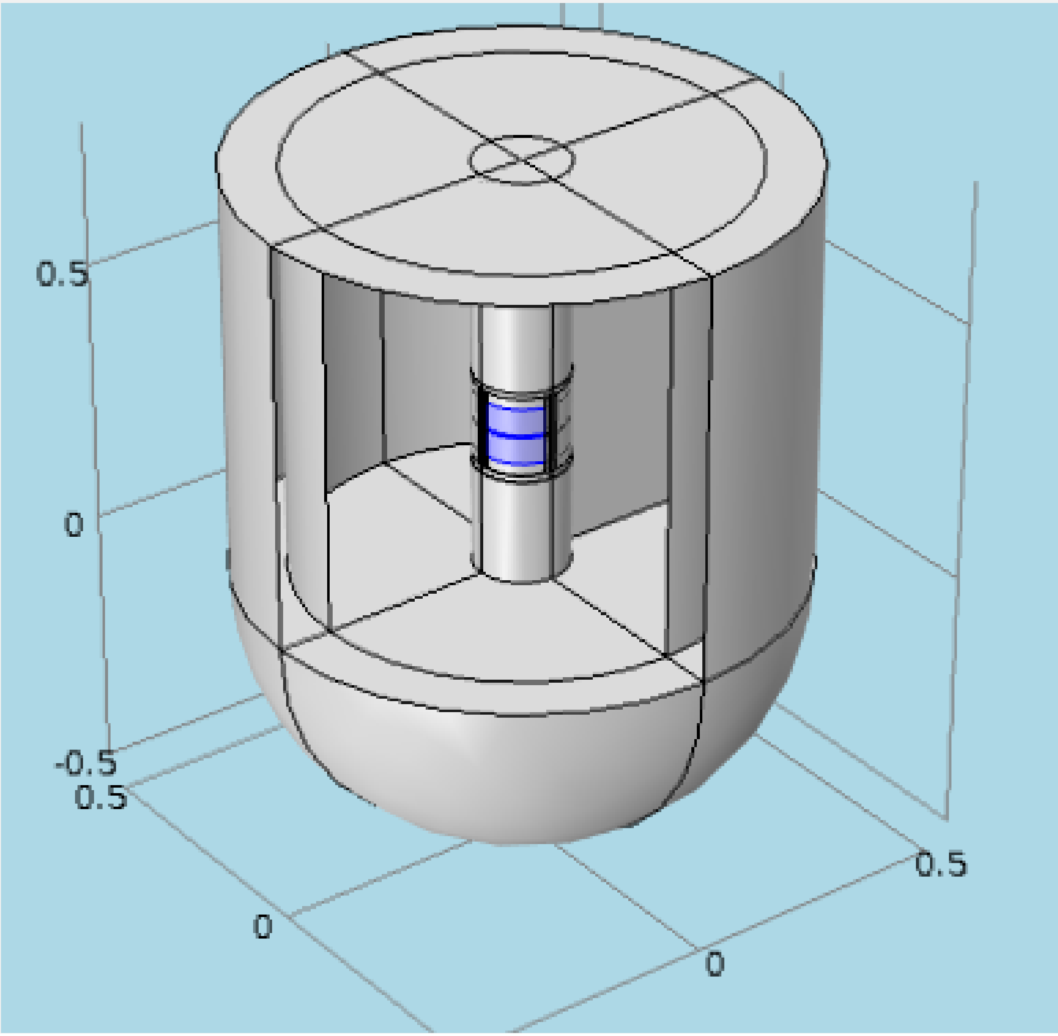

Fig. 6. Acoustic model of transmitter simulation.

Modules

1. Structural Mechanics >> Piezoelectric Devices >> Frequency Domain (pzd)

$$-\rho\omega^2\mathbf{u} - \nabla\cdot\boldsymbol{\sigma} = \mathbf{F}_V e^{i\phi}$$

$$\nabla\cdot\mathbf{D} = \rho_V$$

2. Acoustics >> Acoustic-Structure Interaction >> Acoustic-Piezoelectric Interaction >> Frequency Domain (acpz)

$$\nabla\cdot -\frac{1}{\rho_c}\left(\nabla p_t - \mathbf{q}_d\right) - \frac{k_{eq}^2 p_t}{\rho_c} = Q_m$$

$$p_t = p + p_b$$

$$k_{eq}^2 = \left(\frac{\omega}{c_c}\right)^2$$

Displacement Resonance Frequency Response

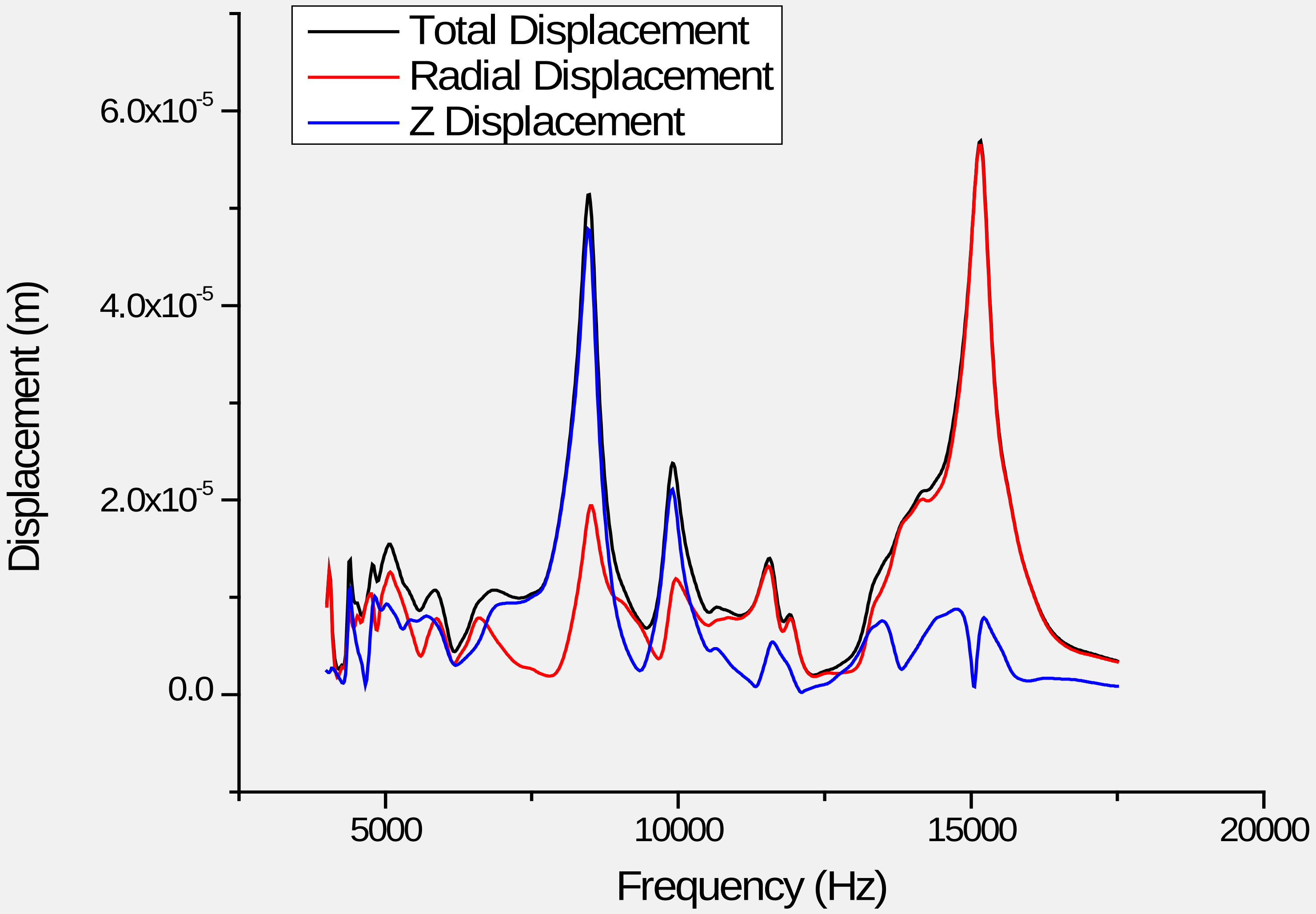

Fig. 7. Transmitter displacement resonance frequency response.

Definition:

RD = sqrt ((pzd.uAmpX)^2 + (pzd.uAmpY)^2)
ZD = pzd.uAmpZ
TD = sqrt (RD^2 + ZD^2)

Analysis:

1. ~ 5 kHz, resonance in half ring arc length
2. ~ 8 kHz, 10 kHz, resonance in height
3. ~ 11.5 kHz, resonance in PZT arc length
4. ~ 15 kHz, third harmonic resonance in half ring arc length

Acoustic Pressure Frequency Response

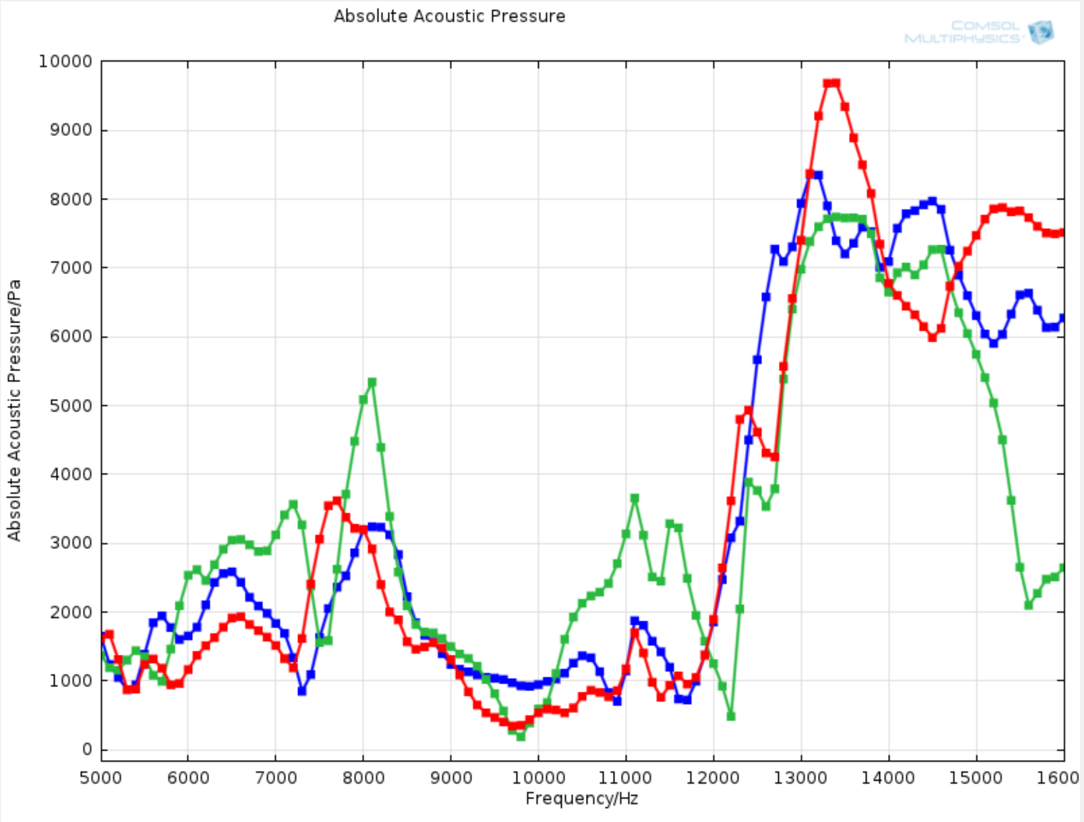

Fig. 8. Transmitter acoustic pressure frequency response.

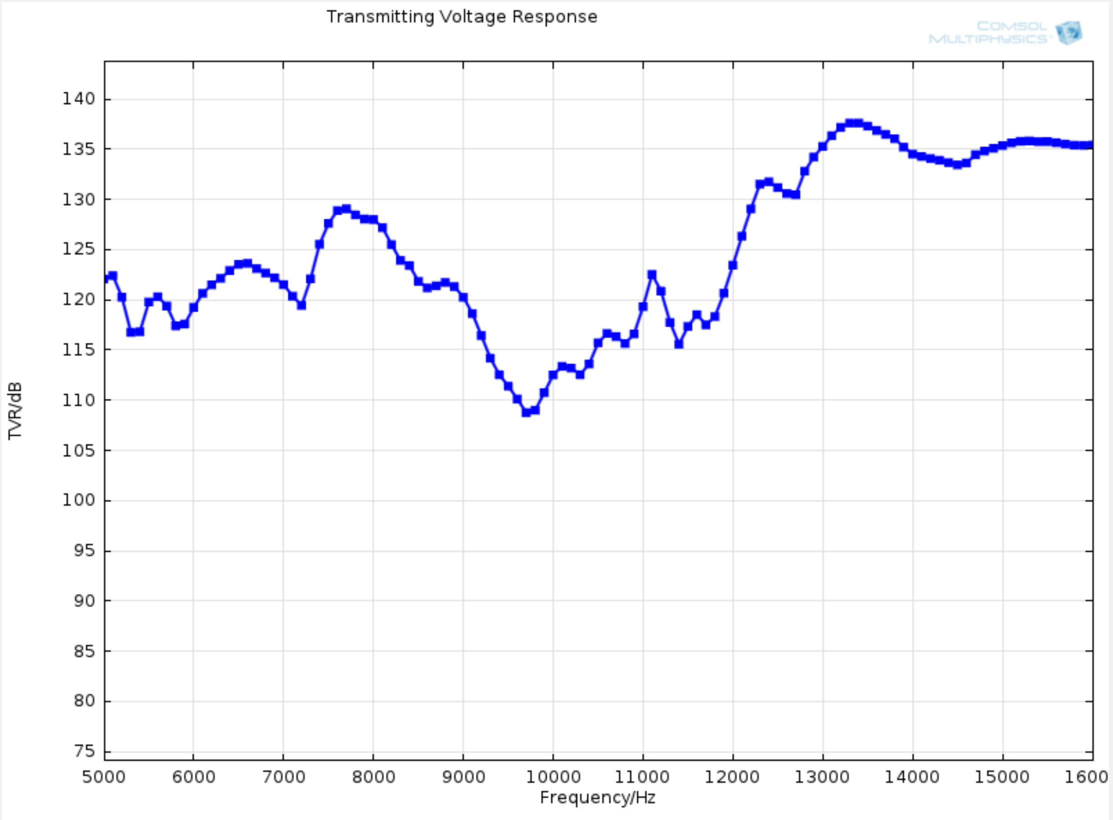

Fig. 9. Transmitting voltage response (TVR) to frequency.

Follows the trend of displacement resonance frequency response.

$$TVR = 20*\log10(p_{rms} / V_{rms} / 1[\mu Pa/V])$$

Spatial Acoustic Field Distribution

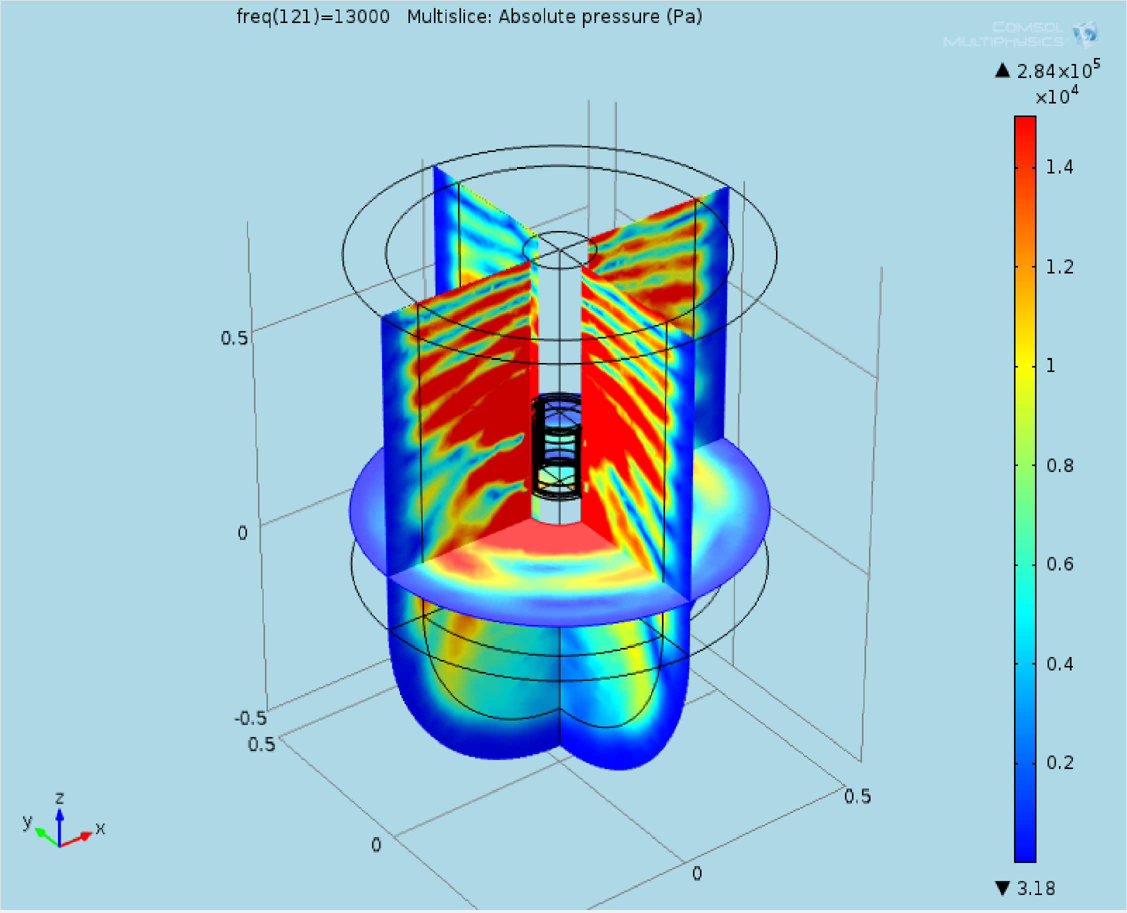

Fig. 10. Transmitter acoustic field distribution.

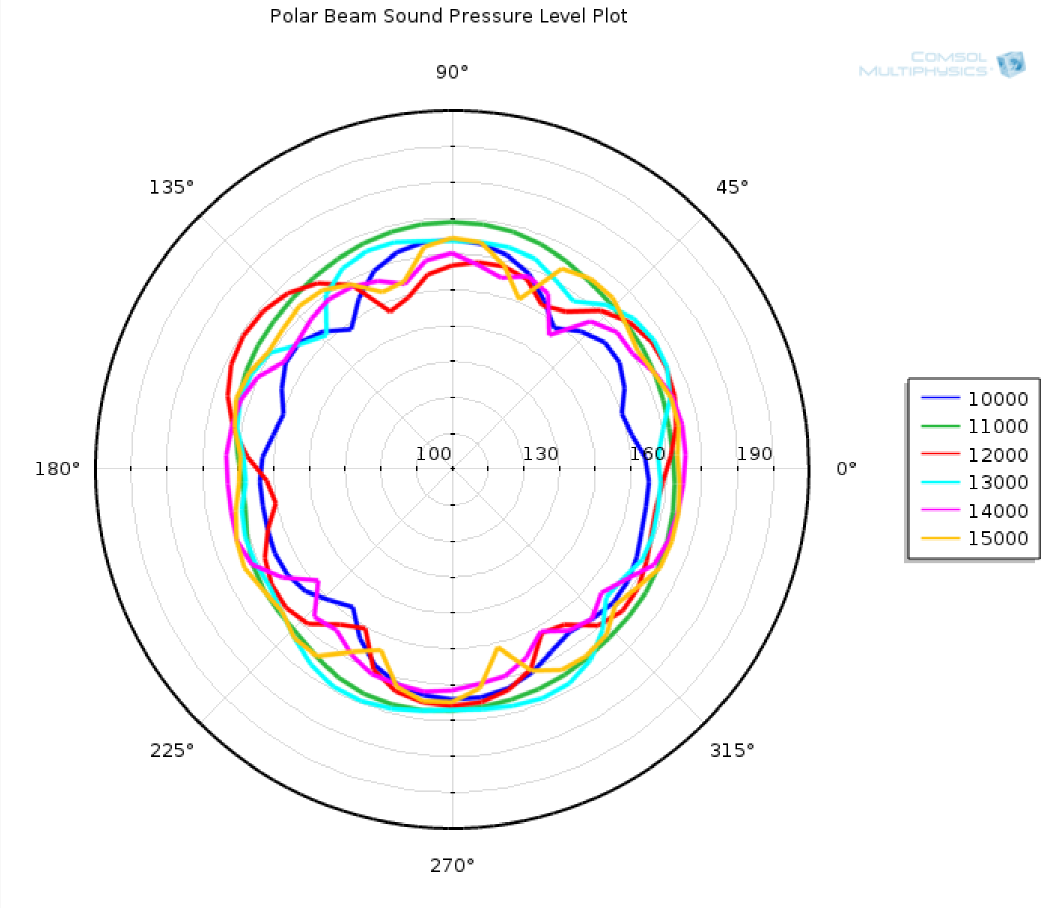

Fig. 11. Transmitter directivity.

High pressure (> 10,000 Pa, yellow and red) area is of most interest.

Receiving Sensitivity

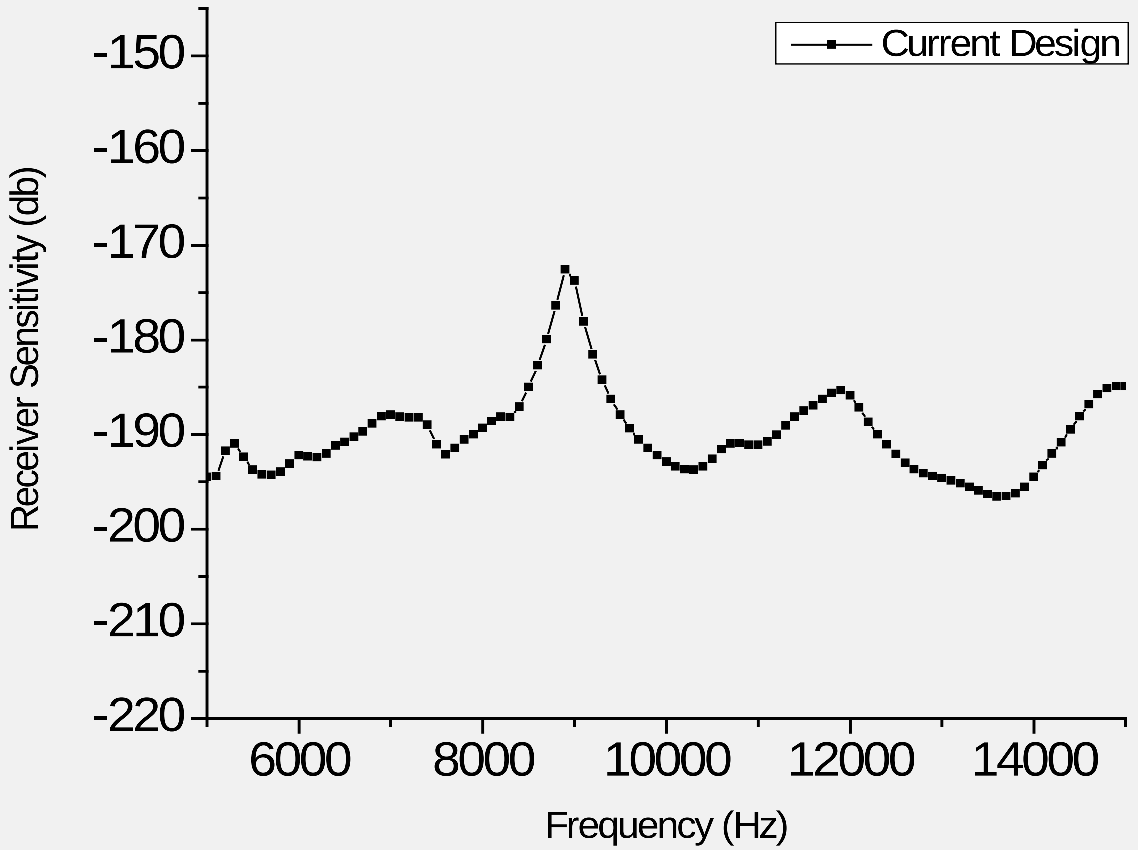

Fig. 12. Receiving sensitivity of the current receiver design.

Peak Displacement Current

$$I_0 = \omega C V_0$$

Receiving Voltage (RV)

RV = intop1(pzd.normJ)/(pzd.omega*C)

Receiving Sensitivity (RS)

RS = 20*log10(RV/(P*1 [V/µPa]))

Signal-to-Noise Ratio

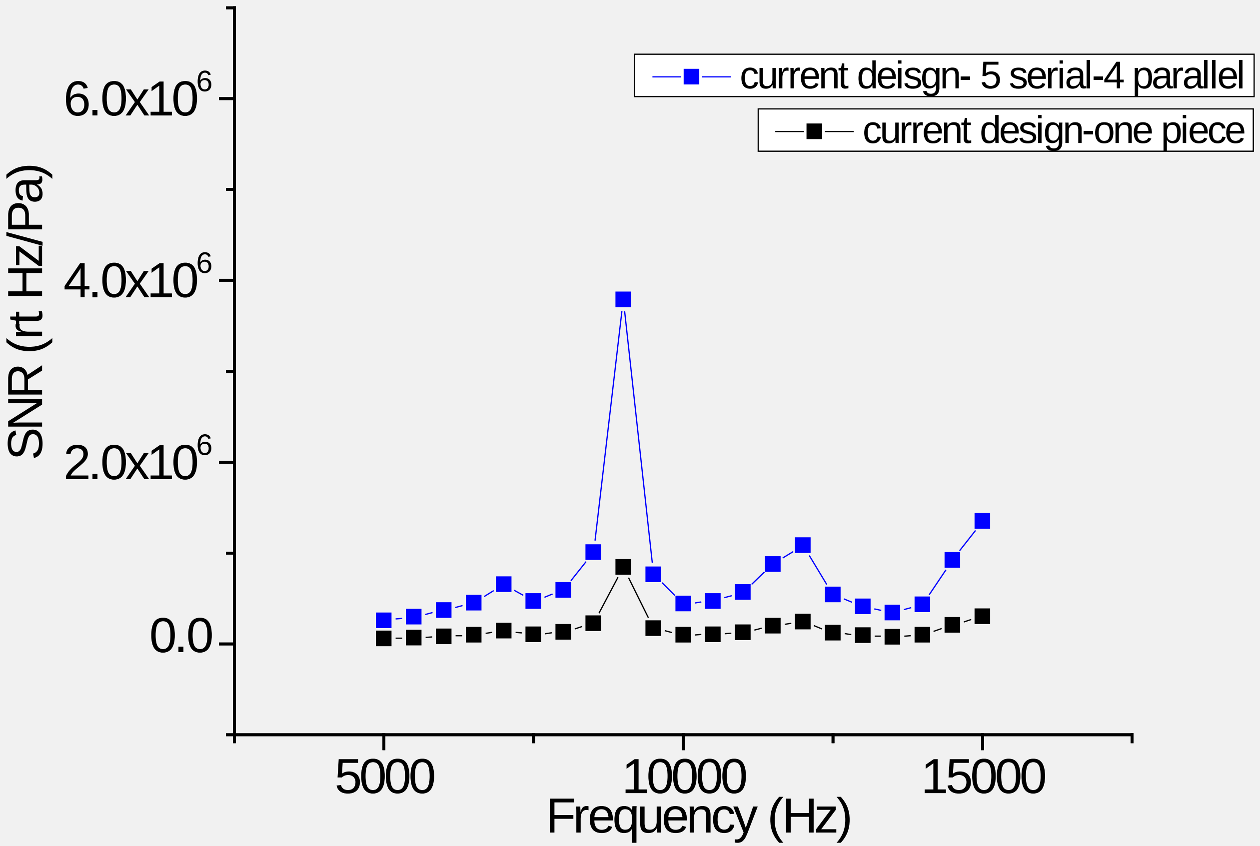

Fig. 13. Signal-to-noise ratio of the current receiver design.

Dielectric loss noise for m receivers in series:

$$i_{n,S} = \frac{1}{\sqrt{m}} \times \sqrt{4kT\omega C_S \tan\delta}$$

Dielectric loss noise for m receivers in parallel:

$$i_{n,P} = \sqrt{m} \times \sqrt{4kT\omega C_P \tan\delta}$$

Summary

1. Showed necessity of studying LWD transducers computationally for better understanding them and improving their designs
2. Established procedure and an example model (pzd and acpz) for studying transmitters

- ✓ Displacement Resonance Frequency Response
- ✓ Acoustic Pressure and TVR Frequency Response
- ✓ Acoustic Pressure Field Distribution and Directivity

3. Established procedure and an example model (pzd) for studying receivers

- ✓ Receiving Sensitivity
- ✓ Signal-to-Noise Ratio

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References

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[2] http://en.wikipedia.org/wiki/Oil_well

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[4] Jeff Alford, *et al.*, Sonic Logging While Drilling - Shear Answers, *Oilfield Review*, **Spring**, 4-15 (2012)

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