Characterization and FEM-based Performance Analysis of a Tonpilz Transducer for Underwater Acoustic Signaling Applications

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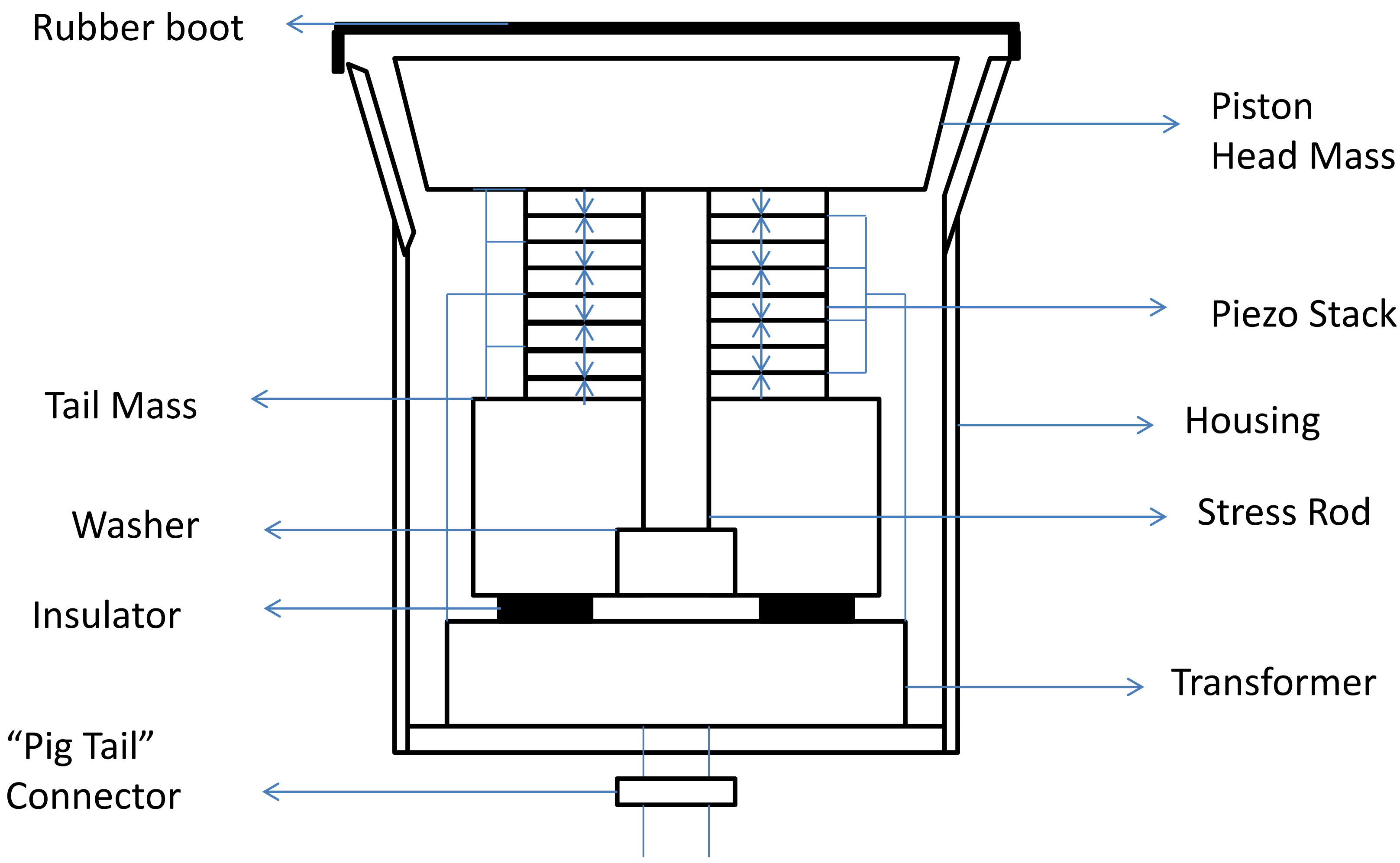
5th Nov 2011

Excerpt from the Proceedings of the 2011 COMSOL Conference in Bangalore

Underwater acoustics and transducers

- Underwater acoustics finds its major applications in SONAR.
- Transducers are processes or devices which convert one form of energy to another.
- Sonars use electro-acoustic transducers. Electroacoustic transduction mechanisms are of 6 major types:
    1. Piezoelectric
    2. Electrostrictive
    3. Magnetostrictive
    4. Electrostatic
    5. Variable Reluctance
    6. Moving coil
- **Piezoelectric transducers** are preferred for their excellent properties

Tonpilz Transducer: overview

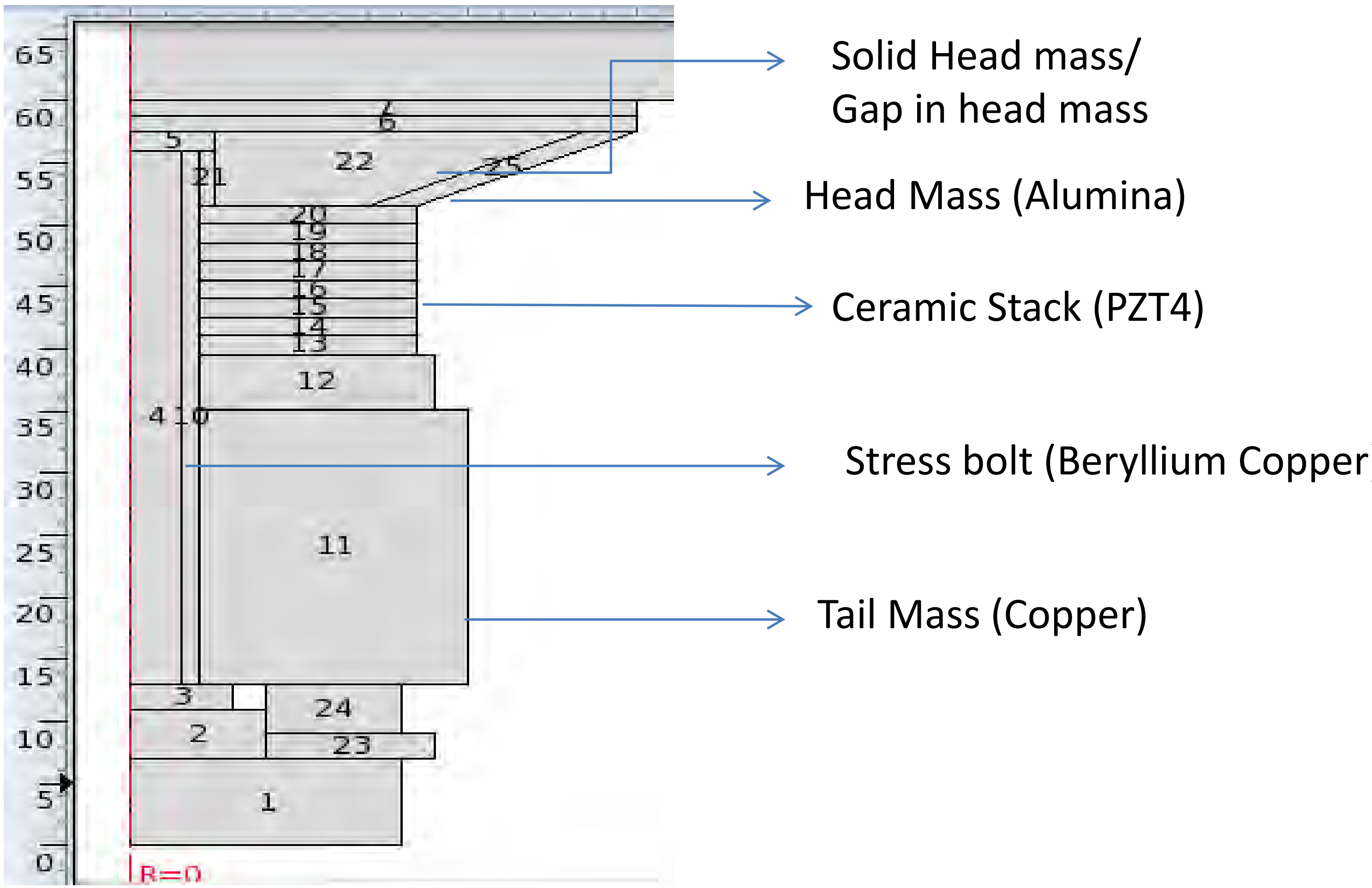


Materials used for transducer parts

Part of transducer	Material used	Density (kg/m^3)
Head	Alumina	3690
Active element	PZT4 Ceramics	7550
Stress rod	Beryllium copper	8200
Tail	Copper	8800
Tail	Steel	7900

- Head material can be alumina or even nylon to lower the weight
- Active material used is PZT4 or a similar ceramic. Ceramics are often preferred to quartz due to their higher coupling coefficient.

Models showing Tonpilz transducer design built in COMSOL



Multi-physics phenomena studied

- **Piezoelectric effect** : Inverse piezoelectric effect which induces a deformation of crystal for an applied electric potential difference.
- The **Pressure acoustics** interface designed for the analysis of various pressure acoustics problem in frequency domain, all concerning pressure waves in fluids.
- The **interaction** of the piezoelectric transducer structure with the aqueous medium and the study of the acoustic wave generated is the main concern.

Equations solved in COMSOL

Using the values of strain tensor and electric field Stress tensor & Electric displacement values are found using below expression in piezoelectric model:

$$S = s^E T + d^t E$$
$$D = d\,T + \varepsilon^T E$$

For 33 mode longitudinal vibrator on expanding the matrix of all the tensors & constants reduces into following four main equations:

$$S_1 = s^E{}_{13} T_3 + d_{33}\,E_3,$$
$$S_2 = s^E{}_{13} T_3 + d_{32} E_3,$$
$$S_3 = s^E{}_{33} T_3 + d_{33} E_3$$
$$D_3 = d_{33} T_3 + \varepsilon^T{}_{33}\,E_3$$

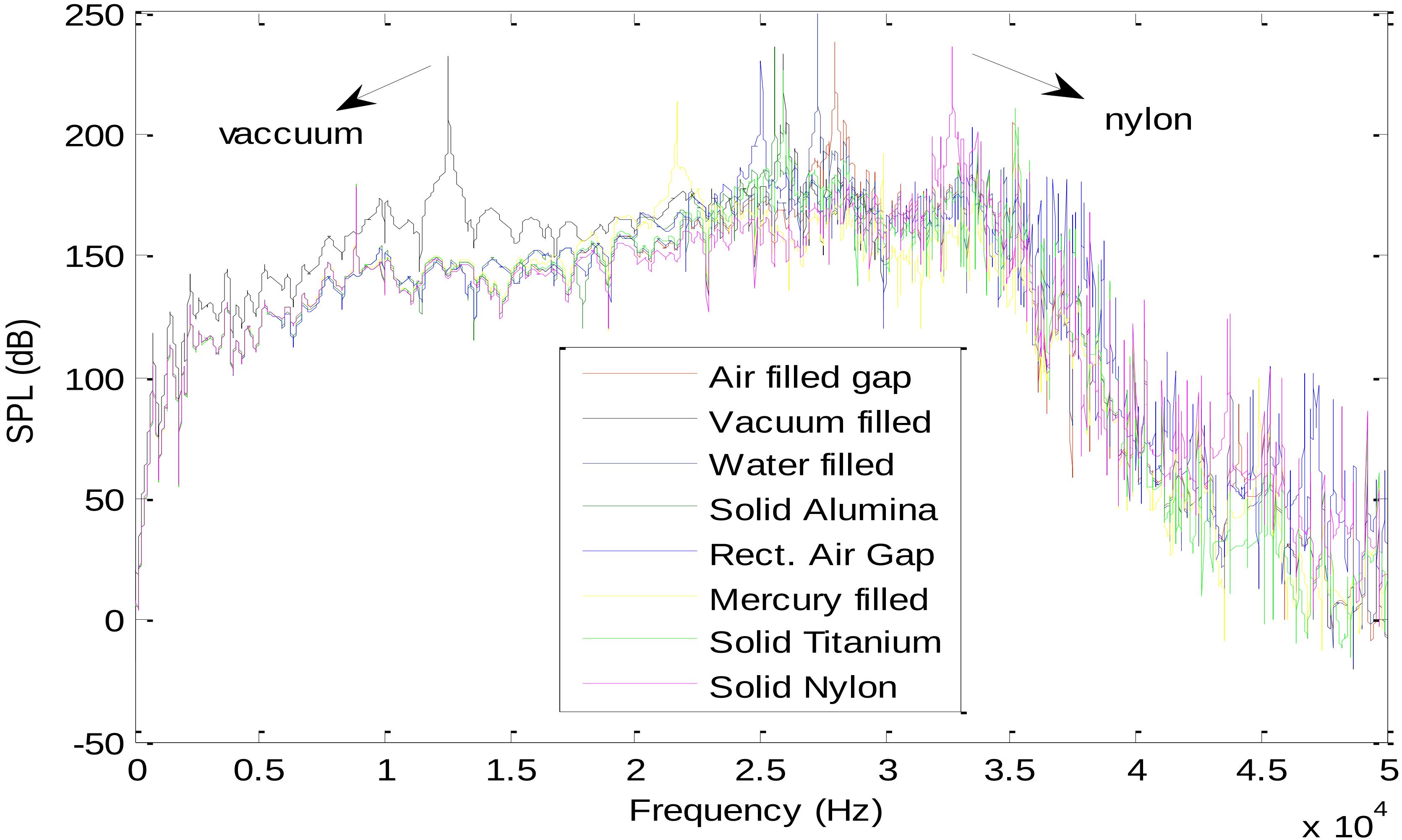
Pressure is solved in pressure acoustics interface using the Helmholtz equation of form given below:

$$\nabla^2 \Psi + k^2 \Psi = 0$$

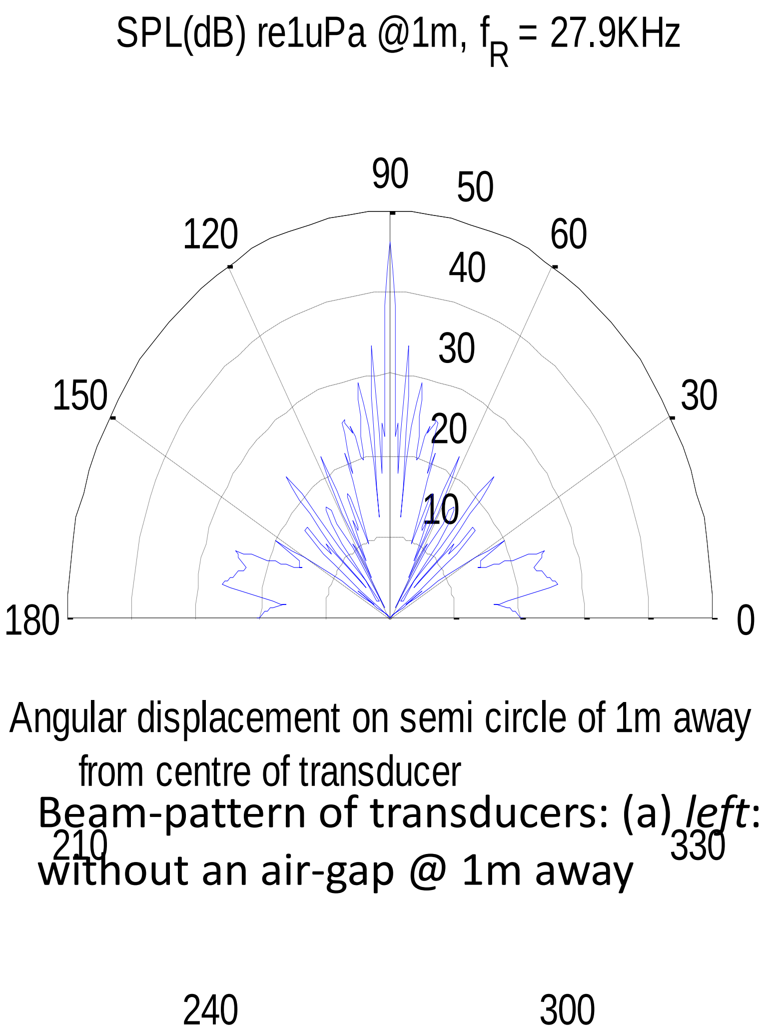
Types of head designs and materials

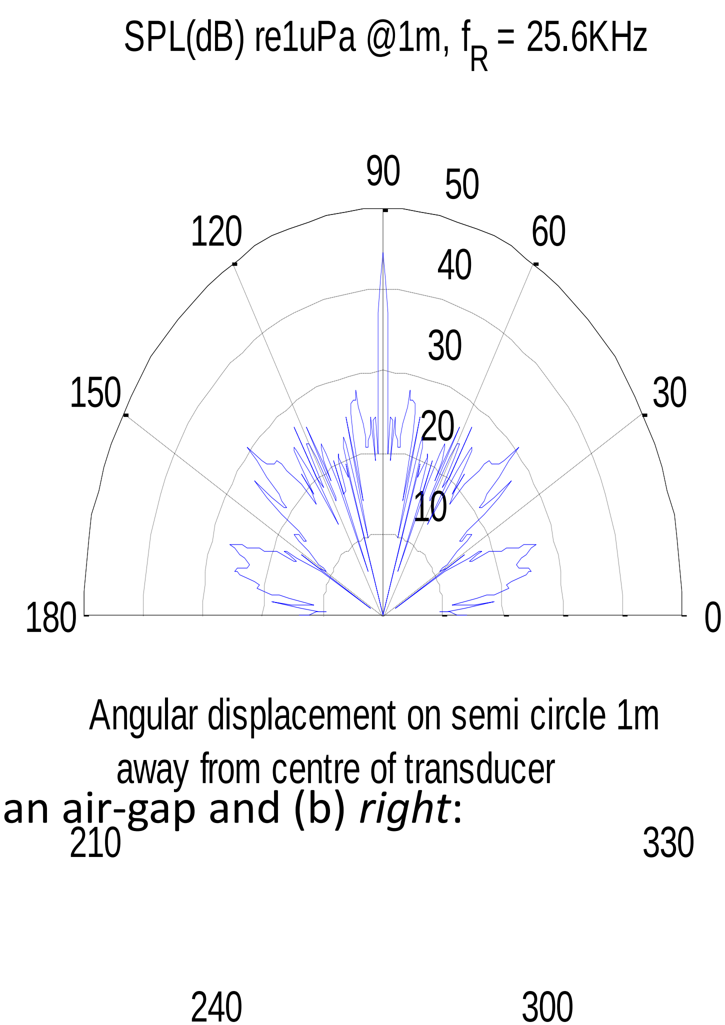
- Transducer heads can be with or without an air-gap. Providing an air-gap helps in lowering head density and mass
- Filling the gap with different materials like water, air, vacuum, mercury etc can also be tried to tweak performance
- Rectangular shape for the air gap at the head portion
- Selecting different material for head portion with different densities like Titanium, Nylon etc.

Effect of head material on performance



Beam pattern for transducer with and without air gap in head portion

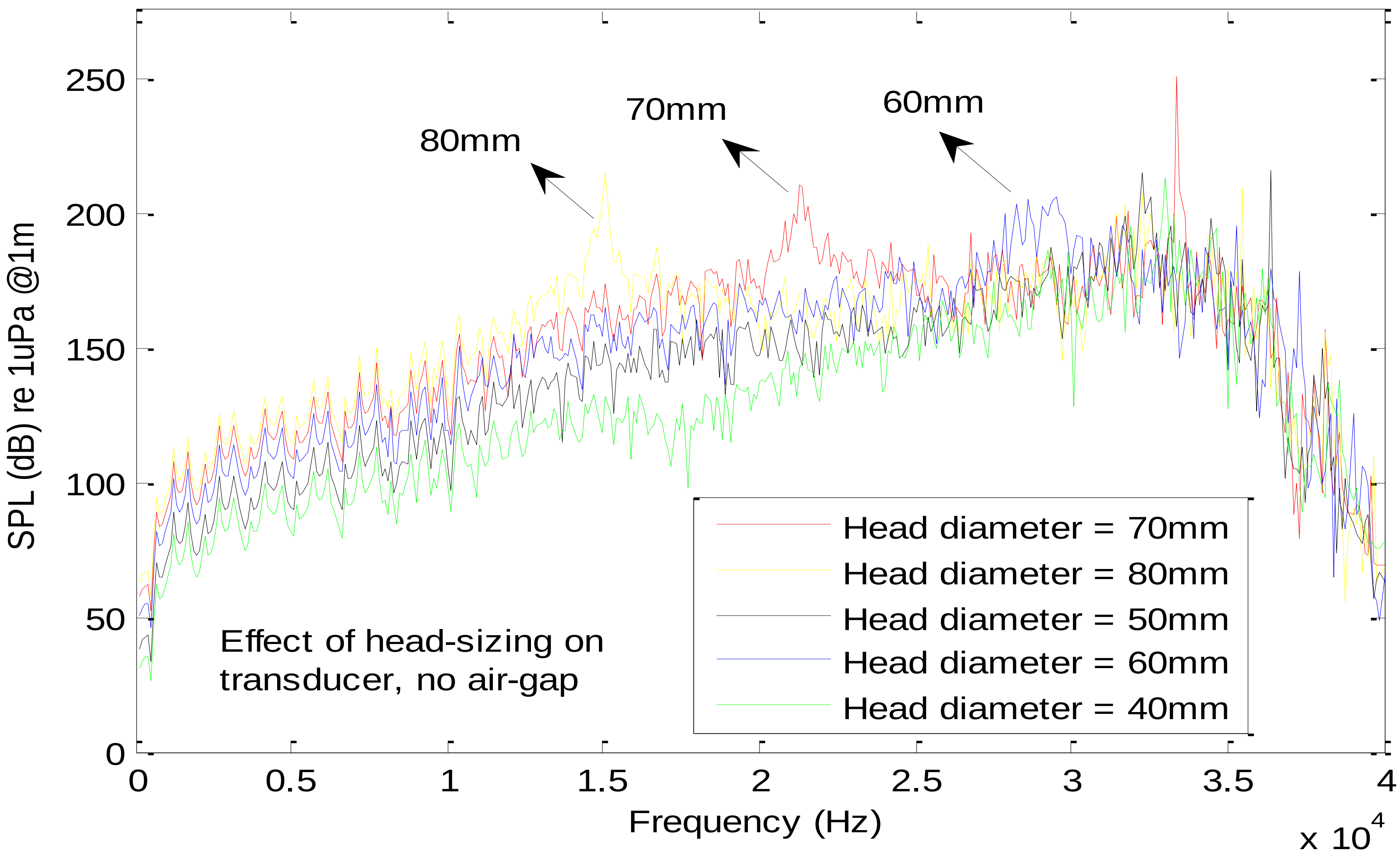




Beam-pattern of transducers: (a) *left*: with an air-gap and (b) *right*: without an air-gap @ 1m away

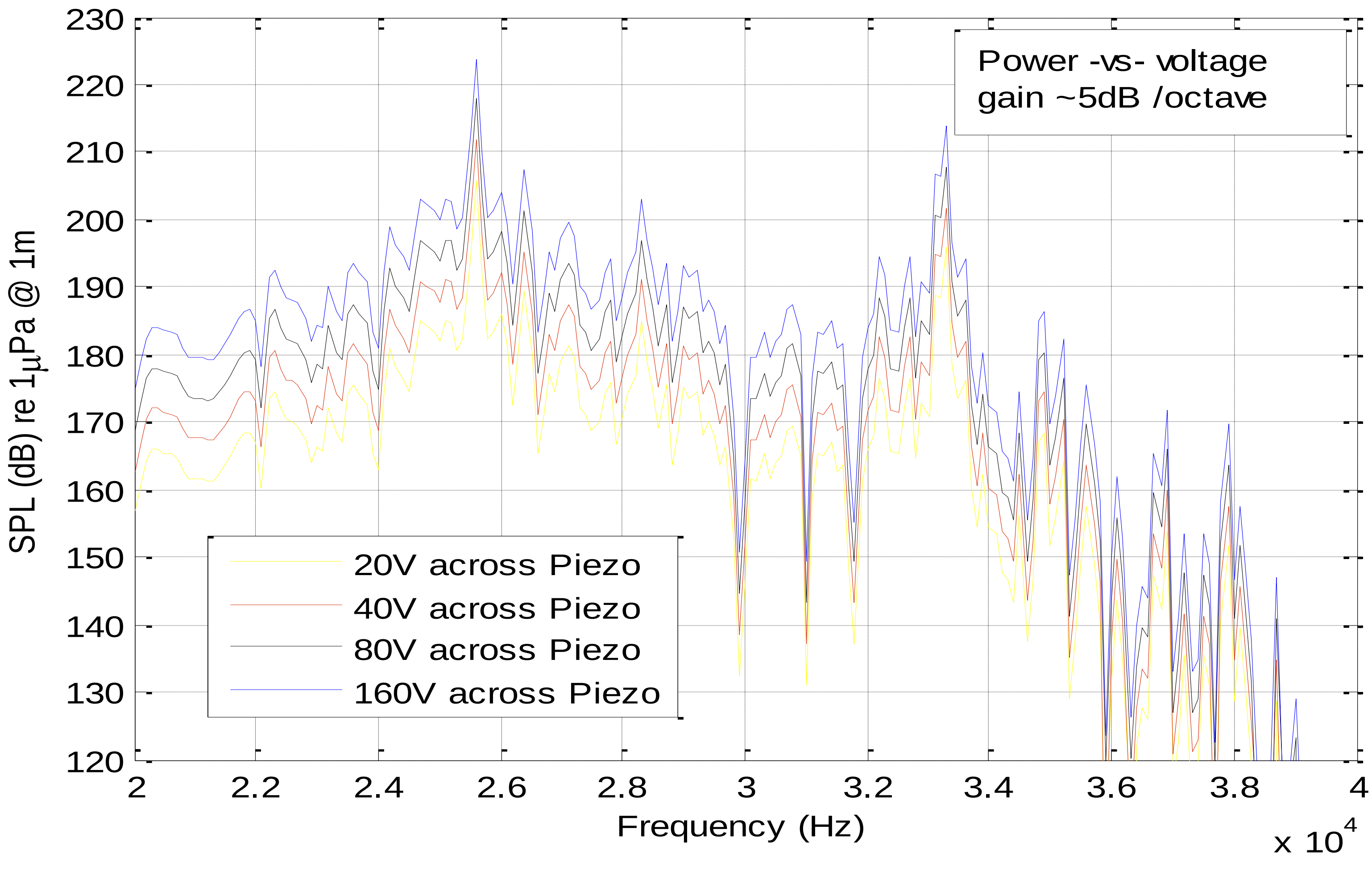
Effect of head sizing

Increasing head diameter leads to reduction in resonant frequency



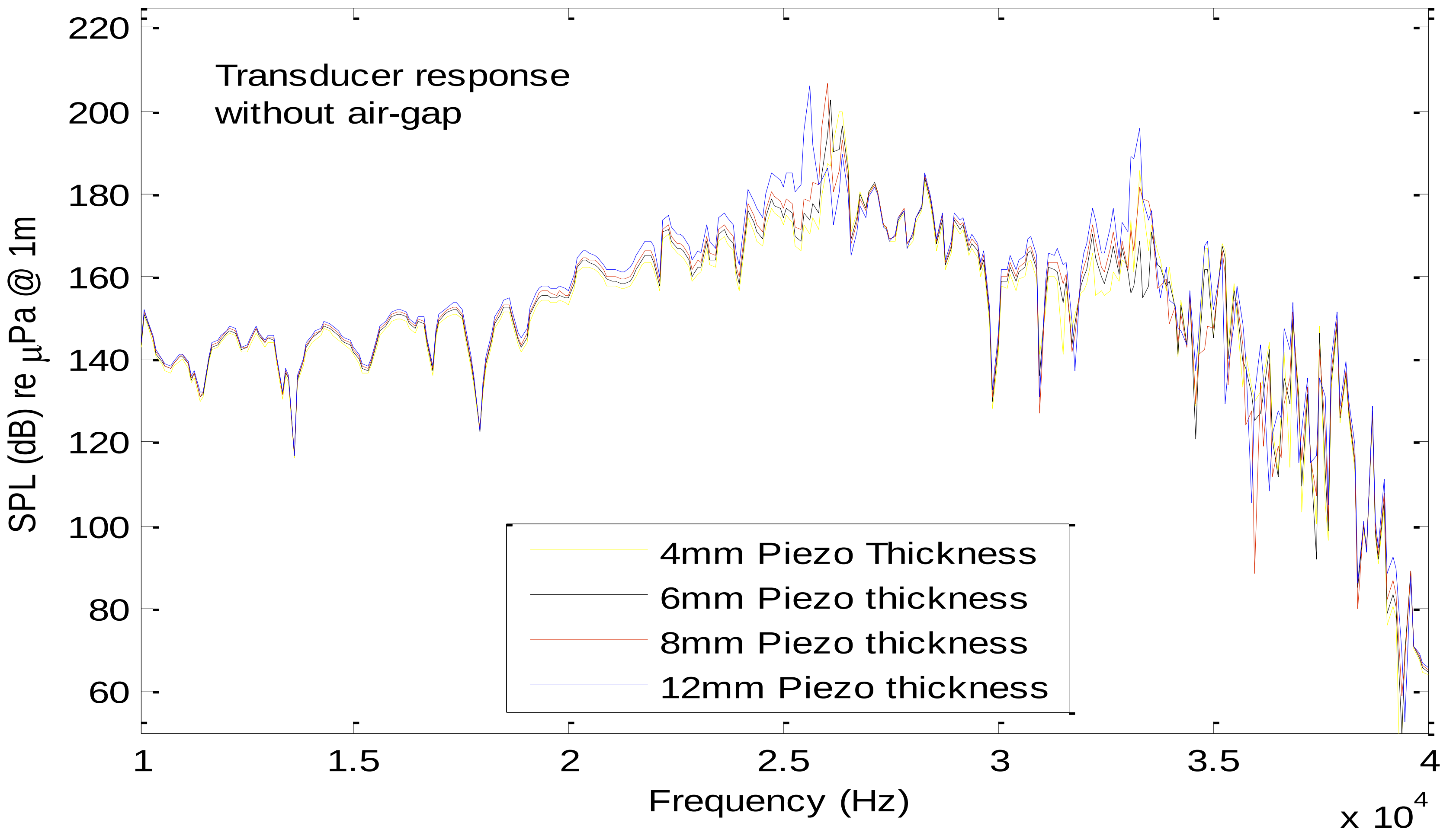
Effect of voltage across piezo-ceramic

- Power differential of nearly 5dB per octave observed



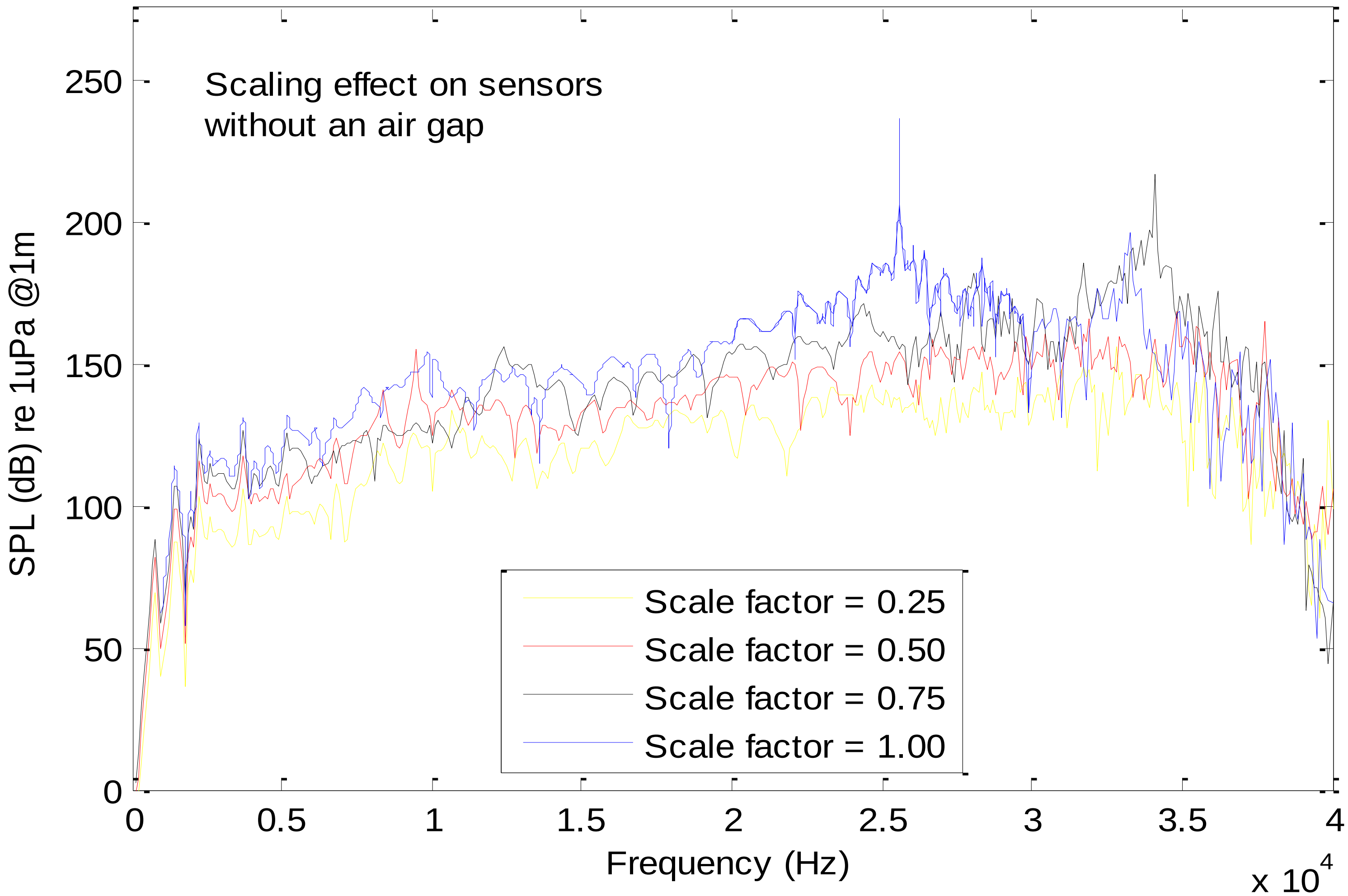
Effect of piezo thickness on transducer response

- Piezo thickness has not much role in tuning resonant frequency



Transducer performance under miniaturization

- Increase in resonant frequency with reduction in size



Conclusions

- We have successfully modeled and simulated in Comsol the performance of a Tonpilz transducer
- Pressure acoustics & piezoelectric phenomena have been explored as a function of sizing and materials
- Key features such as resonant frequency, tunability, beam-pattern and scalability have been investigated
- Factors influencing the value of resonant frequency are:
  - Head mass (Presence & absence of air gap)
  - Head Diameter
  - Size of transducer
  - Voltage across piezo ceramics

Thank You!!