



Heat Drain Device for Ultrasound Imaging Probes

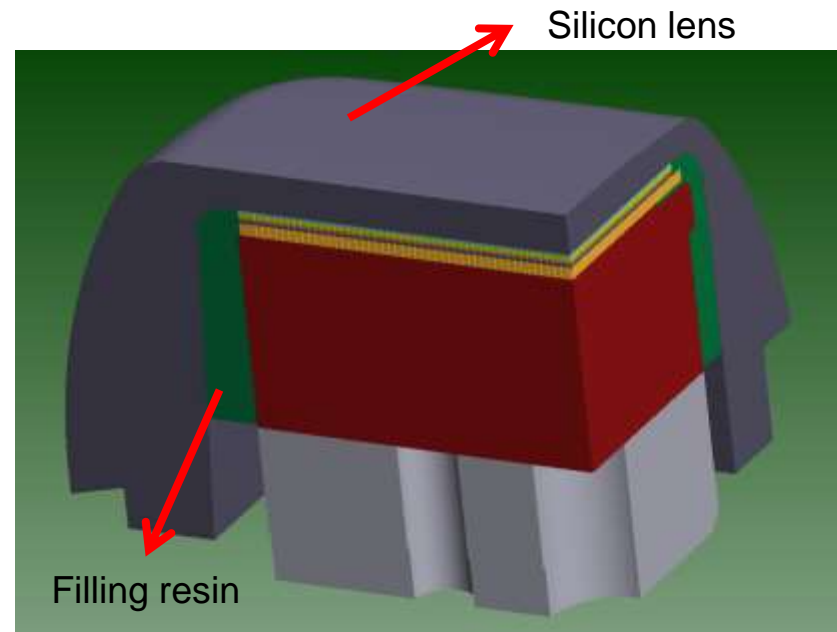
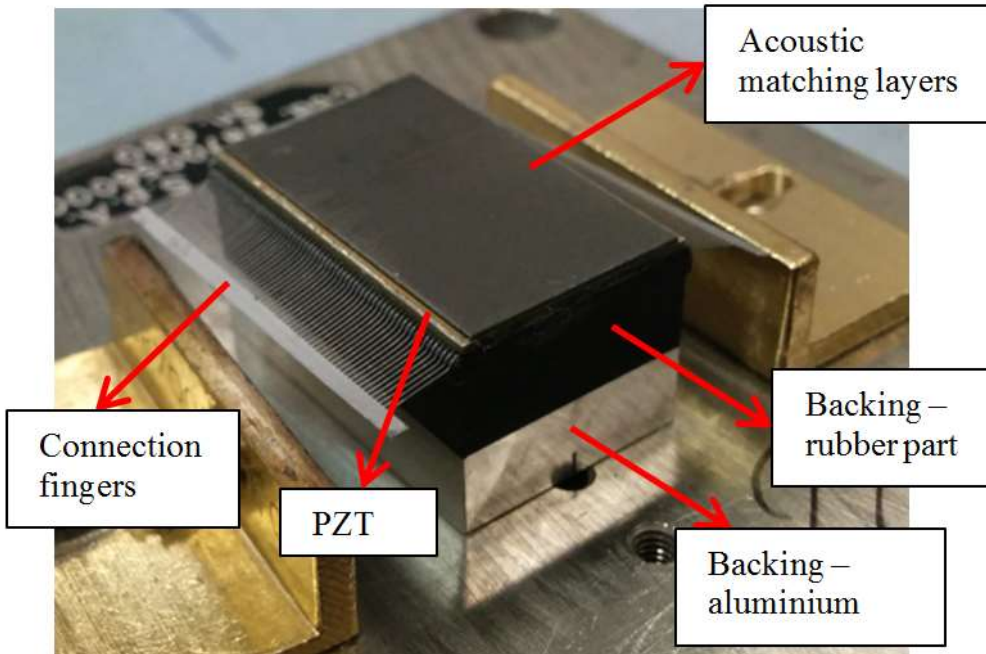
ESAOTE SPA

L. Spicci, G. Vigna

COMSOL
CONFERENCE
2014 CAMBRIDGE



TRANSDUCER STRUCTURE OVERVIEW





INTRODUCTION

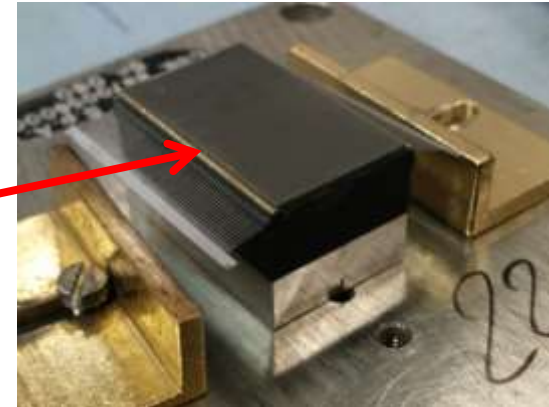
Electrical driving power



Internal loss of the piezo-material (energy conversion between 50% and 60%)



Temperature rise



Maximum temperature of the transducer head is fixed to 50 ° C from the International Safety Standard EN 60601-2-37.



Electrical driving power is often reduced



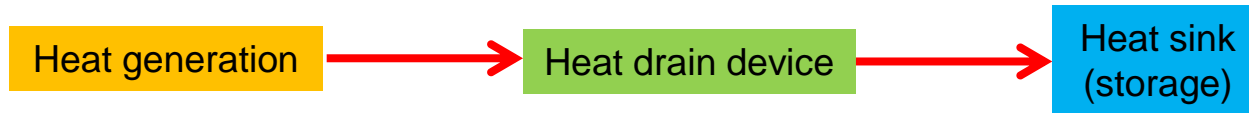
Undesired limitation for transducer acoustic performance in terms of image capability



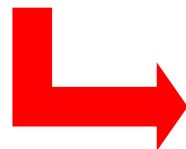
In the present work a solution to reduce temperature on the transducer head is presented and validated by FEM-measurement comparison



Thermal managing system



1. Validation of the 3D FEM for the standard transducer without thermal managing system by comparison with measurement (STANDARD TRANSDUCER CHARACTERIZATION)
2. Design of the 3D FEM for the modified transducer with thermal managing system, validated by comparison with measurement (MODIFIED TRANSDUCER DESIGN)



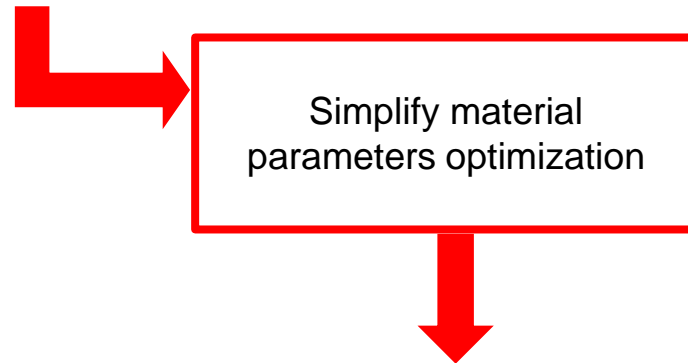
Optimization of heat drain device geometry in order to obtain the best performances

3. Preliminary study of a special heat sink, added on the rear part of the transducer, in order to finish the heat dissipation managing system, through a simplified 3D FEM (ADDITIONAL DISSIPATION SYSTEM)



ANALYSIS APPROACH

On each manufacturing process step, FEM vs measurement comparison has been made (step by step approach)



Comparison in terms of :

1. Electrical Impedance



PZT elasticity matrix, coupling matrix, relative permittivity, backing and matching layers elastic parameters (Poisson coefficient, Young modulus, ...)

2. Transducer Head Temperature



Material losses and thermal material parameters (heat capacitance, thermal conductivity, ...)

Acoustic piezo-electric module (study 1), frequency domain



Power dissipation (heat source in study 2)



Heat Transfer module (study 2), time domain at fixed frequency



Temperature and Heat Flux



MEASUREMENT EQUIPMENT

Electrical Impedance → Hewlett Packard 4195A Network Analyser

Temperature measurement → PC manage a k-thermocouple coupled with a thermally conductive paste to the transducer head

Transducer side and bottom part left to free convection

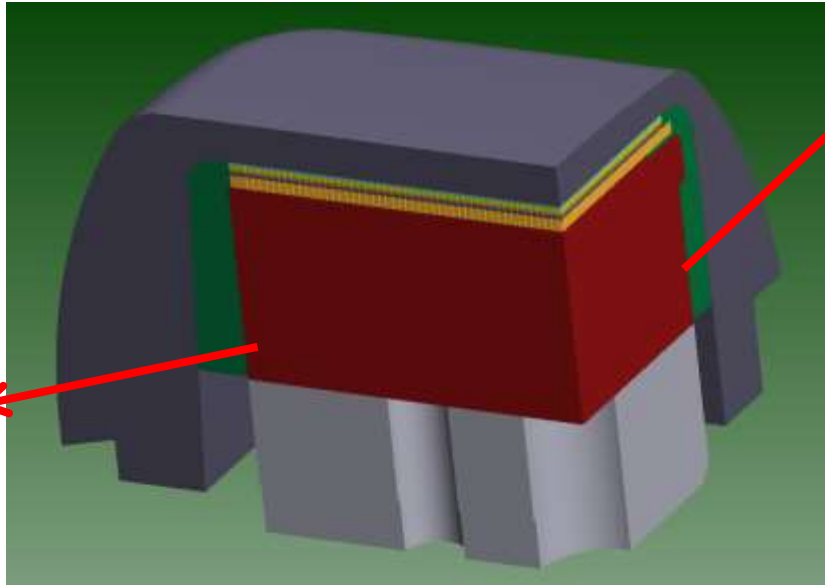
Thermostatic environment at 25 ° C using a specialized plexiglass box

Esaote Scanner device that apply, at 5 MHz or 2.1 MHz, a driving voltage on the PZT poles



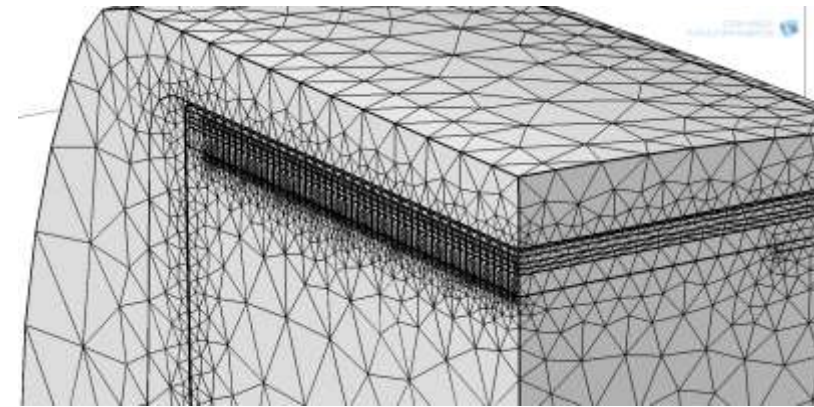


TRANSDUCER FEM AND MESH

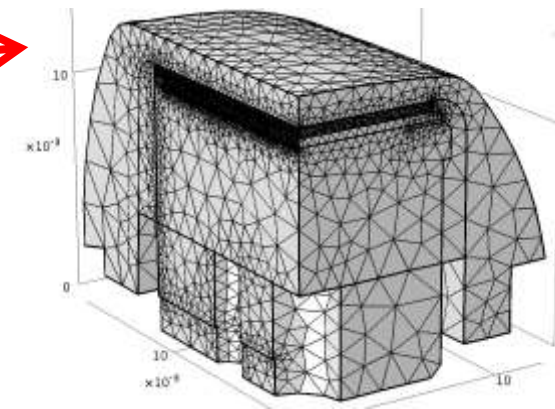


Symmetry plane

Symmetry plane



Free tetrahedral mesh



$\lambda / 10$ (where λ is the minimum wavelength of interest) rule not satisfied because of computing time. Anyway results are satisfactory

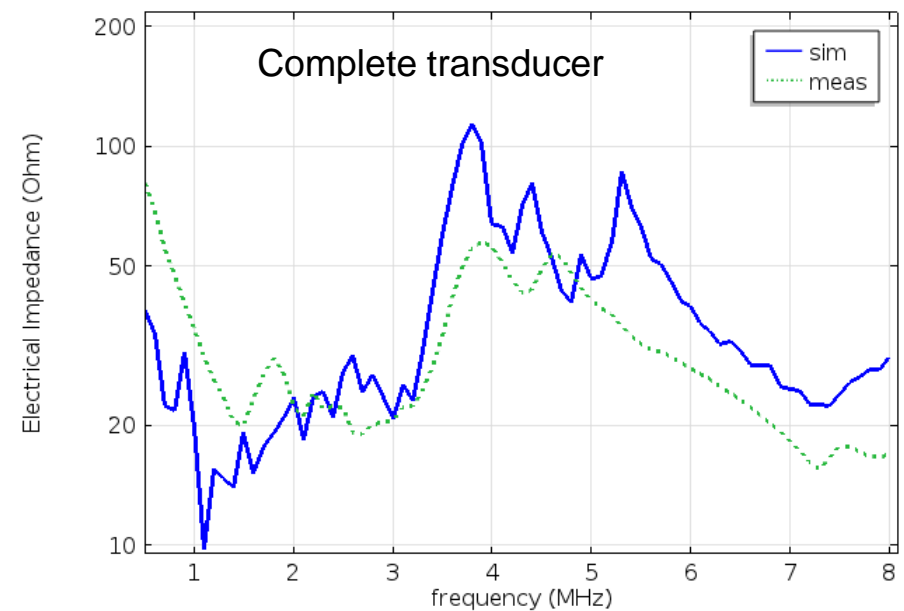
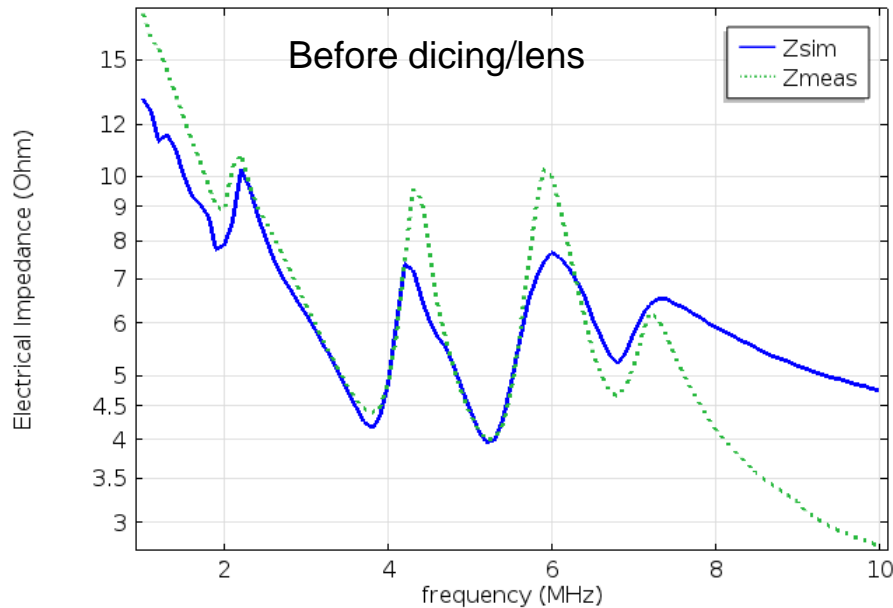
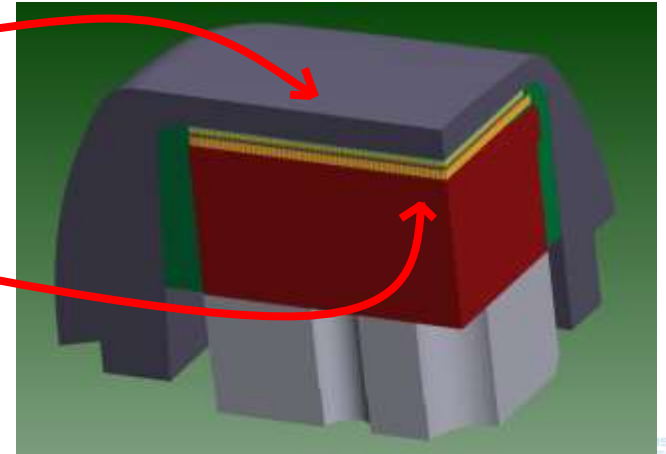


TRANSDUCER FEM – BOUNDARY CONDITIONS

Study 1 \rightarrow Electrical Impedance (Z)

- Ground on PZT top surface
- Electric potential on PZT bottom surface (V)

$$Z = \frac{V}{I} \quad \text{where} \quad I = \int_A \mathbf{J} \cdot \hat{\mathbf{z}} \, dA$$

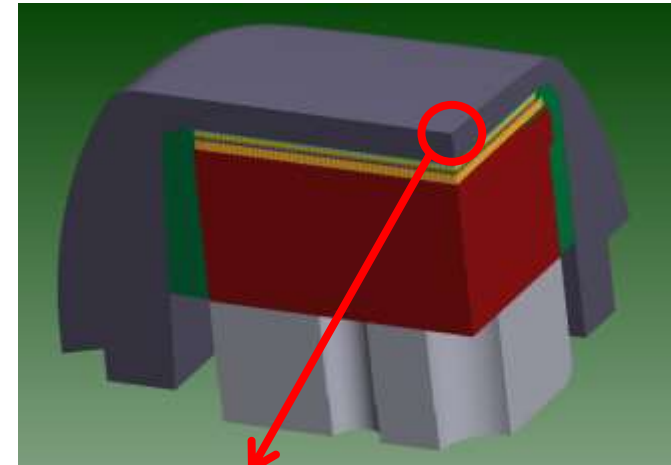





TRANSDUCER FEM – BOUNDARY CONDITIONS

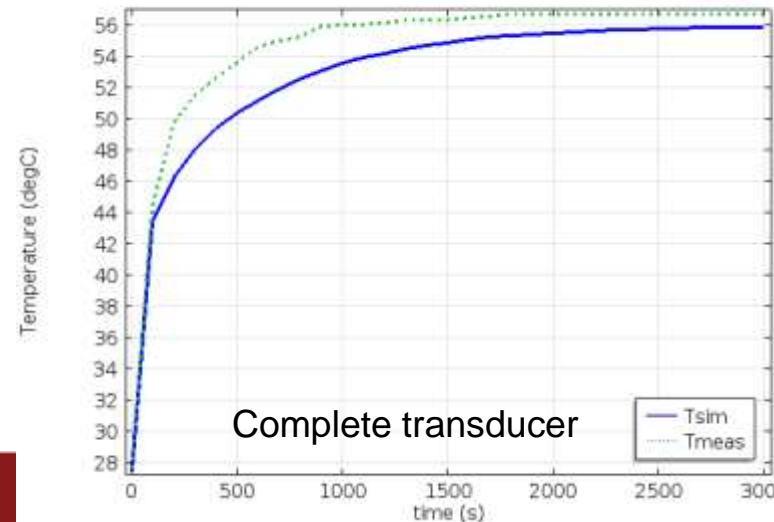
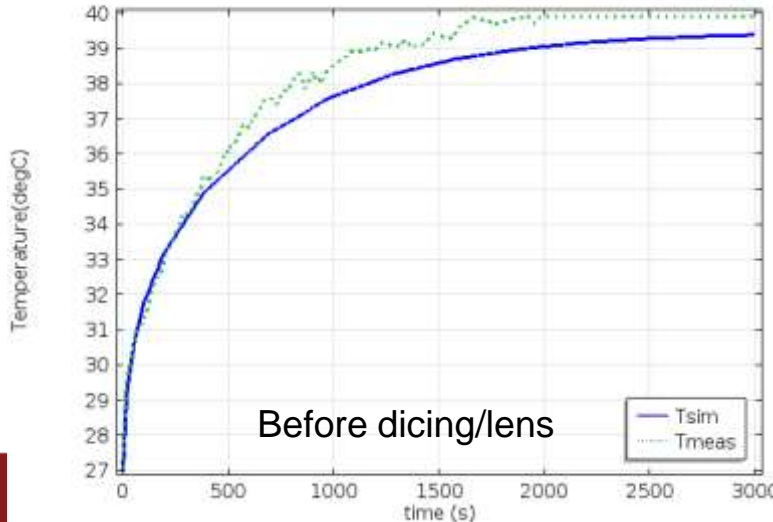
Study 2  Temperature, Heat Flux

- Total power dissipation density on all the materials is impressed as Heat Source (loss factor for electrical permittivity for PZT, isotropic loss factor for other elastic materials)
- Heat flux on all external surface where $h = 10 \frac{W}{m^2 \cdot K}$ is used as heat transfer coefficient



Temperature monitor on graphs

Previous simulation vs measurement optimization of an aluminum block 

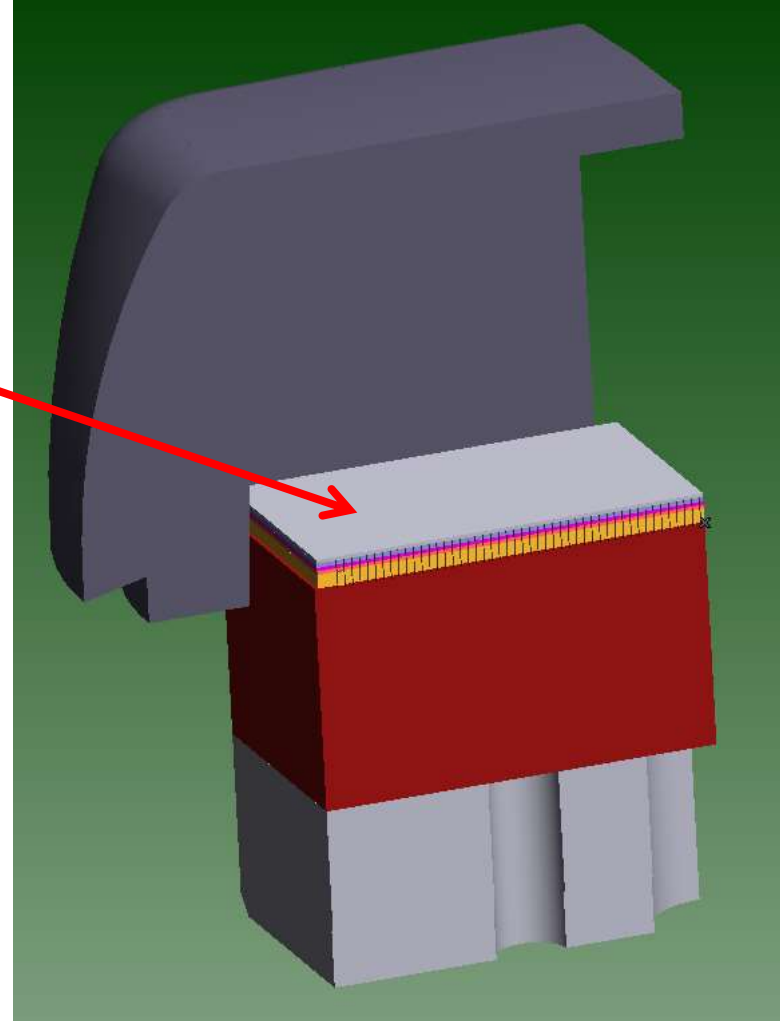


Temperature reach 56° C in standard configuration



MODIFIED TRANSDUCER CHARACTERIZATION

High thermally conductive compound layer bonded between matching layers and silicone lens



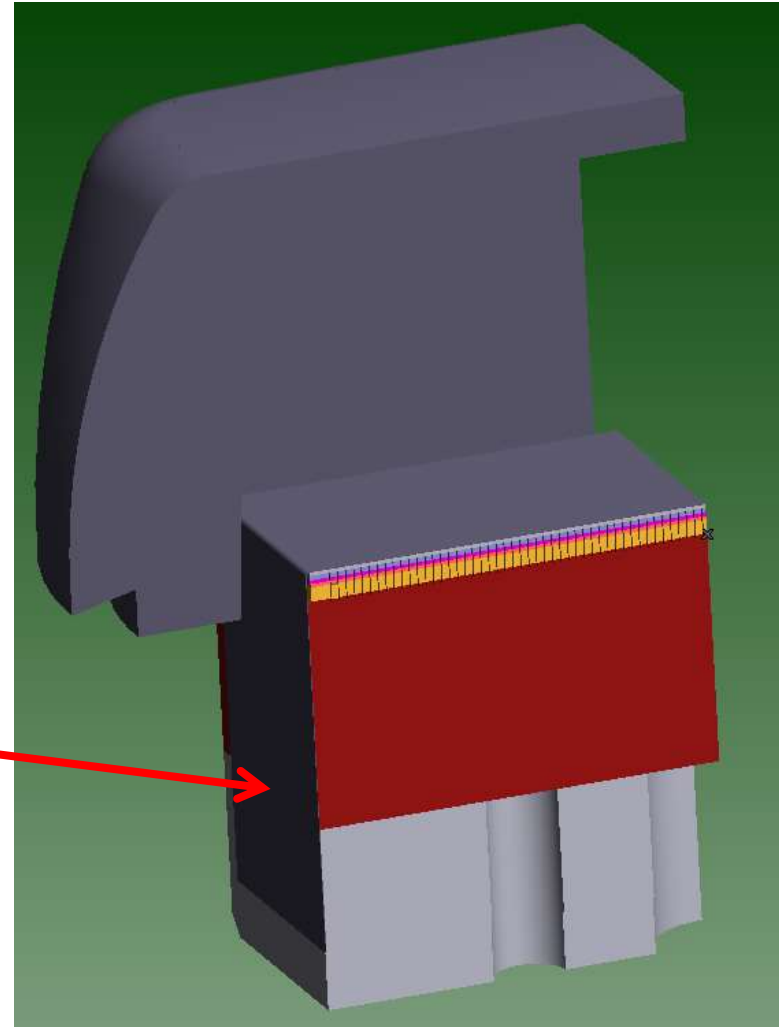


MODIFIED TRANSDUCER CHARACTERIZATION

High thermally conductive compound layer bonded between matching layers and silicone lens

placed to be in contact to the aluminum part of the backing

- Very high thermal conductivity $k = 4000 \frac{W}{m \cdot K}$
- Acoustic properties very similar to silicone (almost transparent to acoustic waves, no efficiency loss)

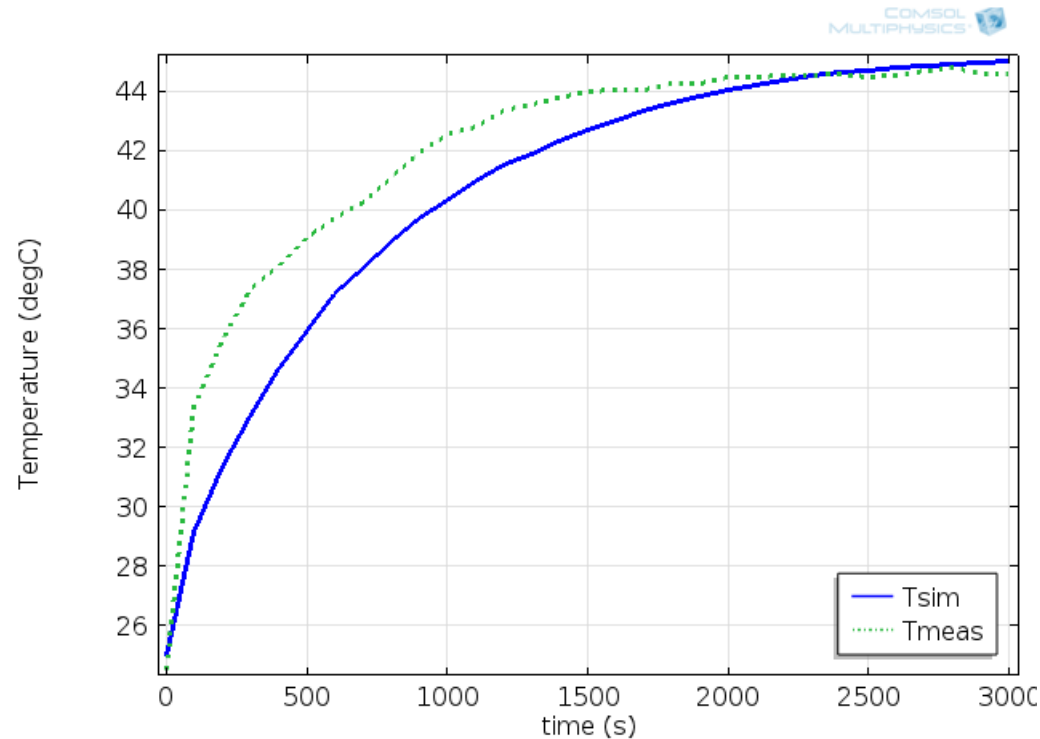




MODIFIED TRANSDUCER CHARACTERIZATION

High thermally conductive compound layer bonded between matching layers and silicone lens

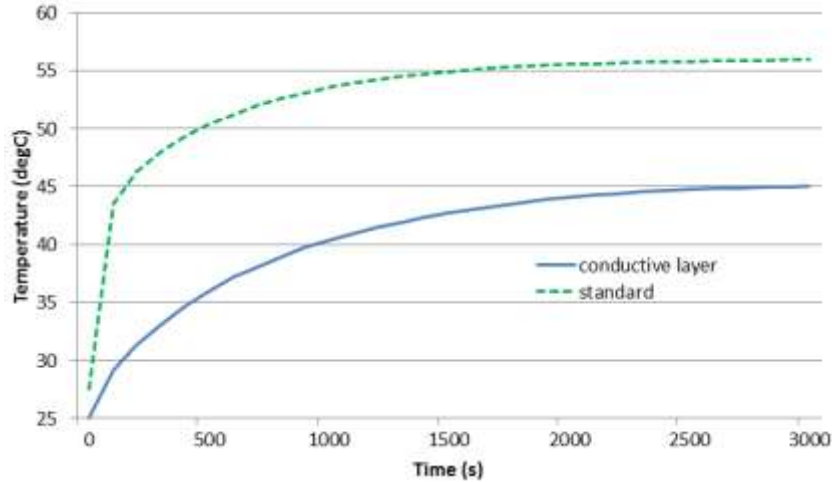
- Very high thermal conductivity $k = 4000 \frac{W}{m \cdot K}$
- Acoustic properties very similar to silicone (almost transparent to acoustic waves, no efficiency loss)



Temperature reach 44° C in modified configuration



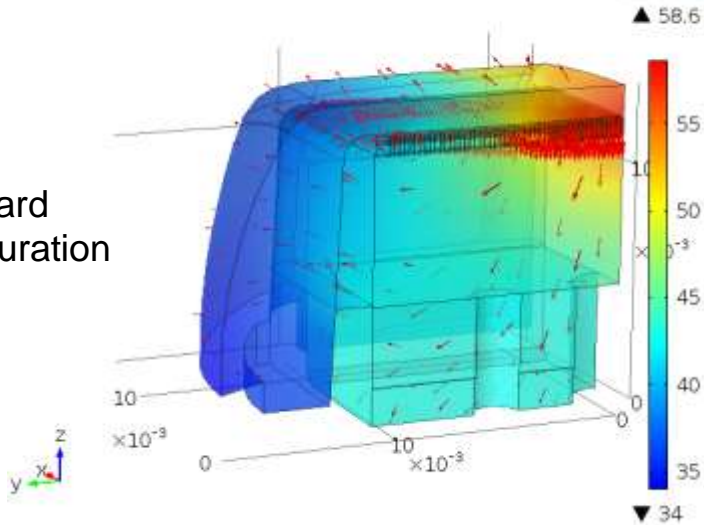
MODIFIED TRANSDUCER VS STANDARD TRANSDUCER



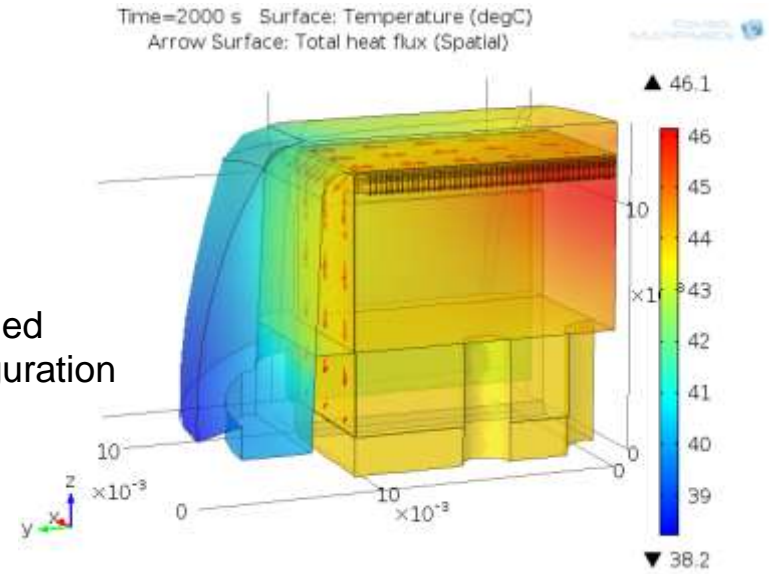
- In modified configuration maximum transducer head temperature is lowered by 12 ° C
- Heat flux is focused along thermal conductive layer instead of scattered as in the standard case

Heat Flux and Temperature Plot

Standard configuration

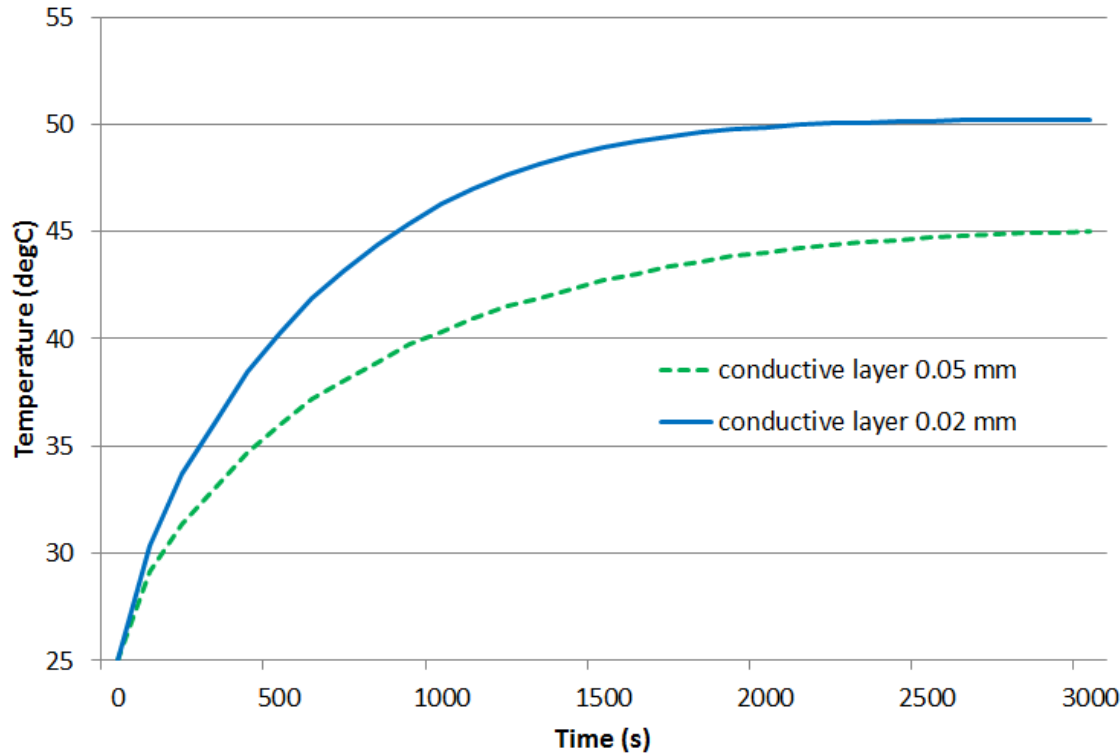


Modified configuration





LAYER GEOMETRY OPTIMIZATION



Thickness of thermal conductive layer has been changed between two values:

- 0.02 mm
- 0.05 mm

If layer is thicker thermal efficiency is higher (5° C lowered) but acoustic efficiency is worse



Thermally layer thickness optimization must be a trade-off between acoustic performance and thermal performance



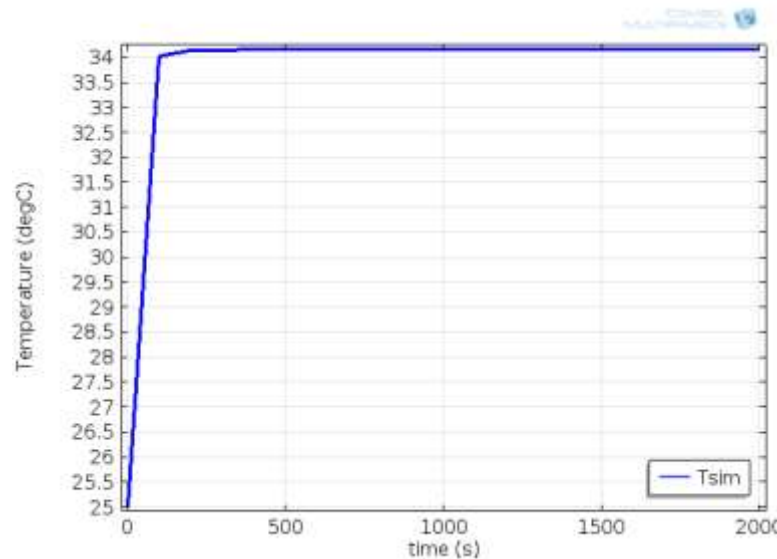
ADDITIONAL DISSIPATION SYSTEM (FUTURE WORK)

Phase change material (PCM) is used to fill probe cases in order to draw heat at steady transition temperature. PCM has been simulated forcing a very high heat transfer coefficient on the backside of the transducer where PCM is applied.

$$Q_{PCM} = h_{PCM} \cdot (T_{trans.} - T)$$

$$h = 1 \cdot 10^5 \text{ W}/(\text{m}^2 \cdot \text{K})$$

$$T_{trans.} = 33 \text{ }^\circ\text{C}$$



Final temperature of the transducer is the equilibrium temperature, slightly higher than $T_{trans.}$.



CONCLUSION

1. Material parameters of an ultrasound transducer has been optimized successfully by comparison between FEM and measurement on a standard configuration. Electrical impedance and temperature curve match well.
2. Thermally conductive layer has been introduced and validated, on a modified configuration, by comparison between FEM and measurement. It has very high impact on transducer performance and it represent a concrete solution on this issue.
3. Thermally conductive layer geometry influence has been verified in terms of thickness. Its optimization is a trade-off between thermal and acoustical performance.
4. Future work has been introduced by simplified 3D FEM of a special heat sink on the rear part of the transducer based on phase changing material (PCM). Its optimization will be very useful in order to lowered and maintain a fixed temperature during the medical exams.