Optimized Surface Acoustic Waves Devices With FreeFem++ Using an Original FEM/BEM Numerical Model

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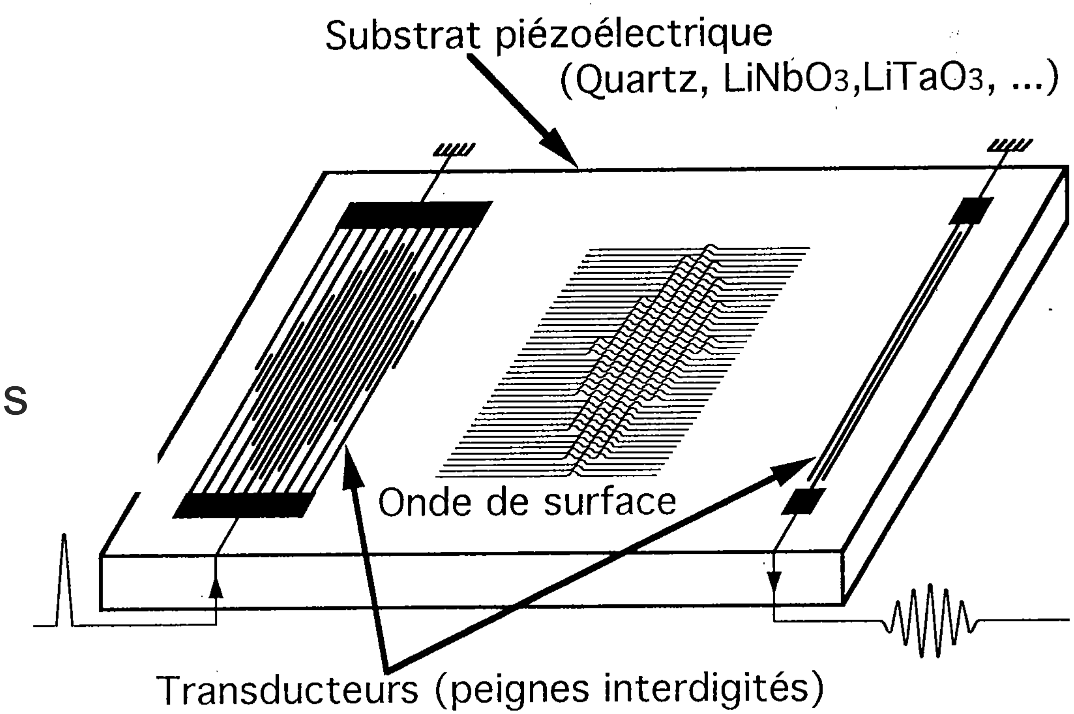
Outlines

- Introduction
- Physical model
- Electro Acoustical Computation : FreeFem++ Model
- Include temperature variations
- Numerical and experimental results
- Conclusions
- Future works

SAW IDT components

How is built a SAW device

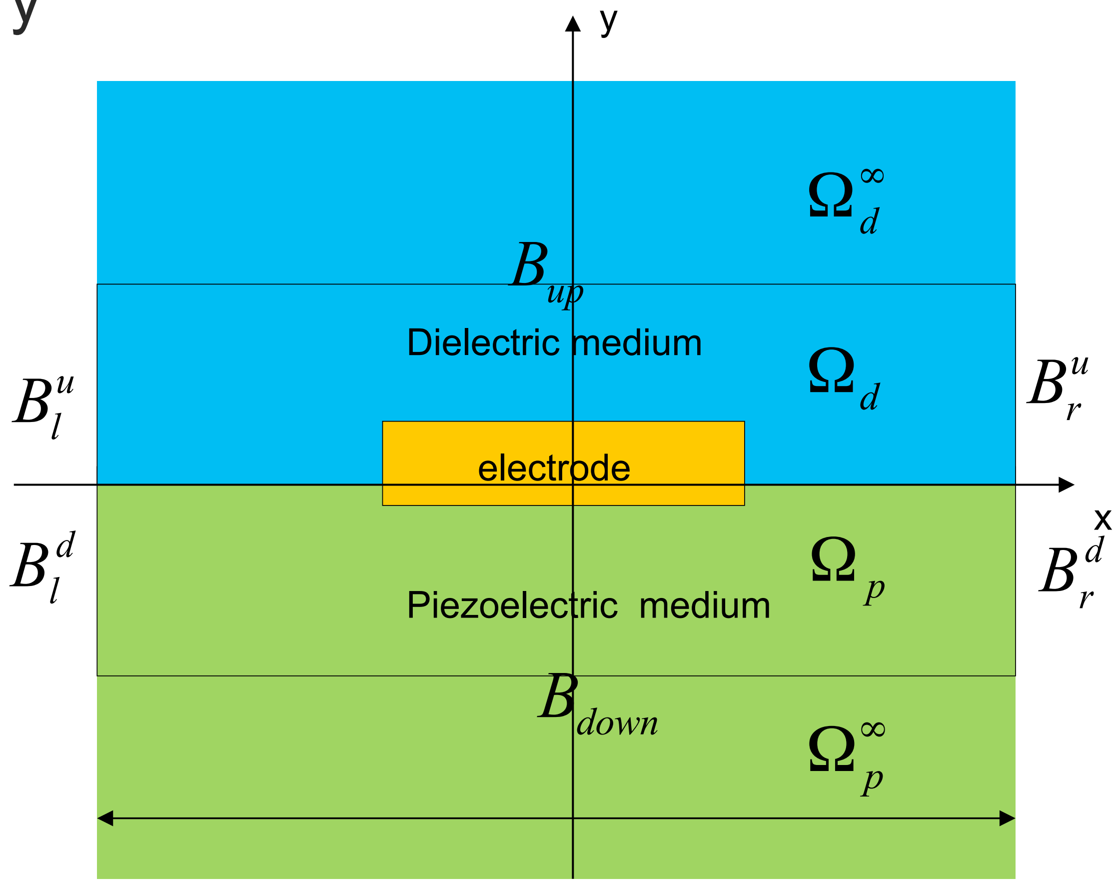
- Piezoelectric substrate
- SAW IDT transducer
- The Surface Acoustic Wave is
  - launched and detected
  - propagating



x

Physical model

- Geometry



Physical model

- Assumptions :
  - 2D analysis (very long electrode) : plain strain approximation
  - p periodic along the x axis
  - harmonic electrical excitation of the electrodes: $V_n(\gamma) = V_0 e^{-j2\pi n\gamma}$
  - electrical assumption: no dielectric losses in the electrode
  - mechanical assumption : the metallic electrode are homogeneous isotropic, elastic materials

Physical model

- The Piezoelectric domain Ω_p and the Elastic domain Ω_E obeys Newton's second law:

$$\nabla \cdot \mathbf{T} = \rho \frac{\partial^2 \mathbf{u}}{\partial t^2}$$

- The Piezoelectric domain Ω_p, the Elastic domain Ω_E, and the Dielectric domain Ω_D obeys the quasistatic Maxwell's equation:

$$\nabla \cdot \mathbf{D} = 0$$

Physical model

- The constitutives equations:

For Ω_P

$$\begin{cases} \mathbf{T}_{ij} = \mathbf{C}^{\mathbf{E}}_{ijkl}\mathbf{S}_{kl} - \mathbf{e}_{ijk}\mathbf{E}_k \\ \mathbf{D}_i = \mathbf{e}_{kli}\mathbf{S}_{kl} + \varepsilon^{\mathbf{S}}_{ik}\mathbf{E}_k \end{cases}$$

For Ω_E

$$\mathbf{T}_{ij} = (\lambda + \mu)\delta_{ij}\mathbf{S}_{kk} - 2\mu\mathbf{S}_{ij}$$

For Ω_D

$$\mathbf{D}_i = \varepsilon_{ik}\mathbf{E}_k$$

Physical model

- γ periodic boundary conditions:
  - For the interfaces B_u^l and B_u^r : $\Phi(+p/2, y) = e^{-j2\pi\gamma}\Phi(-p/2, y)$
  - For the interfaces B_d^l and B_d^r : $\begin{cases} \mathbf{u}(+p/2, y) = e^{-j2\pi\gamma}\mathbf{u}(-p/2, y) \\ \Phi(+p/2, y) = e^{-j2\pi\gamma}\Phi(-p/2, y) \end{cases}$

Physical model – Weak formulation

Finds $\left(\mathbf{u},\phi\right)$ in $V_\gamma^3\left(\Omega_p \cup \Omega_e\right)\times V_\gamma^3\left(\Omega\right)$ (satisfying $\phi = 1$ in the electrode) such that for all $\left(\mathbf{v},\psi\right)$ in $V_\gamma^3\left(\Omega_p \cup \Omega_e\right)\times V_\gamma^3\left(\Omega\right)$ (satisfying $\phi = 0$ in the electrode)

$$\int_{\Omega_p \cup \Omega_E} \overline{\mathbf{S}}\left(\mathbf{v}\right)\cdot\mathbf{T}\left(\mathbf{u}\right)d\Omega - \rho\omega^2\int_{\Omega_p \cup \Omega_E} \overline{\mathbf{v}}\cdot\mathbf{u}\,d\Omega$$

$$-\int_{\Omega_p \cup \Omega_E \cup \Omega_D} \overline{\mathbf{E}}\left(\psi\right)\cdot\left(\mathbf{eS}\left(u\right)+\varepsilon\mathbf{E}\left(\phi\right)\right)d\Omega$$

$$=\int_{B_d} \overline{\mathbf{v}}\cdot\left(\mathbf{T}\cdot\mathbf{n}\right)d\Gamma + \int_{B_u \cup B_d} \overline{\psi}\left(\mathbf{D}\left(\phi\right)\cdot\mathbf{n}\right)d\Gamma$$

$V_\gamma\left(\Omega\right)$ is the mathematical space of $L^2\left(\Omega\right)$ satisfying γ-harmonic periodic boundary conditions

Numerical model

- Incorporates γ periodic boundary conditions in the variational formulation:

- The idea is to transform a γ periodic problem into a periodic problem using the relationship:

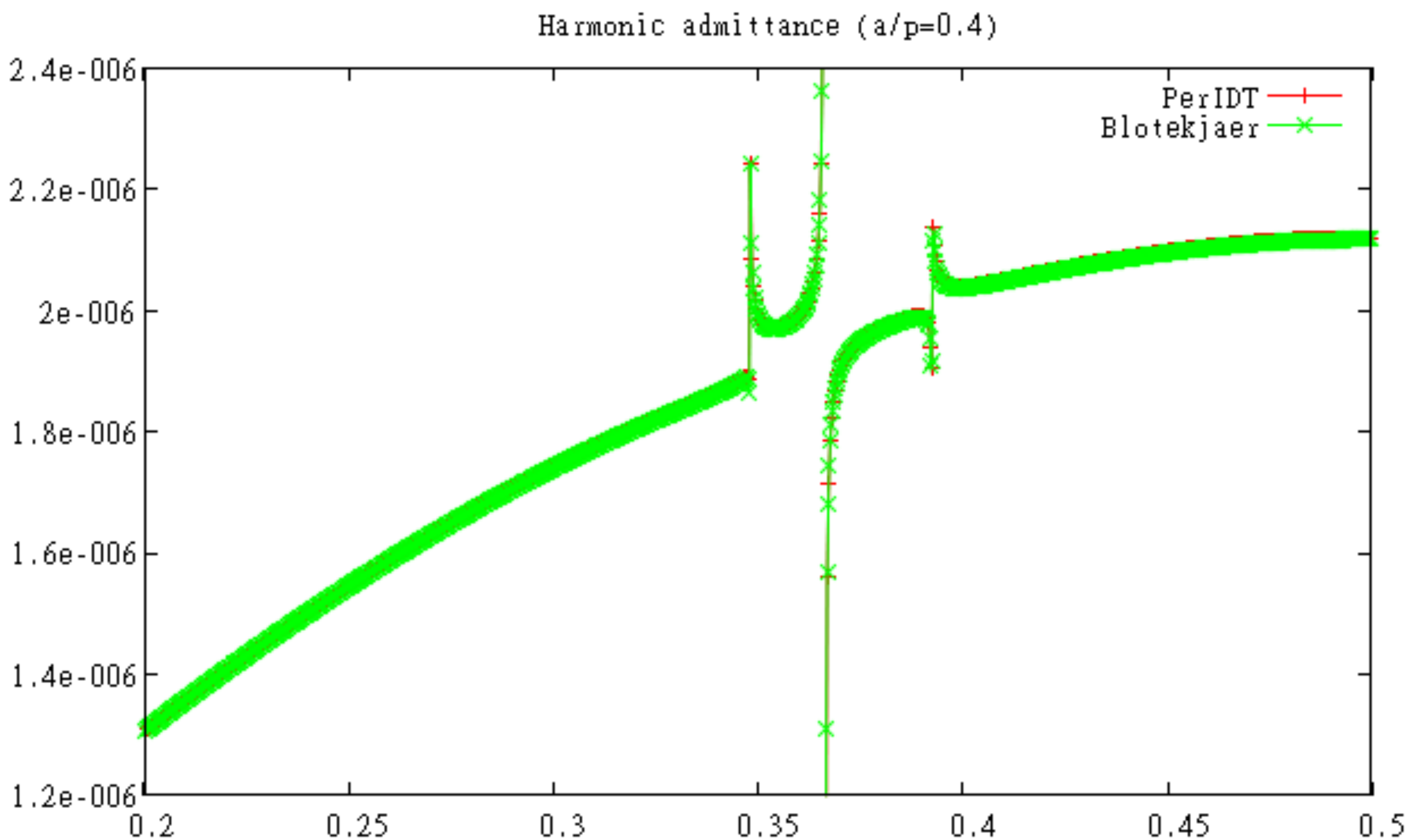
$$u(x,y)=\varphi_\gamma(x)\tilde{u}(x,y) \qquad \varphi_\gamma(x)=\mathrm{e}^{-j2\pi\gamma\frac{x}{p}}$$

Periodic function

- Modify the variational formulation which allows to use only the periodic option in FreeFem++

First Results

- Harmonic admittance computation of buried IDT (comparison with published analytical models)



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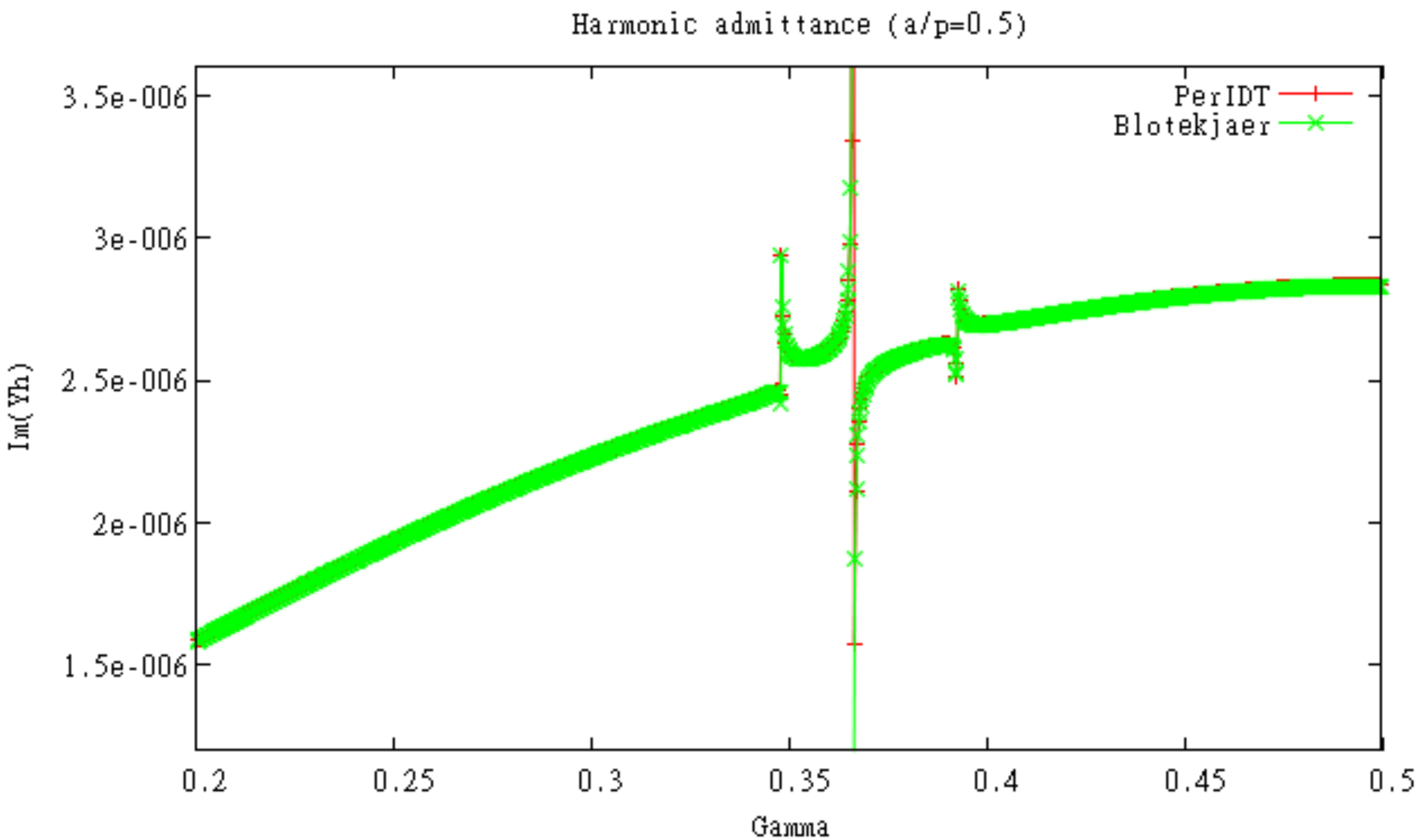


Include temperature dependence

- Taylor expansion of the piezoelectric elastic tensor and mass density around nominal temperature:

$$\mathbf{C}_p^{\mathbf{E}} = \mathbf{C}_0\left(1+\alpha_1^{\mathbf{C}}\left(T-T_0\right)+\alpha_2^{\mathbf{C}}\left(T-T_0\right)^2+\alpha_3^{\mathbf{C}}\left(T-T_0\right)^3\right)$$

$$\rho = \rho_0\left(1+\alpha_1^{\rho}\left(T-T_0\right)+\alpha_2^{\rho}\left(T-T_0\right)^2+\alpha_3^{\rho}\left(T-T_0\right)^3\right)$$

- Piezoelectric substrate expansion:

$$L_S = 1+\alpha_1^{L_S}\left(T-T_0\right)+\alpha_2^{L_S}\left(T-T_0\right)^2+\alpha_3^{L_S}\left(T-T_0\right)^3$$

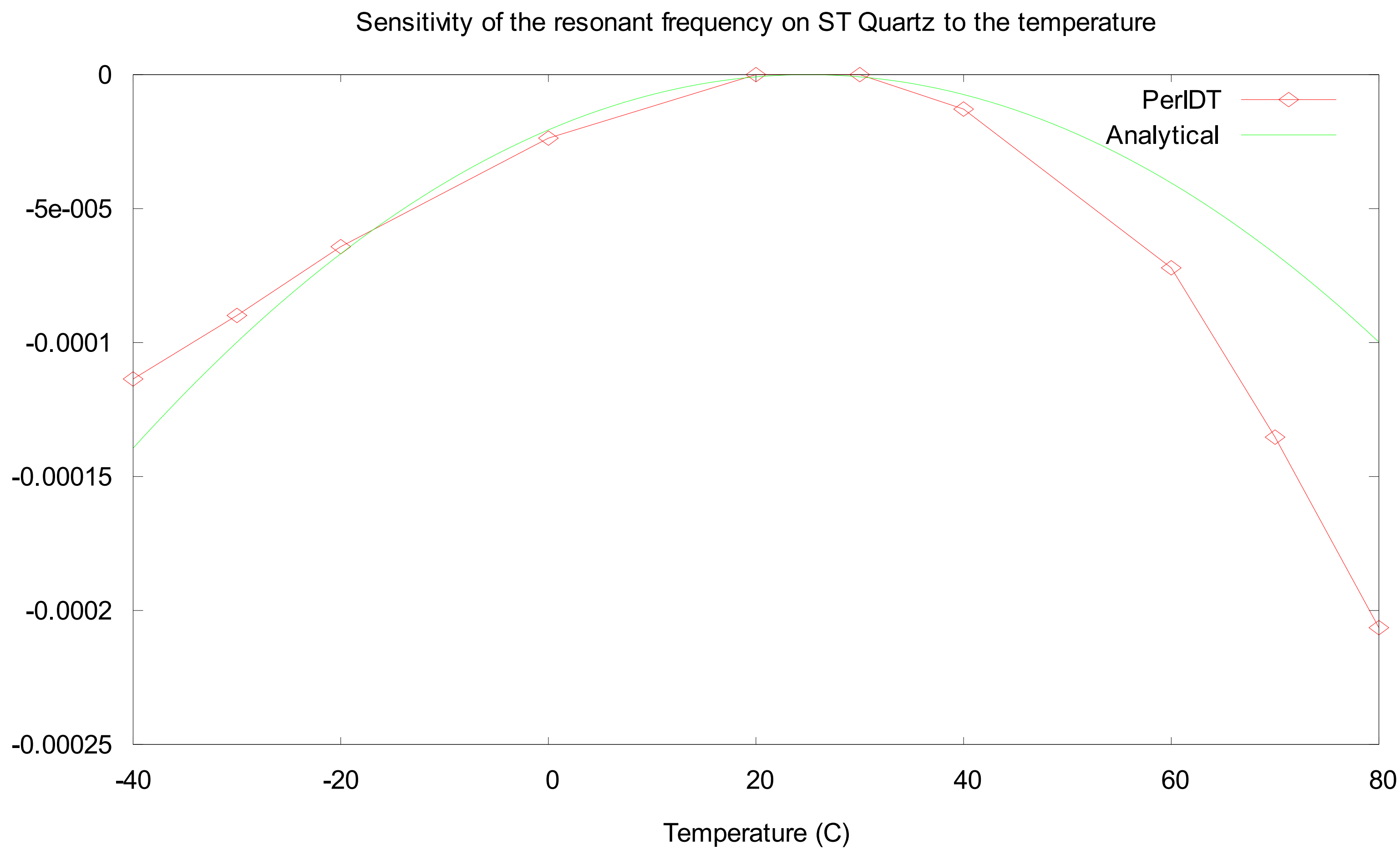
- Temperature effect on the Young's modulus and Poisson's ratio (first order

$$\begin{cases} \dfrac{dE}{dT} = \alpha_E = -0.0375\cdot 10^9\,\mathrm{Pa/^\circ C} \\ \dfrac{d\mu}{dT} = \alpha_\mu = -0.0149\cdot 10^9\,\mathrm{Pa/^\circ C} \end{cases}$$

- Electrode width follows the substrate expansion
- Electrode thickness follows the metal expansion $L_m = 1+\alpha_1^{L_m}\left(T-T_0\right)$

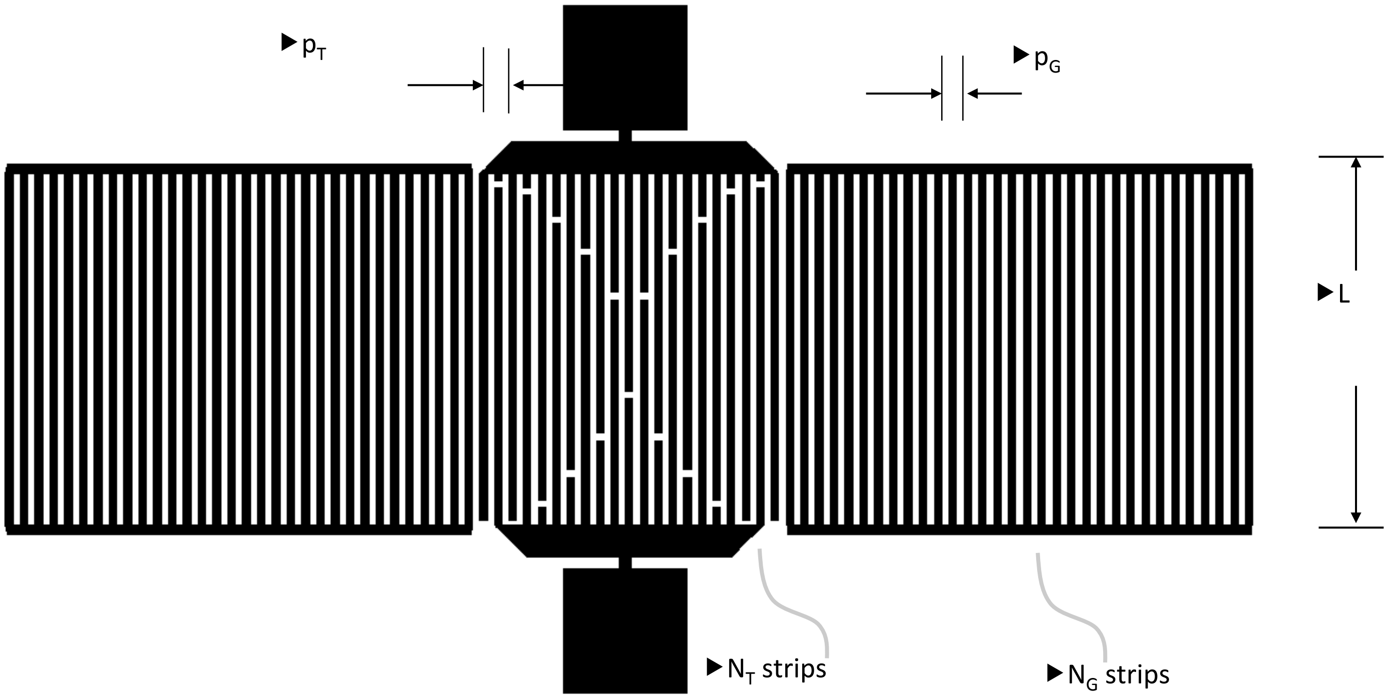
Numerical results

- Quartz cut turnover temperature computations



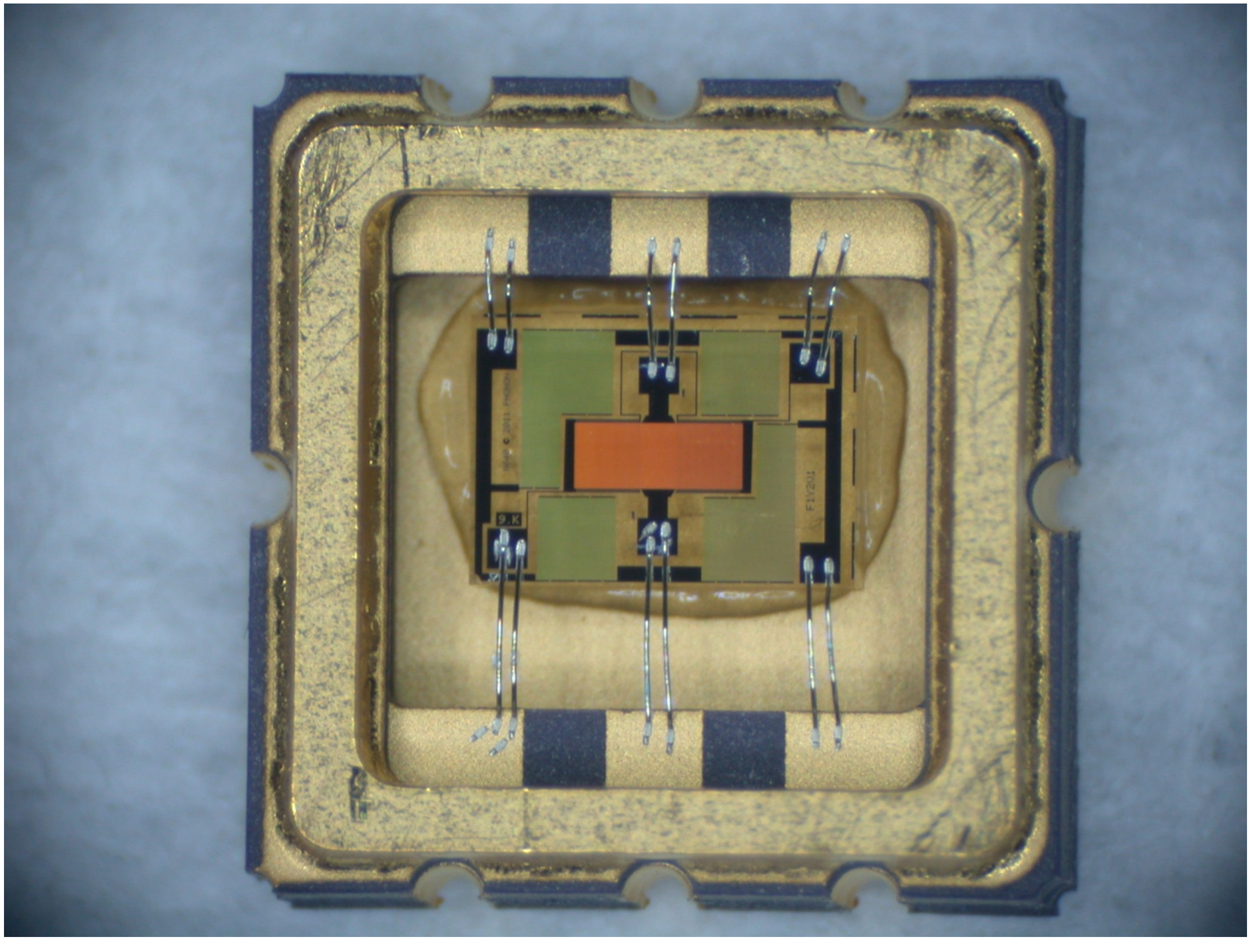
Experimental results

- Schematic of a one port STW Single port resonator



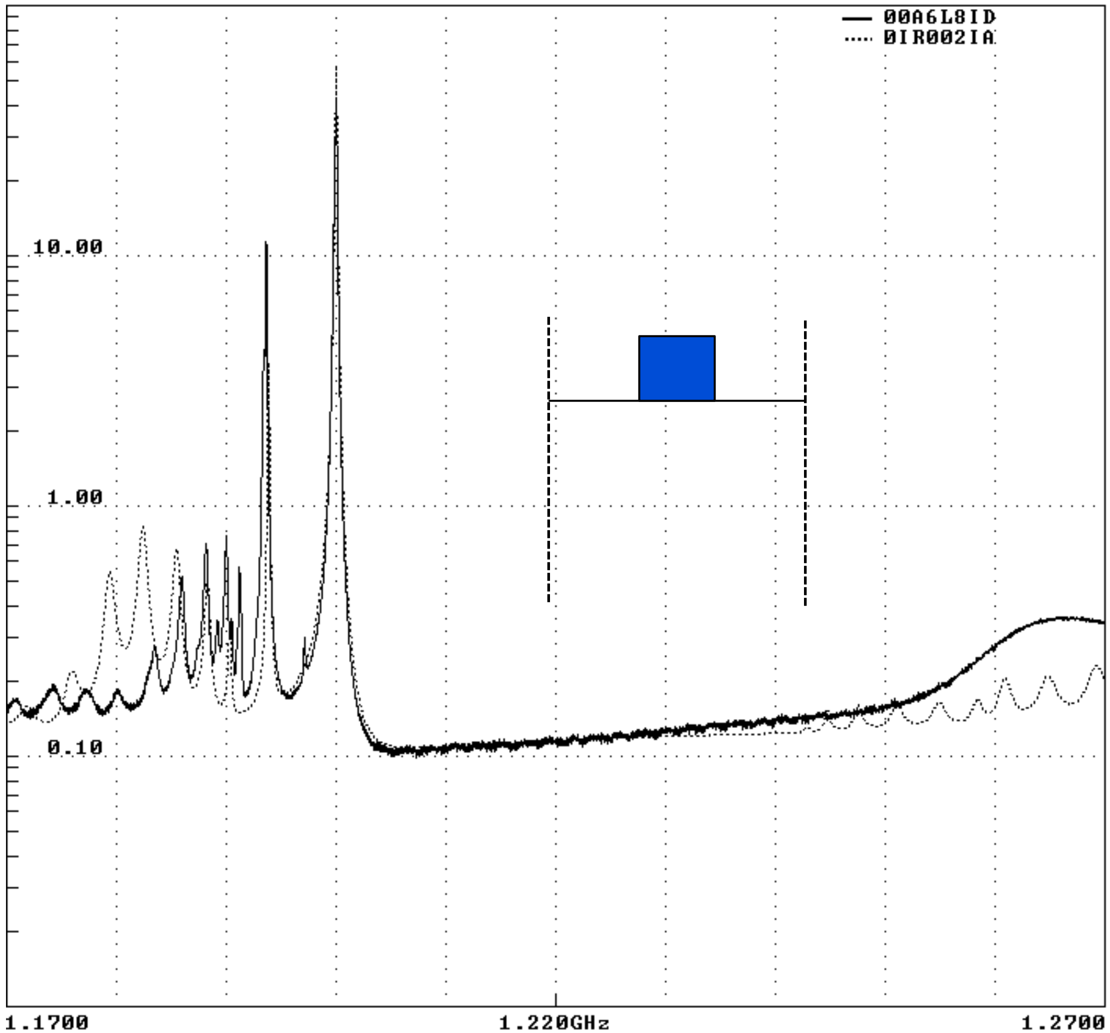
Experimental results

- Actual packaged STW resonator



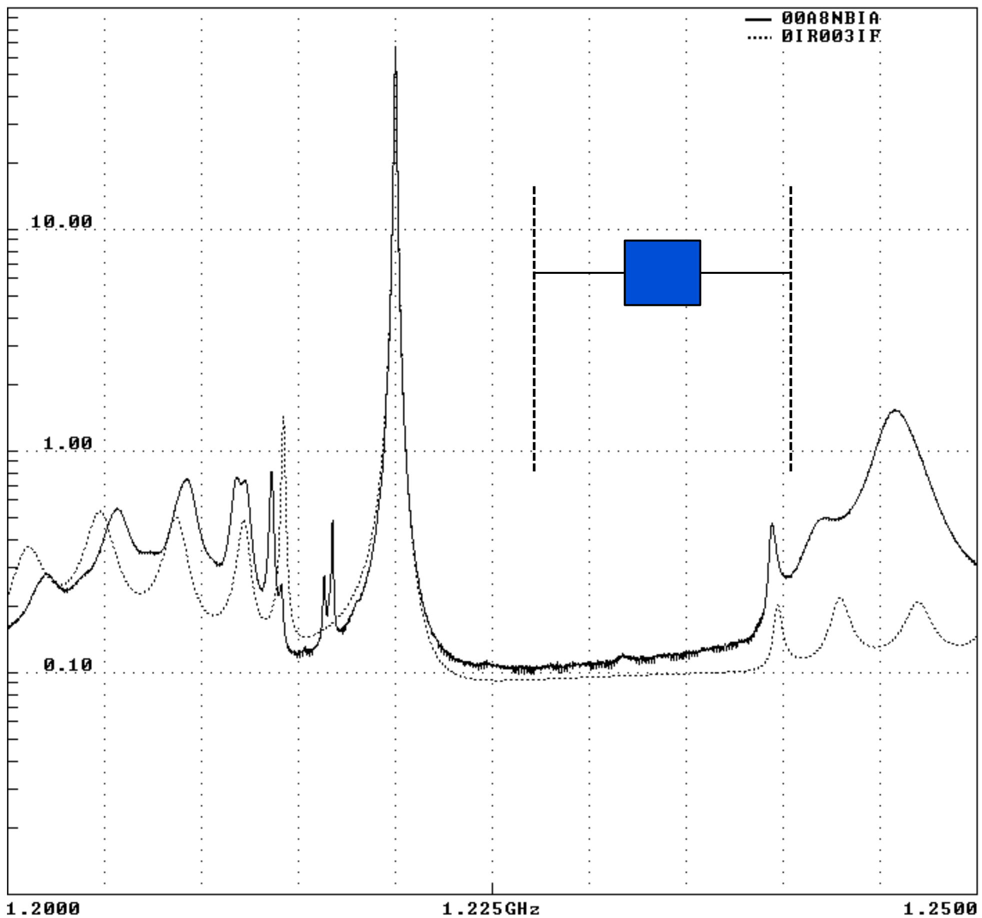
Numerical results

- Conductance of a non buried STW resonator (Q=6300)



Numerical results

- Conductance of a buried STW resonator (Q = 10700)



Conclusions

- A periodic Analysis of Surface Acoustic Waves Transducer has been developed using FreeFem++

- The variational formulation incorporates:
  - The Green's function for the Piezoelectric semi-space
  - The γ periodic boundary conditions

- The temperature dependence has been included using simplified assumptions

- Partially buried electrode STW resonators with improved Q have been developed with the aid of the mixed FEM/BEM numerical model PerIDT

Future works

- Develop a 3D periodic model using FreeFem++ 3D to take into account transverse wave guiding effects

- code parallelization