Analysis of Surface Acoustic Waves Transducer Having Aperiodic Multi Electrode Cells Using a Coupled FEM/ BIE Numerical Model

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Outlines

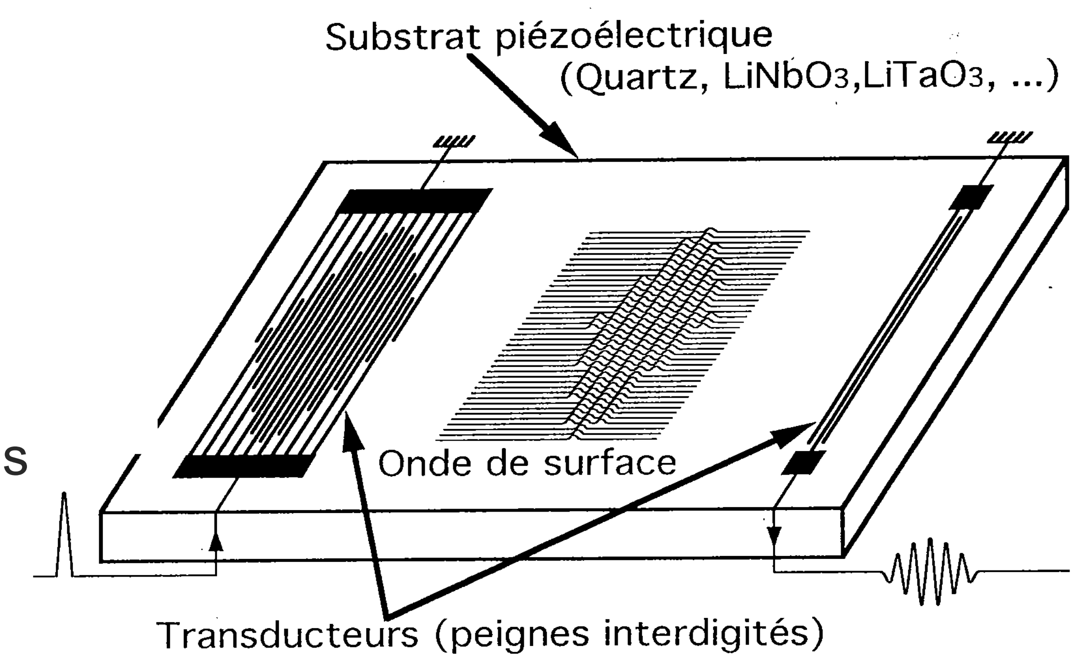
- Introduction
- Physical model
- Weak Formulation
- First results - Validations
- Application to Multi electrodes Aperiodic Transducers
- Filter Frequency Response
- Conclusions
- Future works

Introduction

SAW IDT components

How is built a SAW device

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



Introduction

- For many years, SAW devices were designed with periodic (bandpass filters, resonators) or locally periodic (dispersive devices) electrode structures.
- Analysis of these structures were accurately made using models for single electrodes in a periodic structure.
- Current devices incorporate more complex electrode pattern structures such as Hanma-Hunsinger cells and EWC Cells.
- The design of high performance SAW devices requires an accurate model of the electro-acoustic parameters of each cell.
- A coupled FEM/BIE numerical model able to deal with aperiodic multi-electrode cell has been developed.

Introduction

- **published in the Journal of Computational Physics, 246 (2013), pp. 265-274**

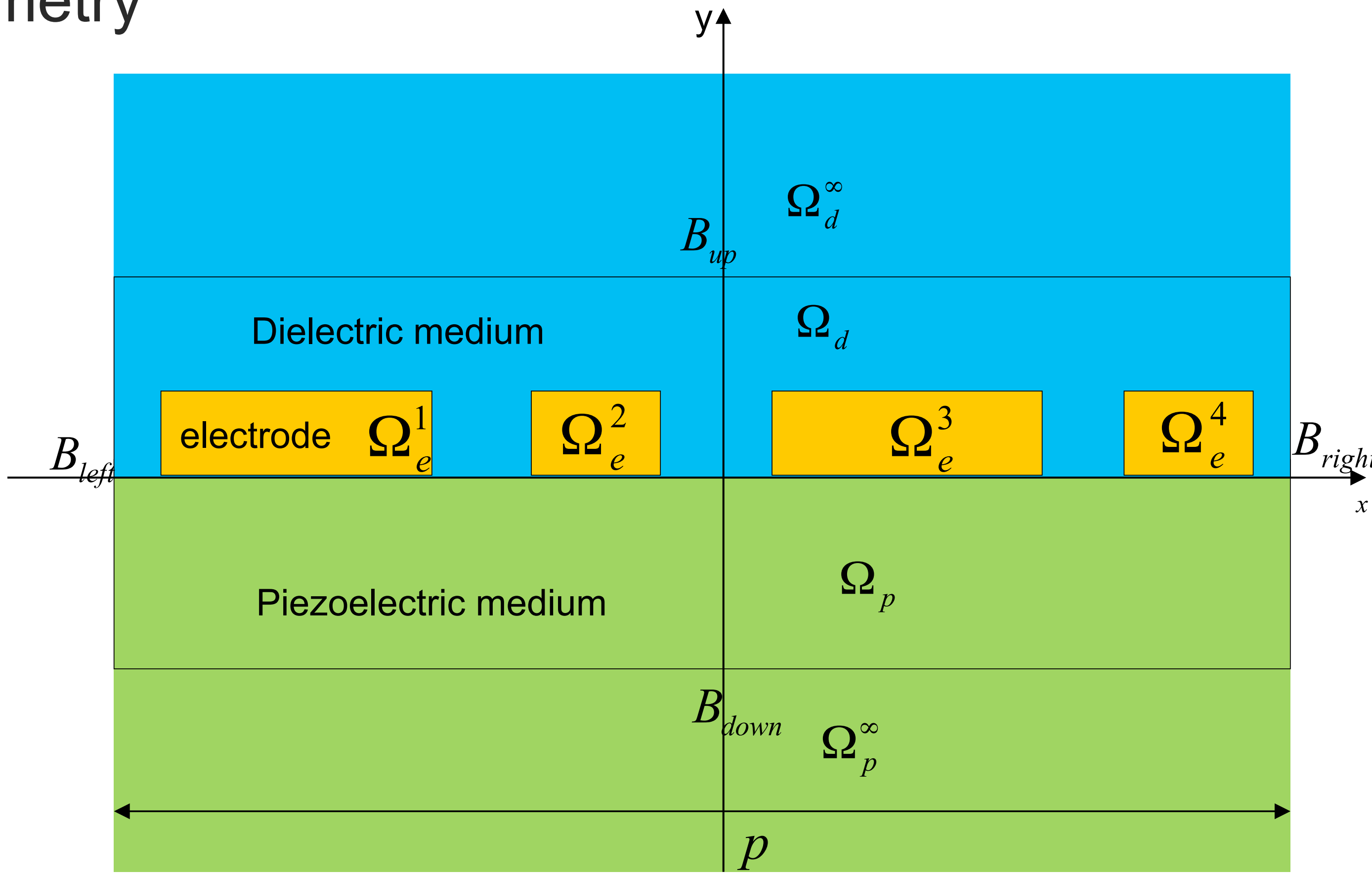
  “Original FEM/BIE numerical model for analyzing infinite periodic surface acoustic wave transducers”, F. Hecht, P. Ventura, P. Dufilié

- **To be published in the proceedings of the IEEE Ultrasonics Symposium 2013,**

  “Analysis of SAW Transducers Having Aperiodic Multi-Electrode Cells Using a Coupled FEM/BIE Numerical Model”, P. Ventura, P. Dufilié, F. Hecht

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: $V_n\left(\gamma\right) = V_0 e^{-j2\pi n\gamma}$
    (allow to apply Bloch-Floquet's theorem and take into account only a single period of the array)
  - 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 : $\begin{cases} \mathbf{u}(+p/2, y) = e^{-j2\pi\gamma}\mathbf{u}(-p/2, y) \\ \Phi(+p/2, y) = e^{-j2\pi\gamma}\Phi(-p/2, y) \end{cases}$

Weak Formulation

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

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

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

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

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

Weak Formulation

- 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++

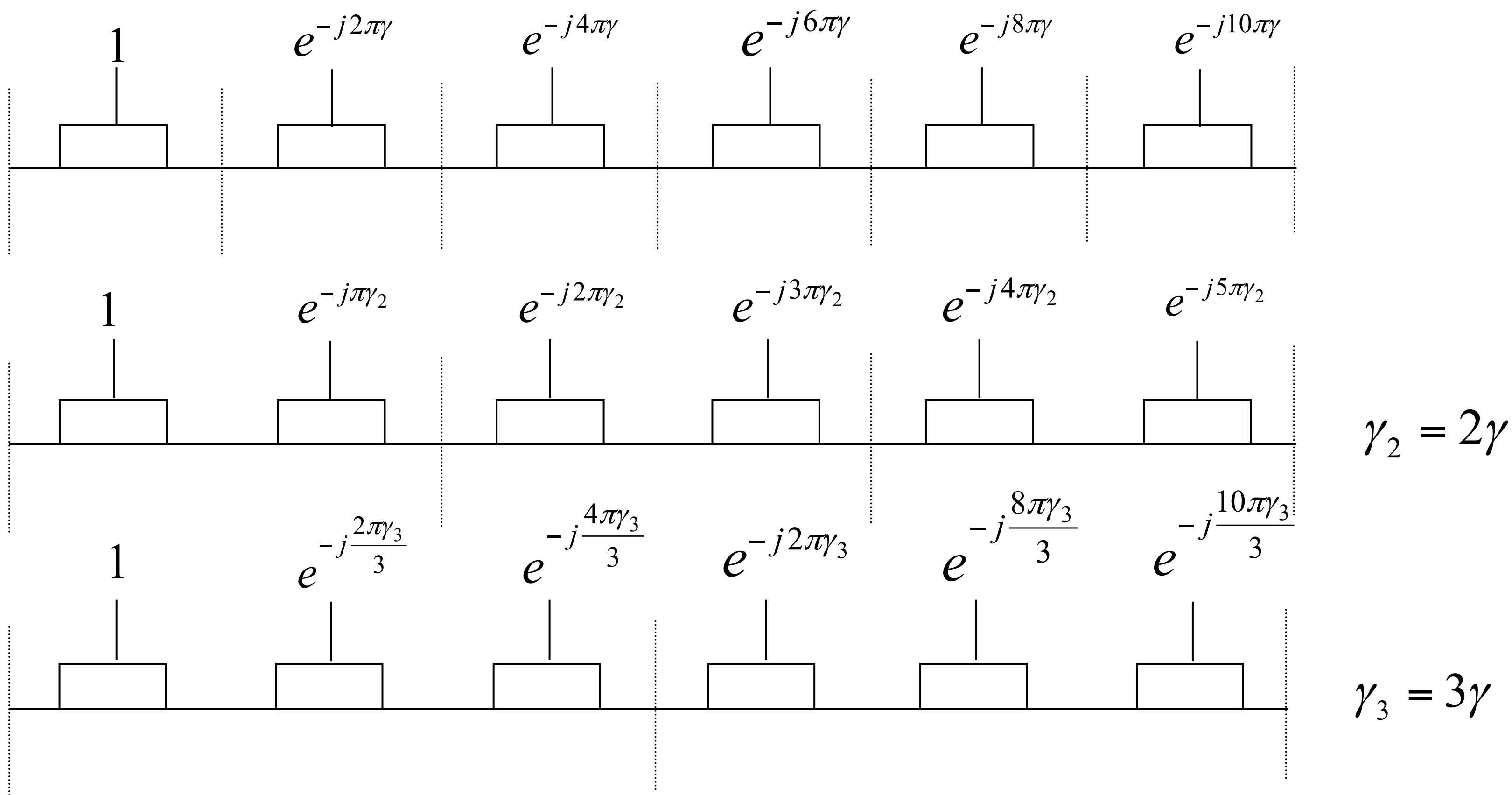
Weak Formulation

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

BIE terms take into account periodic harmonic Green's function at the dielectric and at the piezoelectric boundaries, lead to full matrix coupling degree of freedom belonging to the upper and lower boundaries.

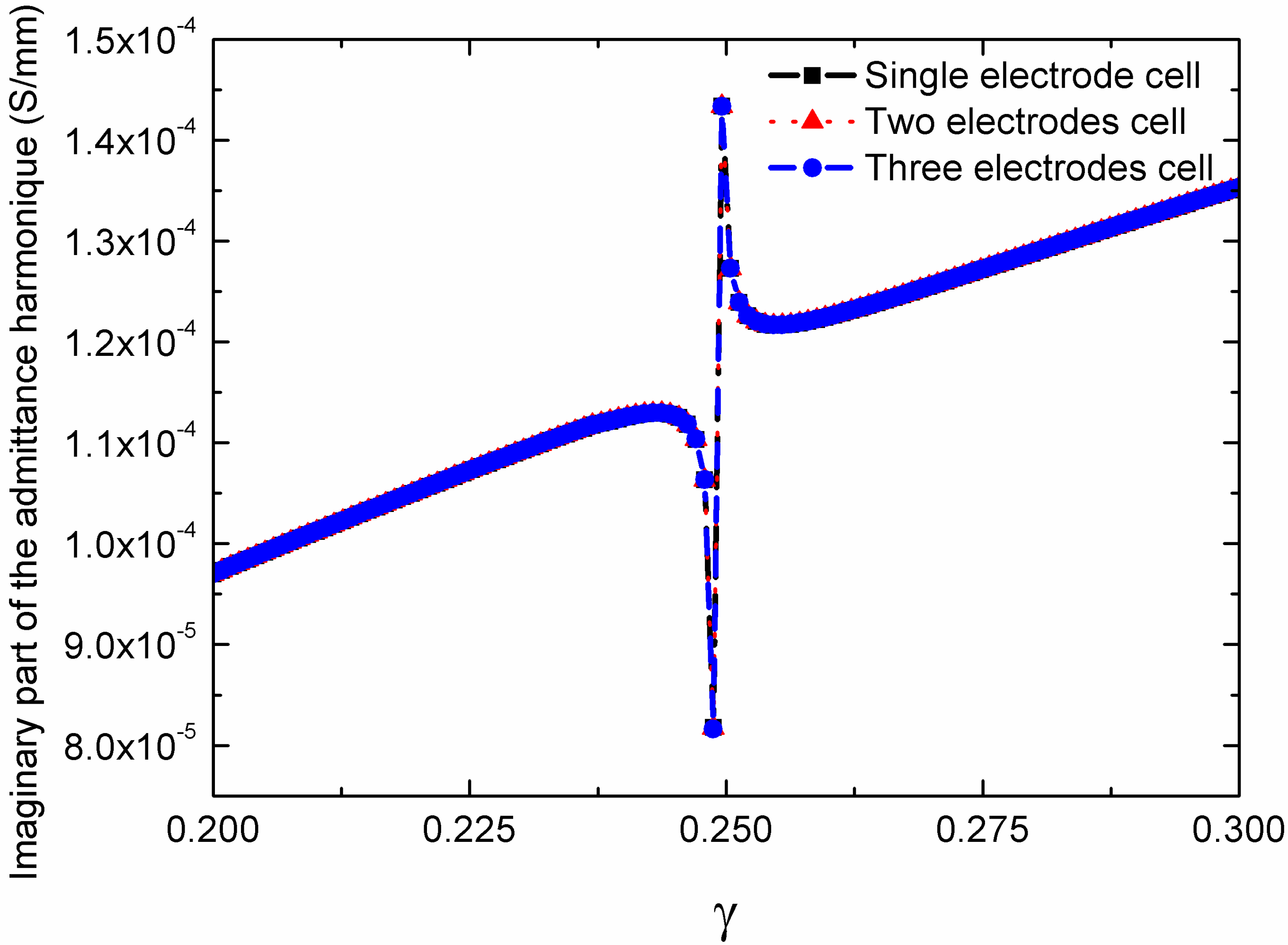
First Results - Validation

- Purpose : compare the computation of the harmonic admittance of a single electrode periodic array with the harmonic admittance of aperiodic multi electrode cells having two, and three electrodes



First Results - Validation

Plots of the imaginary part of the harmonic admittance



Application to Aperiodic Multi-Electrode Transducers

- In the neighborhood of the pole, the surface acoustic wave contribution to the harmonic admittance is assumed to be:

$$Y(\gamma, f) \approx Y_r + \frac{F}{\sin^2(\pi\gamma) - \sin^2(\pi\gamma_{sc})}$$

Amplitude of the pole

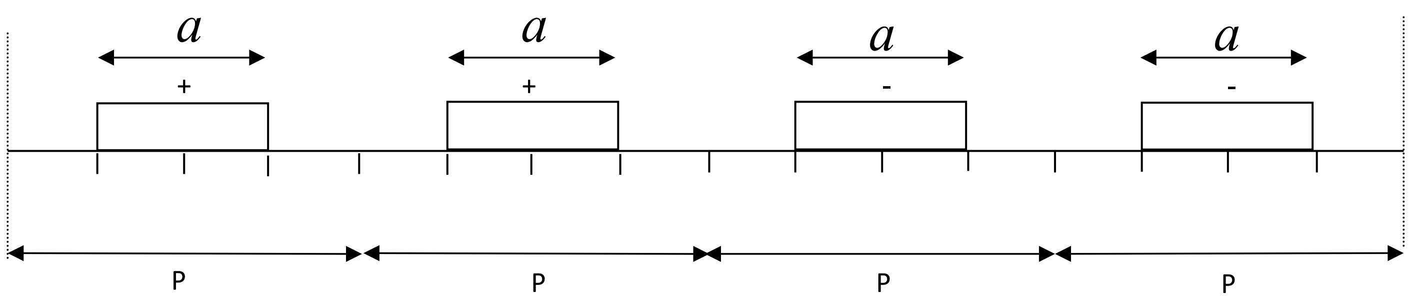
Residual Harmonic Admittance

Position of the pole

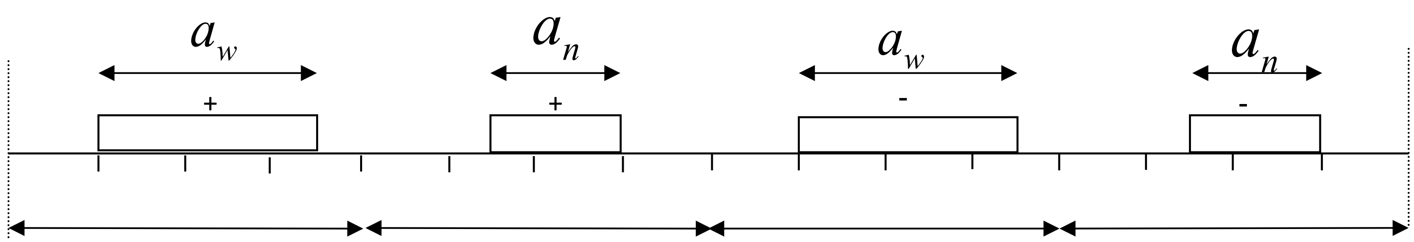
- From the linear interpolation of the amplitude F and the quadratic interpolation of the phase $\sin^2(\pi\gamma_{sc})$, it is possible to derive the phase velocity V, the reflectivity r, the piezoelectric coupling G, and the directivity δ within the cell

Application to Aperiodic Multi-Electrode Transducers

- Classical Split Finger (SF) Periodic Cell



- Modified Hanma-Hunsinger (HH) Cell



Application to Aperiodic Multi-Electrode Transducers

- First computation : the piezoelectric substrate is Y+38° X propagation Quartz, the electrode are not buried, and the metal thickness is 1600 Å. For the SF cell, $a/p = 0.55$, for HH cell $a_\omega/p = 0.65$ $a_n/p = 0.45$

- Second computation : the piezoelectric substrate is Y+36° X propagation Quartz, the electrode are not buried, and the metal thickness is 3200 Å. Same a/p ratio than for the first computation

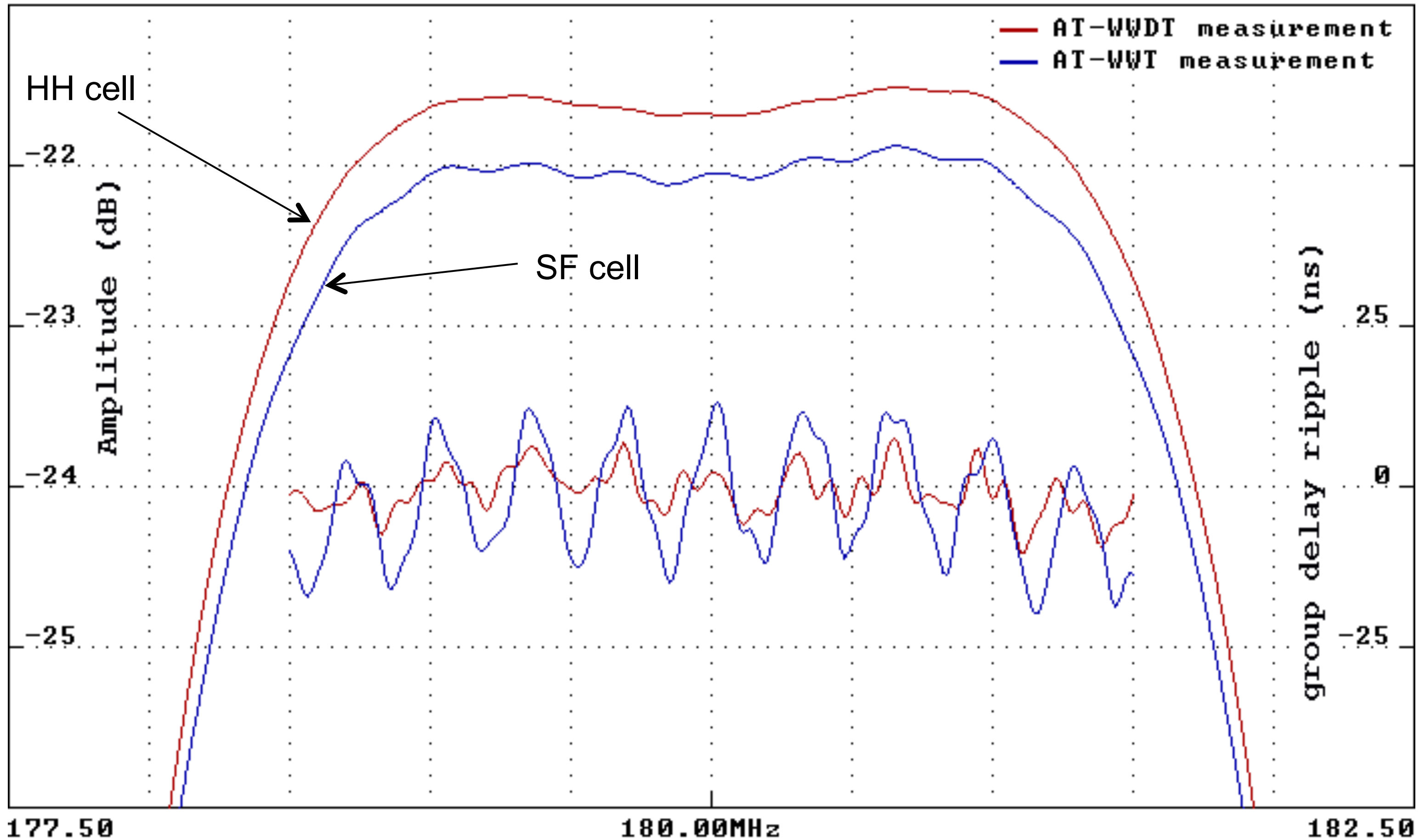
Application to Aperiodic Multi-Electrode Transducers

	FEM/BIE	Analytical model
split finger (1)		
V (m/s)	3146.15	3143.56
G (S/mm)	1.25E-7	1.14E-7
Split finger (2)		
V	3129.64	3121.92
G (S/mm)	1.30E-7	1.13E-7

Application to Aperiodic Multi-Electrode Transducers

	FEM/BIE	Analytical model
HH (1)		
V	3146.193	3143.98
r (%)	0.352	0.349
δ (degree)	54	
G (S/mm)	1.26E-7	1.13E-7
HH (2)		
V	3129.841	3123.40
r (%)	0.774	0.768
δ (degree)	52	
G (S/mm)	1.31E-7	1.12E-7

Filter Frequency Response



Lower Insertion Loss for HH cell

Conclusions

- The coupled Finite Element Model / Boundary Integral Equation (FEM/BIE) for a single periodic strip has been successfully extended to include aperiodic cells in a periodically repeating cell structure.

- An efficient validation method has been used, giving a very good degree of confidence in the software.

- Comparison for a modified Hanma-Hunsinger cell on Quartz have been presented.

Future works

- Develop a 3D periodic model using FreeFem++ 3D to take into account transverse wave guiding effects
- Take into account non linear acoustical effects
- code parallelization