Extraction of COM Parameters and Quality Factor of One Port SAW Resonator using FEM Based Simulation

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Introduction

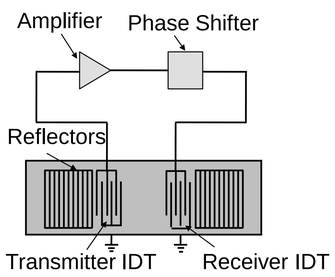
We present a method of **extraction of coupling of modes (COM) parameters and quality factor** for a one port surface acoustic wave (SAW) resonator from the results of finite element analysis in COMSOL Multiphysics.

The parameters are calculated for **various aspect ratios** of the interdigital transducer (IDT) electrodes. It is needed to reduce **resistive loss at high frequency** due to reduced size of IDT electrodes.

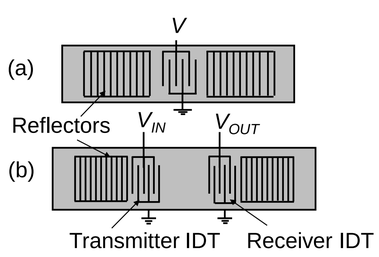
The calculation of COM parameters and quality factor for various aspect ratios of IDT electrodes is useful in **designing high frequency SAW devices.**

SAW Devices:

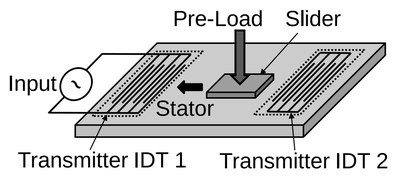
Popular devices which use SAW [1-2]



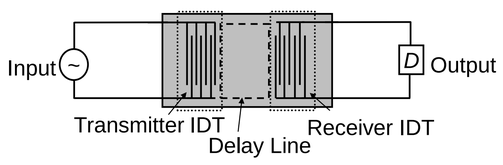
SAW oscillator



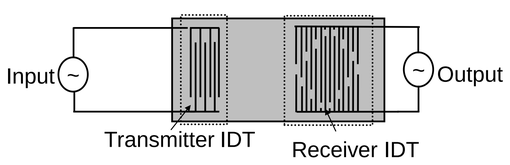
SAW resonator: (a) One port
(b) Two port



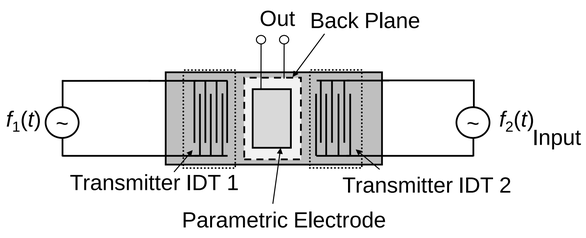
SAW actuator



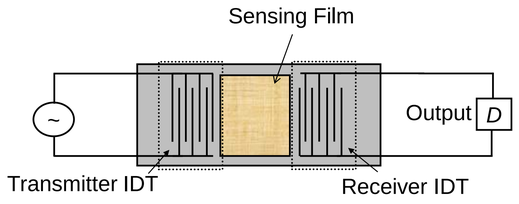
SAW delay line



SAW filter



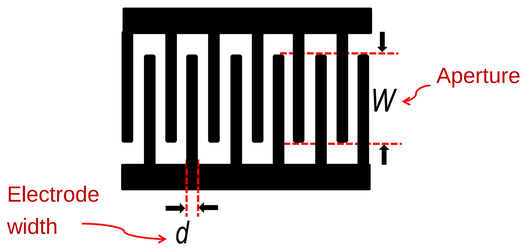
SAW convolver



SAW sensor

Interdigital Transducer (IDT):

- ✓ Developed by 'White' and 'Voltmer'[4].
- ✓ Co-planar metal comb shape electrodes.
- ✓ Deposited on piezoelectric substrate.
- ✓ Converts electrical energy into mechanical energy and vice versa[2].



SAW wavelength $\lambda = 4d$

SAW frequency $f_\circ = v/\lambda$

SAW velocity

Constitutive Equations[1]

Stress tensor component

$$T_{ij} = \sum_k \sum c^E_{ijkl} S_{kl} \quad \sum_k e_{kij} E_k$$

Electric displacement component

$$D_i = \sum_j \varepsilon^s_{ij} E_j + \sum_j \sum e_{ijk} S_{jk}$$

c^E_{ijkl} = stiffness tensor for constant electric field
S_{kl} = strain tensor
e_{kij} = elastic constant or piezoelectric tensor
E_k = electric field
D_i = electric displacement
ε^s_{ij} = permittivity tensor for constant strain

Quality Factor and COM parameters Equations[6]

Quality factor

$$Q_r = \frac{f_r}{\Delta f}$$

Reflection coefficient

$$|\kappa_p| = \pi \left(\frac{f_{ar} - f_r}{f_0} \right)$$

SAW phase velocity

$$v = p\left(f_{ar} \quad f_r\right)$$

Electromechanical coupling coefficient

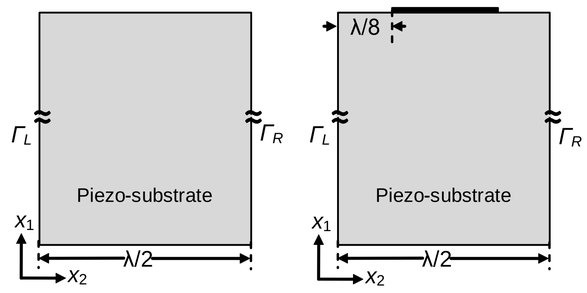
$$K^2 = 2\left(\frac{v - v_m}{v_f} \right)$$

f_r = Resonance frequency of SAW resonator
f_{ar} = Anti-resonance frequency of SAW resonator
v_m = Metalized surface SAW phase velocity
v_f = Free surface SAW phase velocity
f_0 = Free surface resonance frequency
p = Period of IDT electrodes

Modeling in COMSOL Multiphysics®[3]

Geometry Settings:

- ➢ The 2D plane geometry of a simple piezo-substrate and a one port SAW resonator with periodic structure are modeled as shown below.
- ➢ The size of the piezo-substrate used is 1 μm (0.5 λ) × 20 μm (10 λ).
- ➢ Various aspect ratios of the IDT electrodes are used.



Sub-domain Settings:

- ➢ The substrate used for the simulation is *YZ*-cut $LiNbO_3$.

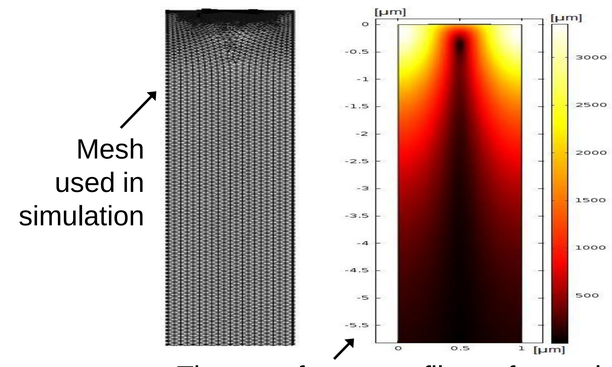
Boundary Settings:

- ➢ Boundary in the top of the substrate is given as **n·T** = 0.
- ➢ The bottom surface is fixed as $u = 0$.
- ➢ Periodic boundary conditions[5] are applied as follows

$$\Gamma_L(u,v,V) = \rho\Gamma(u,v,V), \quad \rho = (-1)^n, \; n = 2a/\lambda$$

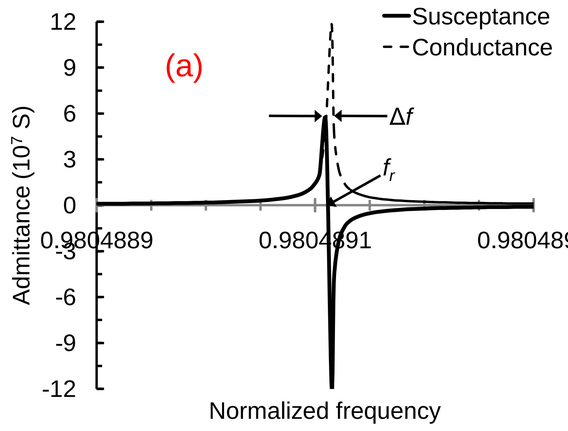
Mesh Settings:

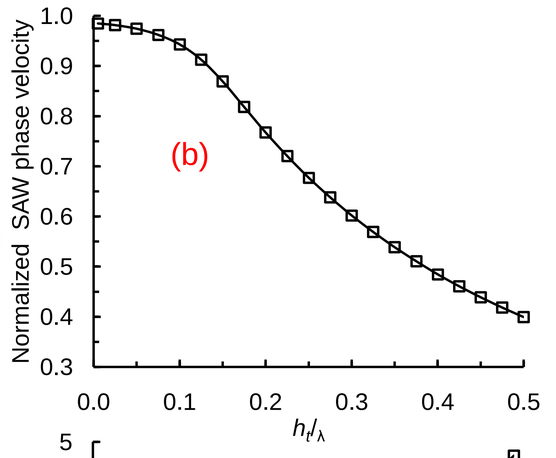
- ➢ The extremely fine optimized mesh with 32 element per λ is used in all the simulation.

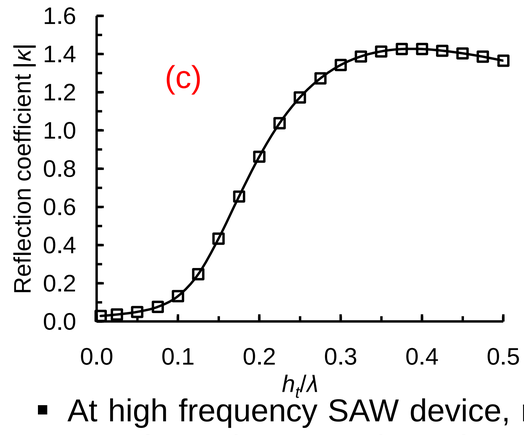


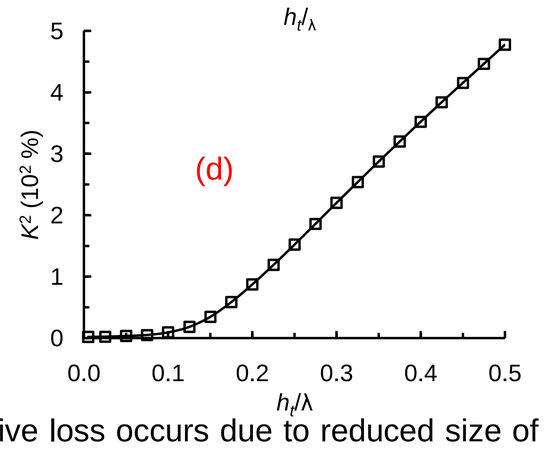
The surface profile of total displacement of one port SAW resonator at resonance frequency.

Results of Simulation in COMSOL Multiphysics®









- At high frequency SAW device, resistive loss occurs due to reduced size of IDT electrodes. It can be reduced by increasing the height of electrode.
- Quality factor of SAW resonator with IDT electrodes aspect ratio of 0.1 is about 1.5 order less than the aspect ratio of 0.005.
- High aspect ratio of IDT electrodes reduces the SAW phase velocity.
- Reflection and electromagnetic coupling coefficient increase with increase in aspect ratio.

References

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3. *COMSOL Multiphysics Users Guide Ver. 3.4*, COMSOL, Inc., Burligton (2007)
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