Extraction of Electrical Equivalent Circuit of One Port SAW Resonator Using FEM-based Simulation

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Introduction

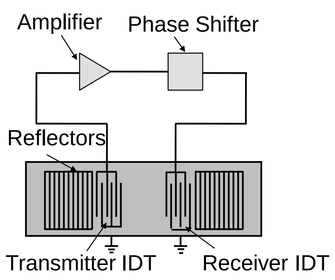
A method of extraction of electrical equivalent circuit of a one port surface acoustic wave (SAW) resonator from the results of simulation based on finite element method using COMSOL Multiphysics is presented

A one port SAW resonator consisting of large number of periodic IDT electrodes fabricated on a piezoelectric substrate is incorporated in the simulation

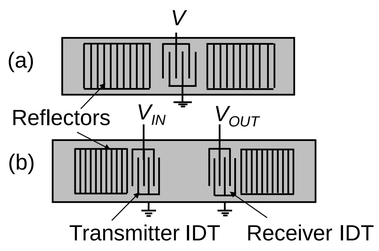
The equivalent circuit of a SAW resonator comprises of motional resistance, capacitance and inductance connected in series, and static capacitance in parallel

SAW Devices:

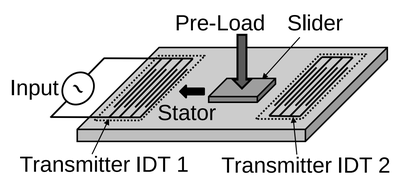
There are many popular devices which use SAW[1-2]



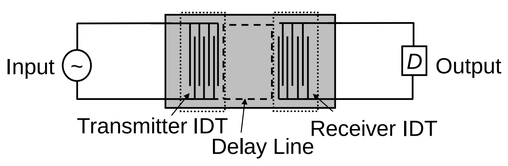
SAW oscillator



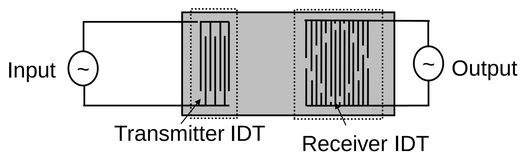
SAW resonator: (a) One port (b) Two port



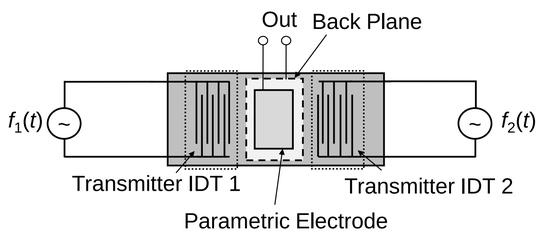
SAW actuator



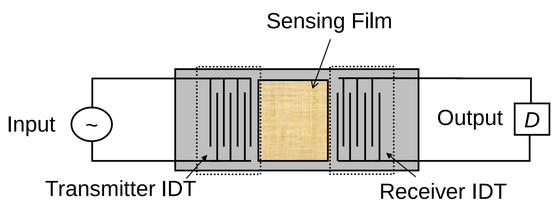
SAW delay line



SAW filter



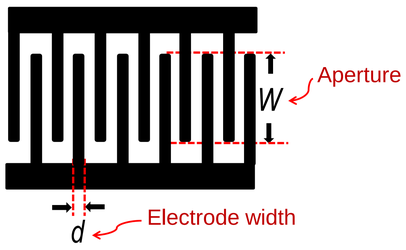
SAW convolver



SAW sensor

Interdigital Transducer (IDT):

- ✓ Co-planar metal comb shape electrodes[1]
- ✓ Deposited on piezoelectric substrate
- ✓ Converts electrical energy into mechanical energy and vice versa



SAW velocity

SAW wavelength $\lambda = 4d$ SAW frequency $f_\circ = v/\lambda$

Constitutive Equations[2]

Stress tensor component

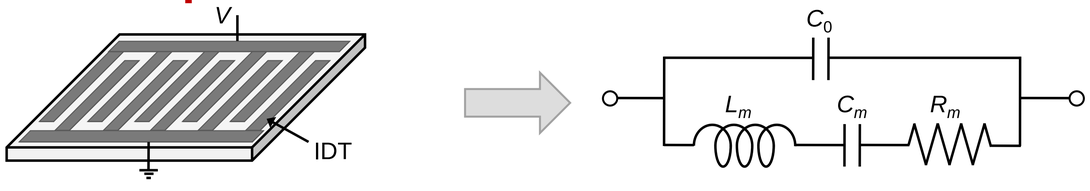
$$T_{ij} = \sum_k \sum_l c^E_{ijkl} S_{kl} - \sum_k e_{kij} E_k$$

Electric displacement component

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

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

Electrical Equivalent Circuit[5]



SAW resonator with large number of IDT electrodes

Electrical equivalent circuit

Electrical equivalent circuit parameters are calculated from the following equations

Resonance and anti-resonance frequency

$$\omega_r = \frac{1}{\sqrt{L_m C_m}}; \quad \omega_{ar} = \frac{1}{\sqrt{L_m C_m C_0 / (C_m + C_0)}}$$

Capacitance ratio

$$\gamma = \frac{C_0}{C_m} = \frac{1}{(\omega_{ar}/\omega_r) - 1}$$

Quality factor

$$Q_r = \frac{f_r}{\Delta f} = \frac{\omega_r L_m}{R_m} = \frac{1}{\omega_r C_m R_m}$$

SAW phase velocity

$$R_m = G^{-1}\Big|_{f=f_r}$$

f_r = Resonance frequency
f_{ar} = Anti-resonance frequency
L_m = Motional inductance
C_m = Motional capacitance
R_m = Motional resistance
$\omega = 2\pi f$, Angular frequency
G = Conductance peak value
C_0 = Period of IDT electrodes

Modeling in COMSOL Multiphysics[3]

Geometry Settings:

- 2D plane geometry of a one port SAW resonator with one period of IDT electrode used in simulation is shown below
- The dimensions of the piezoeletric substrate and IDT electrodes are 16 μm (1 λ) × 160 μm (10 λ) and 4 μm × 0.2 μm, respectively

Sub-domain Settings:

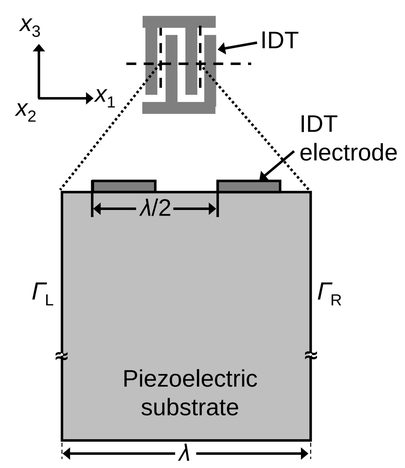
- The substrate used for the simulation is YZ-cut $LiNbO_3$

Boundary Settings:

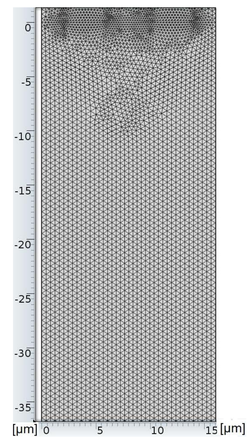
- Boundary in the top of the substrate is given as $\mathbf{n}\cdot\mathbf{T} = 0$.
- The bottom surface is fixed as $u = 0$
- Periodic boundary conditions[4,6] are applied as follows

$$\Gamma_L(u,v,V) = \rho\Gamma_R(u,v,V)$$

$$\rho = (-1)^n, n = 2a/\lambda$$



2D geometry used in simulation

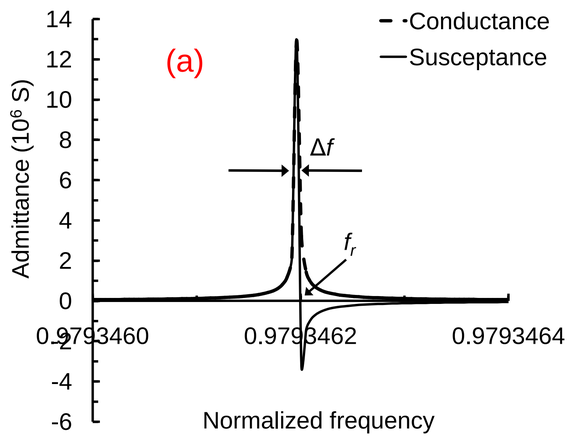


Mesh applied in the model

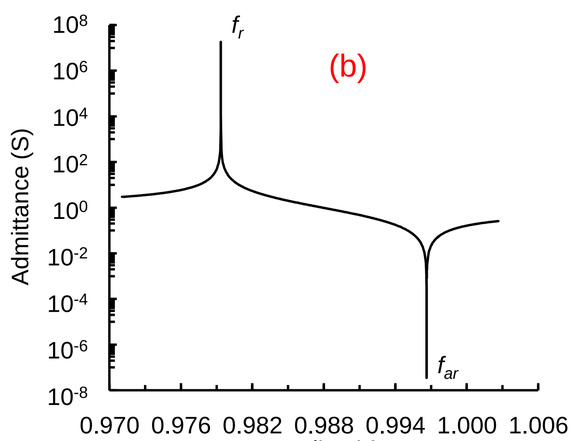
Mesh Settings:

- Extremely fine mesh, 32 elements per λ, is used in simulation

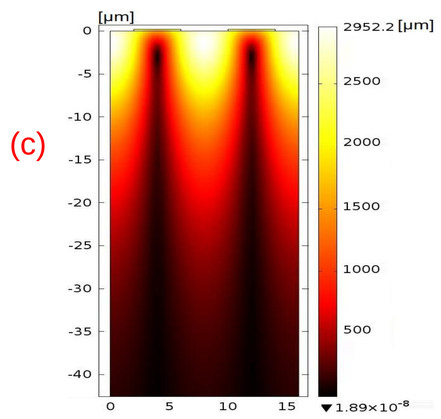
Results of Simulation in COMSOL Multiphysics



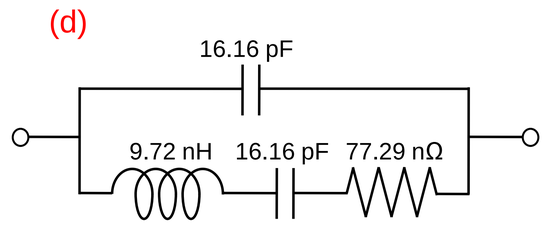
Plot of harmonic admittance per period versus normalized frequency



Log plot of harmonic admittance per period versus normalized frequency



Surface profile of total displacement at f_r



Electrical equivalent circuit

- The calculated value of lumped parameters are shown in figure (d)
- The value of motional resistance is very small *i.e.* 77.29 nΩ because the damping is not considered in the simulation of one port SAW resonator
- The admittance value shown in figure (a) and (b) is high due to low damping in the substrate & infinite aperture of IDT electrodes
- The calculation of electrical equivalent circuit parameters is useful in the design of matching circuits for SAW devices

References

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