Interdigital Transducer for Acoustic-Wave Filter

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Introduction

SAW filter on piezoelectric substrate can be designed by exciting and coupling several types of waves, including longitudinal (L), shear-vertical (SV), shear-horizontal (SH), and potential ϕ. Both L and SV waves are coupled with each other through boundary conditions to constitute an eigenmode called Rayleigh-type surface acoustic wave(SAW). Similarly, SH and ϕ are coupled by the boundary conditions to form a Bleustein-Gulyaev-Shimizu (BGS) wave. SAW filter designs based on Rayleigh-type, Bleustein-Gulyaev-Shimizu (BGS), Love and surface transverse wave (STW) have been presented in many literatures.

Conventional transversal SAW filters composed of two interdigital transducers have high insertion loss due to triple transit echo (TTE). To eliminate mismatch of such regeneration and acoustic reflections, grating reflectors can be placed on both side of the interdigital transducer to construct a single-phase unidirectional transducers (SPUDT) which can serve as a resonator component to construct a more complex filter. Different types of resonator can be synthesized as an impedance element in conventional electrical networks, and SAW filter like ladder-type filter can be design to exhibit required passband and stopband characteristics.

In this paper, the free software FEMSDA in [1] is used to obtain the dispersion relations of SAW propagation along interdigital metallic grating on 36°YX-LiTaO_3 substrates. A resonator-type filter can thus be designed using several types of transducer which is basically a cascade of N interdigial elements. Instead of approximating the lumped electrical impedance, we simulate a two-port resonator filter based on the relation between the COM model and the dispersion properties calculated by applying the boundary element method upon anisotropic substrate and metal material.

Methodology

An interdigital transducer is treated as a four-port acousto-electric network with two acoustic and two electric ports as illustrated in Fig.1. The P-matrix of a sub-transducer describes the relation among the incident waves and the reflected waves at the two acoustic ports, and the current applied to the transducer bus-bars with given voltages at the two electric ports. To determine the COM parameters, Plessky and Abott proposed two approximate dispersion equations among which the upper and lower edges of stopband are estimated with FEMSDA [1]. The P-matrix of a single interdigital element of transducer with periodic metallic grating can be derived from the COM equations and approximated by using the three parameters, η, ϵ, and

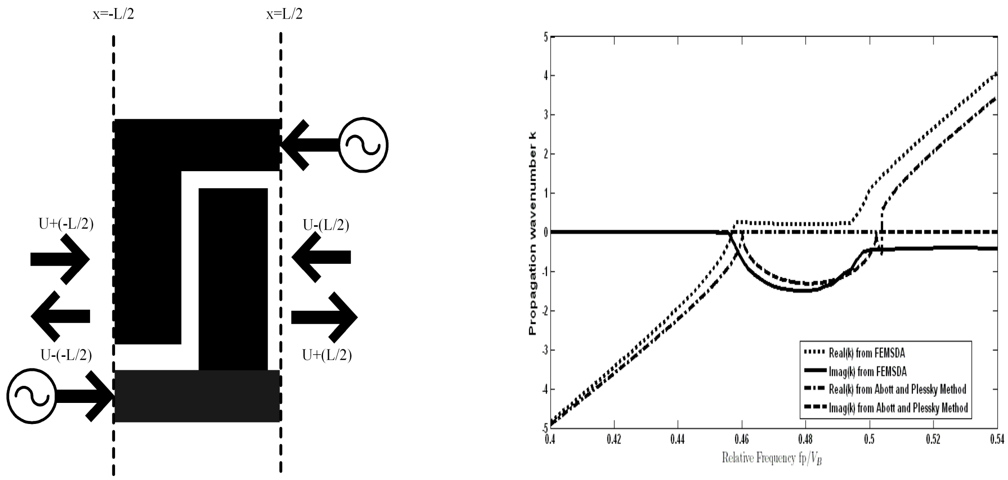

Figure 1: (a) Interdigital transducer SAW with excitation, (b) dispersion relation on 36°YX-LiTaO_3 substrate.

K^2. To connect different transducers in grating or interdigital forms, the associated P-matrices are first converted to transmission scattering matrices. The transducers in series can hence be described by cascading their transmission scattering matrices. The scattering coefficient performance of such sub-transducers can be calculated after proper arrangement of these transmission scattering matrices.

Formulation

Two approximate dispersion equations proposed by Abott and Plessky, respectively, are used to derive γ, κ_{12}, η, ϵ, K^2, and δ as [2], [3], [4]

$$\gamma = c\sqrt{[\Delta - \Delta_v + |\kappa_B|\nu(\Delta)]^2 - [\kappa + \kappa_B \nu(\Delta)]^2} \tag{1}$$

$$\gamma = c\sqrt{(\Delta^2 - \frac{1}{4}(|\epsilon| + \eta\sqrt{2|\epsilon|^2 - \eta^2 - 4\Delta})^2} \tag{2}$$

Consider a single interdigital element of transducer with metallic grating width w=0.4p and metal distance d=0.25p. The P matrix becomes

$$\begin{bmatrix} U_-(0) \\ U_+(L) \\ I \end{bmatrix} = \begin{bmatrix} P_{11} & P_{12} & -P_{31}/4 \\ P_{21} & P_{22} & -P_{32}/4 \\ P_{31} & P_{32} & P_{33} \end{bmatrix} \begin{bmatrix} U_+(0) \\ U_-(L) \\ V \end{bmatrix} \tag{3}$$

with

$$P_{11} = \frac{-i\kappa_{12}^* \sin\gamma L}{\gamma\cos\gamma L + i\delta\sin\gamma L}, \qquad P_{12} = \frac{\gamma}{\gamma\cos\gamma L + i\delta\sin\gamma L}$$

$$
\begin{aligned}
P_{31} &= \frac{(\kappa_{12}^{*}\varsigma - \delta\varsigma^{*})(1-\cos\gamma L) + i\gamma\varsigma^{*}\sin\gamma L}{\gamma(\gamma\cos\gamma L + i\delta\sin\gamma L)} \\
P_{21} &= \frac{\gamma}{\gamma\cos\gamma L + i\delta\sin\gamma L}, \qquad P_{22} = \frac{-i\kappa_{12}\sin\gamma L}{\gamma\cos\gamma L + i\delta\sin\gamma L} \\
P_{32} &= \frac{(\kappa_{12}^{*}\varsigma - \delta\varsigma)(1-\cos\gamma L) + i\gamma\varsigma\sin\gamma L}{\gamma(\gamma\cos\gamma L + i\delta\sin\gamma L)} \\
P_{33} &= \frac{8j|\varsigma|^2\sin(\gamma L)[\gamma(\delta^2-\eta_r) + j(\delta - 2\delta\eta_r + |\eta|^2)\tan(\gamma L/2)]}{\gamma^3(\gamma\cos\gamma L + i\delta\sin\gamma L)} \\
&\quad -8j\gamma^{-3}|\varsigma|^2(\delta-\eta_r) + j\omega CL
\end{aligned}
$$

where $\gamma^2 = \delta^2 - |\kappa_{12}|^2$, $\eta = \eta_r + j\eta_i = \kappa_{12}\varsigma^{*}/\varsigma$.

The P-matrix can be converted to a transmission scattering matrix or an admittance matrix

$$
\begin{bmatrix} b_1 \\ a_1 \\ I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} t_{11}^1 & t_{12}^1 & t_{13}^1 & t_{14}^1 \\ t_{21}^1 & t_{22}^1 & t_{23}^1 & t_{42}^1 \\ t_{31}^1 & t_{32}^1 & t_{33}^1 & t_{43}^1 \\ t_{41}^1 & t_{42}^1 & t_{34}^1 & t_{44}^1 \end{bmatrix} \begin{bmatrix} t_{11}^2 & t_{12}^2 & 0 & t_{13}^2 \\ t_{21}^2 & t_{22}^2 & 0 & t_{23}^2 \\ 0 & 0 & 1 & 0 \\ t_{31}^2 & t_{32}^2 & 0 & t_{33}^2 \end{bmatrix} \begin{bmatrix} b_3 \\ a_3 \\ V_1 \\ V_2 \end{bmatrix}
$$

$$
\begin{aligned}
Y_{11} &= T_{33} - T_{31}T_{11}^{-1}T_{13} = t_{33}^1 - (t_{31}^1 t_{11}^2 + t_{32}^1 t_{21}^2)(t_{11}^1 t_{11}^2 + t_{12}^1 t_{21}^2)^{-1} t_{13}^1 \\
Y_{11} &= m_{33} + \frac{m_{32}^1 m_{23}^2 m_{11} e^{-2jkL}}{1 - e^{-2jkL} m_{22}^1 m_{11}^2}
\end{aligned}
$$

Results and Conclusion

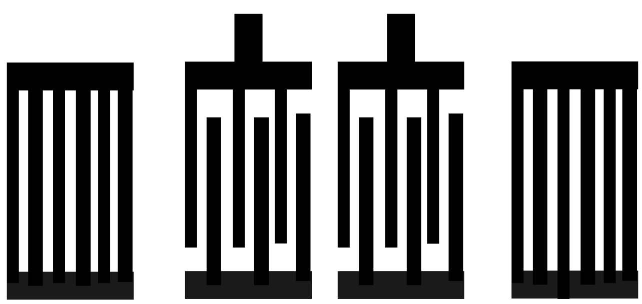

Figure 2: Two IDT resonators to form a bandpass filter.

Fig.1(b) shows the estimate dispersion relations of grating using both FEMSDA and Abott and Plessky's method. Fig.2 shows a filter design which consists of two resonators. The numuerical results are obtained by cascading the transmission matrices of the grating and the IDTs, respectively. The operation frequency is related to the period p, and can be determined by specifying a realistic period p. As shown in Fig.3 where we choose $p = 0.1$m, the insertion loss and stopband rejection are simulated by using the COM model equation. The phenomenon of leaky or nonleaky mode is affected by the mixing between Rayleigh-type and Bleustein-Gulyaev-Shimizu

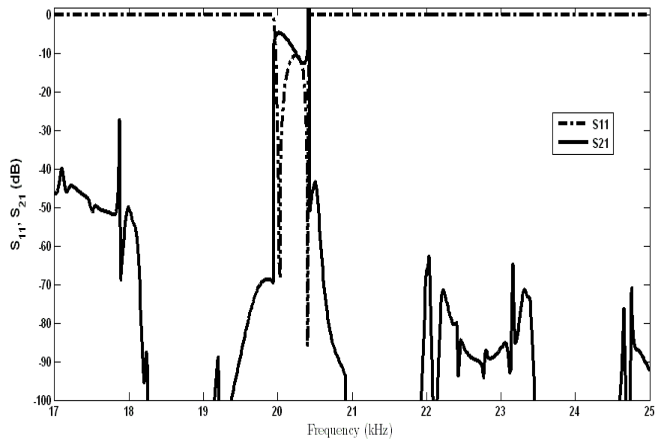

Figure 3: Simulated return loss and insertion loss.

(BGS) SAWs, which can be estimated from the dispersion relations. Through the extraction of dispersion parameters for the COM model, a more robust design on SAW filters can be expected.

References

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