FEM Simulation and Fabrication of SAW Filter with Interdigital Transducer Parametric Variations

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***Abstract*—This report was aimed to evaluate the in-house design and fabrication process of SAW filter. Detailed effect of Interdigital Transducers (IDTs) were investigated by fabrication of SAW filters with parametric variation, including the presence of reflectors, IDT's length, separation of ports, the number of reflectors and IDTs per port. The fabricated SAW filters gave the best performance around 480 MHz with less than 3 dB of insertion loss.**

***Keywords*—FEM, SAW, S-parameters**

I. Introduction

SAW filter is widely used in wireless communication due to its compact size and high quality factor [1]-[2]. Since it shares the same fabrication processes with the integrated circuit's industry, the SAW filters are mature to be massively produced and reduce the cost [3].

The physics of SAW filter was well studied and the equations nicely describe the behavior of the filter with simple structure. The traditional modeling methods include coupling of modes and Green's function method [4]-[5]. However, these methods do not depict how the detailed design parameters could influence the performance of the filter. These design parameters include length, number, position, and the shape of the IDTs and reflectors.

One of the solutions is to use Finite Element Method (FEM) which is used for handling complex structure. Researchers mainly focus on FEM modal analysis to predict the resonance frequency. However, prediction of frequency response from FEM involves frequency sweep that requires much more computational resources. A fully built 3D SAW device required more than three days for computation even with high-end hardware setting [6]. Simplified 2D FEM models are commonly used for resonance frequency prediction. When the details of the design are ignored, the verification by fabrication becomes necessary.

In this report, the design, 2D FEM simulation, fabrication and measurement of SAW filter will be presented. The resonance frequency was estimated by FEM simulation. Then, fabrication and measurement were carried to investigate the frequency response and the effect of variation of design parameters.

II. SAW Filter Design Process

A. Fundamental of the SAW filter

Basic SAW filter has piezoelectric material at the base with Interdigital Transducers (IDTs) on its top. Piezoelectric material induces electric potential when it has mechanical strain and vice versa. Therefore, the stress-strain relation and electric displacement-electric potential relationship are coupled together as depicted by eq. (1) and eq. (2), [7].

$$D = [e][S] + [\varepsilon]E \tag{1}$$

$$[T] = [c][S] + [e^t]E \tag{2}$$

In the above equations, D represents the electric charge density displacement. $[e]$ is the piezoelectric coupling coefficient matrix. $[S]$ is the strain matrix. $[\varepsilon]$ represents dielectric permittivity matrix. E represents the electric field. $[T]$ is the stress tensor. $[c]$ is the stiffness matrix and $[e^t]$is the transpose of piezoelectric coupling coefficient matrix.

B. Design, fabrication and measurement

Investigation of SAW filter with of detailed parametric variations by running 3D FEM model for each variation is competitive reliable. However it could take more than one month to complete simulation for just ten parametric variations [6]. Instead, 2D one-port FEM model used by previous researchers was modified and extended to two-ports configuration [8]. This 2D model could quickly predict resonance peak of the SAW filter by ignoring the effect of reflectors and other parametric variations. Frequency around 440 MHz was simulated as shown in Fig. 1. Resonance frequency was expected to be drifted because this design required the 2 μm pitch between IDTs, which is the minimum feature size fabricated by the in-house facilities. Then, the multiple design variations were fabricated and investigated by in-house fabrication and measurement. Different parametric variations are listed in Table 1. and Fig. 2 shows the 2D structure of SAW filter with its design parameters. The SAW filter's features were the bold value in Table 1 when other features were used for variations. For example, when the length of IDT overlaps were varying from 20 μm to 200 μm, all the SAW filters would have reflectors, 40 IDTs per port, 40 reflectors per port and 200 μm separation.

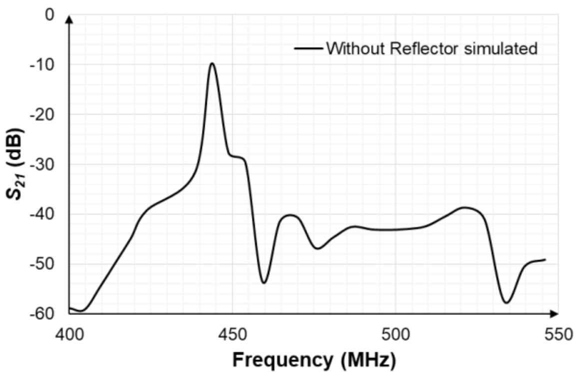

Fig. 1. Simulated frequency response of 2D model

TABLE I. Parametric Variations for Fabrication

Item	Feature	Variation
1	Presence of reflector	**With**/ Without
2	Length of IDT overlap	20/**100**/200 μm
3	Number of IDTs per port (N)	10/20/**40**/80
4	Number of reflectors per port (M)	10/20/**40**/80
5	Separation of two ports	100/**200**/400/800 μm

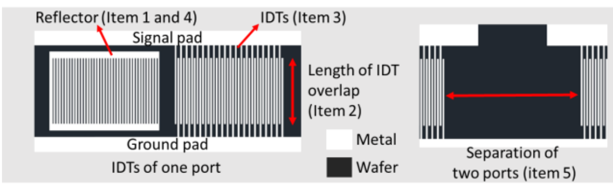

Fig. 2. Design parameters and overview

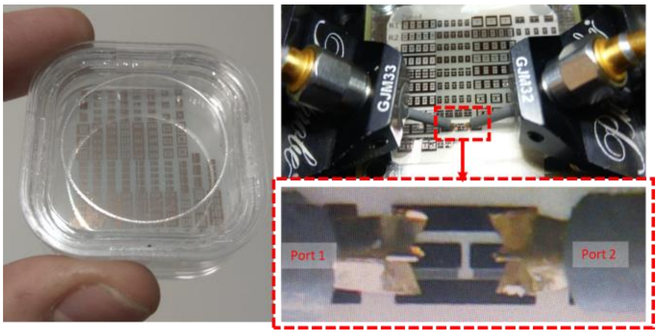

Fig. 3. Fabricated SAW filters and its measurement

III. EXPERIMENTAL RESULTS

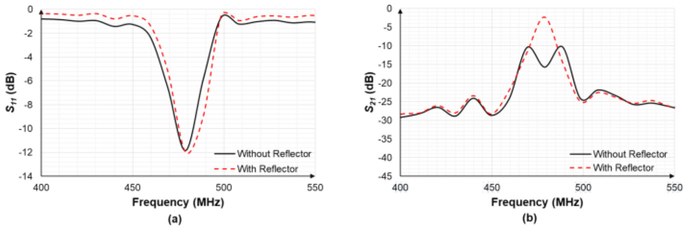

Fig. 4. Frequency response comparison of (a) reflection coefficient (S_{11}) and (b) transmission coefficient (S_{21}) with reflector's variations

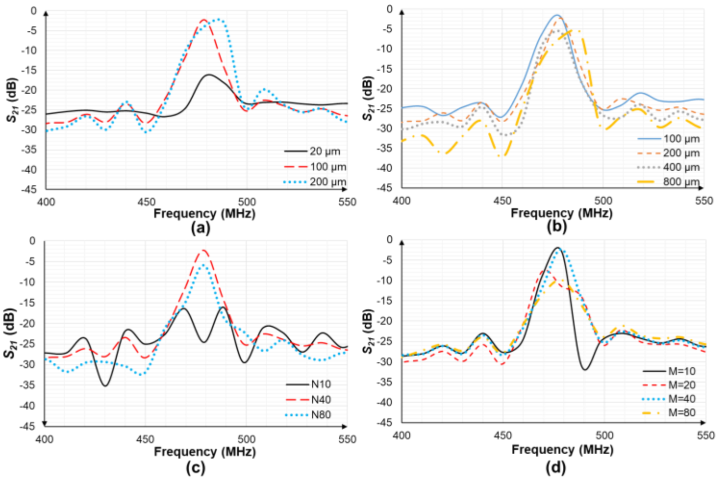

Fig. 5. Comparison of transmission coefficient (S_{21}) with variations of (a) length of IDT overlap, (b) separation of two ports, (c) number of IDTs per port and (d) number of reflectors per port.

The *S*-parameters (S_{11} and S_{21}) were measured shown in Fig. 3 and then compared in Fig. 4. and Fig. 5. The impact of reflectors could be observed in Fig. 4(b) that the filter with reflectors gives significantly better transmission performance. The filter with reflectors has the best S_{21}, which is around -3 dB, at the resonance peak. While the one without reflectors only has -10 dB around the peak. In Fig. 4(a), the S_{11} of both designs are almost identical. Therefore, the difference in S_{21} depends on how well the reception instead of transmission. The induced mechanical waves are reflected between two ports by reflectors so that the same wave could transmit to the reception port with multiple times. Therefore, the filter with reflectors gives better transmission performance.

In Fig. 5(a), S_{21} of filters with different IDTs overlapping length is plotted. The 20 µm in overlapping length is insufficient to fully activate electro-mechanical coupling. While both with 100 µm and 200 µm are sufficient. Verifications between 20 to 80 µm would be needed if a minimal design is desired. However, the 200 µm in overlapping length shows slightly drift in the resonance peak as well as broadening the bandwidth. This characteristic should be further verified in future.

Fig. 5. (b) depicts the impact of port separation on S_{21}. More attenuation is expected with increasing separation. The filter with 800 µm in separation is about 3dB worse than those with 100 µm and 200 µm in separations. While the separation is increased to 800 µm, wider bandwidth and drift in resonance peak could be observed.

Both numbers of IDTs *(N)* and reflectors *(M)* are varied independently as shown in Fig. 5(c) and Fig. 5(d) respectively. The number of reflectors per port is fixed to be 40 when varying the number of IDTs per port and vice versa. The performance of M = 10 and M = 40, are almost identical with the best S_{21} of more than -3 dB. When M = 80, the peak value of S_{21} is dropped to -10 dB. It implies that few reflectors could reflect the incident mechanical waves. However, the excessive number of reflectors or miss matching number of IDTs and reflectors could deteriorate the performance.

The best fabricated SAW filters are with reflectors, more than 100 µm in IDT length, 100 µm in port separation or less, 40 pairs of reflectors and IDTs per port. This SAW filter has around -3 dB transmission coefficient at around 480 MHz .

IV. IMPACT STATEMENT AND CAREER PLANS

The MTT-S scholarship provided me an opportunity and resources to explore the design and fabrication of the passive wireless device. I gain interest in the related field and I would continue the research on this topic. I would like to extend the current work for further publication.

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