Spurious free TC-SAW duplexer using the $SiO_2/LiNbO_3$ structure

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***Abstract*— In this study, modeling and suppression method of the spurious response that are indispensable for the design of Temperature Compensated Surface Acoustic Wave filter (TC-SAW) of $SiO_2/LiNbO_3$ structure are introduced. First, we propose an extended COM model that considers multiple mode mutual coupling. This multi-mode COM model can predict the interaction between Rayleigh and SH modes in the TC-SAW structure. It was then applied to the analysis of a dual-mode SAW filter (DMS), and this method was very effective in improving the prediction accuracy of the spurious response. Next, the modeling method of the transverse mode in TC-SAW and suppression method are introduced. We have developed the spurious free LTE Band 8 TC-SAW Duplexer that is mass-produced and commercialized.**

Keywords—Temperature compensated SAW (TC-SAW), SiO_2, $LiNbO_3$, Rayleigh mode, SH mode, Transverse mode, Ladder filter, DMS

I. Introduction

Radio Frequency (RF) components, especially the electrical performance improvement of an RF filter makes a significant impact on meeting the increasing demands within mobile communication. SAW (Surface Acoustic Wave) filters are widely used as high-frequency filter in the mobile communication systems because of their small size, good electrical characteristics and mass productivity. 42°YX-$LiTaO_3$ substrate structure has been used as a filter for mobile communication for many years. [1] [2] To meet the tight roll off characteristics, temperature drift of filter characteristics is a critical issue. Rayleigh SAWs propagating on the SiO_2 overlay/$LiNbO_3$ substrate structure shown in Fig. 1 are widely used for realization of TC-SAW devices to achieve the improvement of TCF (Temperature Coefficient of Frequency) with low loss and moderate passband width. [3]-[10]. This paper describes and development of TC-SAW using $SiO_2/LiNbO_3$ structure for LTE Band 8. For this realization, spurious suppression is necessary without deteriorating the other performance.

TC-SAW with $SiO_2/LiNbO_3$ structure has good Q, TCF and coupling coefficient. However, one of the major drawbacks is generation of spurious resonances due to the shear horizontal (SH) SAW and transverse mode resonances. Fig. 2 shows the influence of SH mode and transverse mode on TC-SAW filter transmission characteristics. The SH mode and the transverse mode affect the transmission characteristics of the filter as a ripple in the passband. In today's SAW filter designs, having a complicated structure, highly accurate acoustic simulation is indispensable for achieving desired electrical characteristics, and the simulation accuracy has a great impact on the electrical characteristics of the final product. The authors pointed out that when the structure is applied to the double-mode SAW (DMS) topology, coupling between these two SAWs causes another spurious resonance at frequencies not far from the main resonance, and their behaviors can be explained by using extended coupling of modes (COM) theory taking this coupling into account. [11]. Authors also introducd the modeling and supression method of transvese mode. [12] In this study, actual filter design example is demonstrated by utilized with intoroduced simulation and supression techniques.

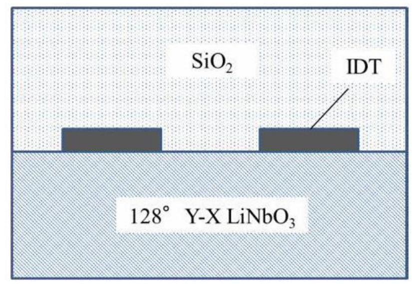

Fig. 1. Cross sectional view of TC-SAW structure.

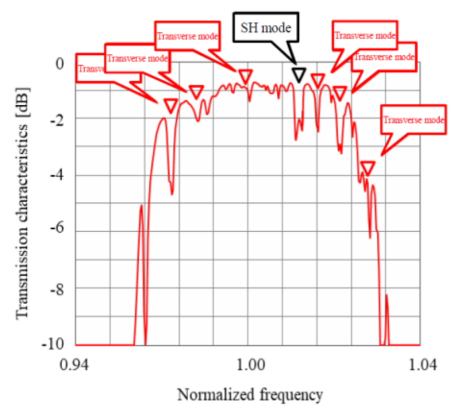

Fig. 2. Spurious responses appeared in passband of TC-SAW.

II. MODELING OF MUTAL COUPLING OF SH MODE AND RAYLAIG MODE

First kind of spurious response excited in $SiO_2/LiNbO_3$ structure is SH mode. This response doesn't come from just exciting the SH mode, but mutually coupled with the Rayleigh mode used in main mode. Therefore, dispersion characteristics near the SH mode and Rayleigh mode are distorted each other. Predicting the electrical performance especially in non-periodic structure such as DMS is difficult without considering mutual mode coupling. Figure 3 shows Dispersion characteristics calculated by FEM/SDA[13][14] and proposed

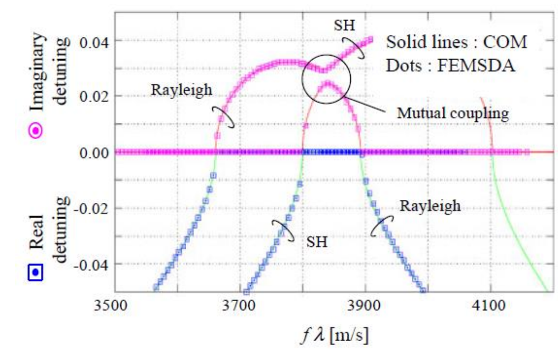

Fig. 3. Dispersion characteristics calculated by FEM/SDA [13][14] and proposed multi-mode COM model.

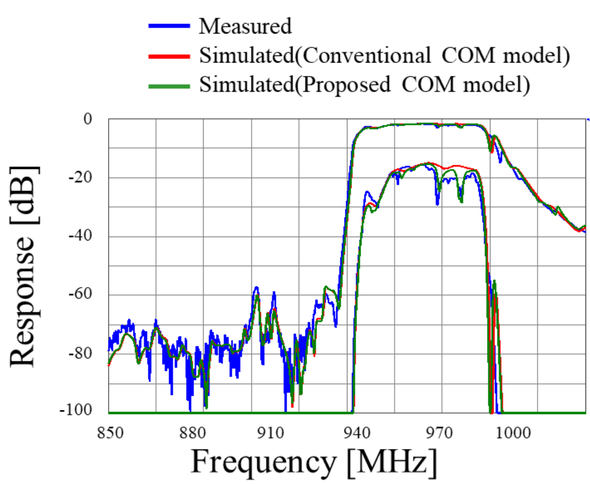

Fig. 4. Measured and simulated (Conventional COM model and propoesd COM model) transmission characteisics.

multi-mode COM model. The proposed model successfully traces the mutual coupling part of dispersion characteristics. Figure 4 shows, measured and simulated with the conventional COM model and proposed multi-mode COM model. Proposed multi-mode COM model can catch the spurious response excited in pass band that is missed by the conventional COM model.

III. SUPRESSION METHOD OF TRANSVERSE MODES

Another type of spurious issue is come from the transverse mode. In this section, a transverse mode reduction technique in cascaded IDTs is intoroduced. It is a well know technique to cascade the same design IDTs to improve the power durabirity. Figure 5 shows a topology of ladder type filter with cascaded IDTs. Figure 6(a) shows typical cascading IDTs with

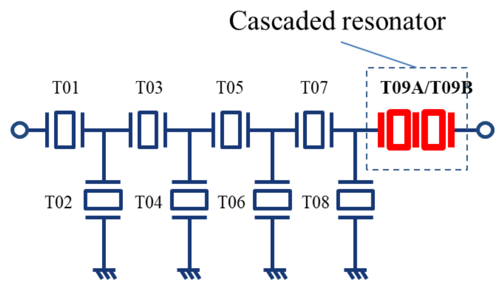

Fig. 5. Circuit topology of cascaded IDTs used in a ladder type filter.

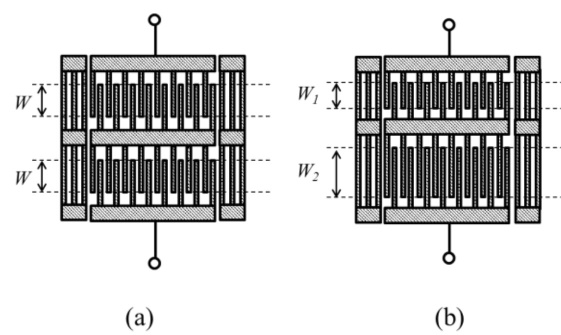

Fig. 6. Illustration of the cascaded resonators with (a) same aperture length and (b) different aperture length.

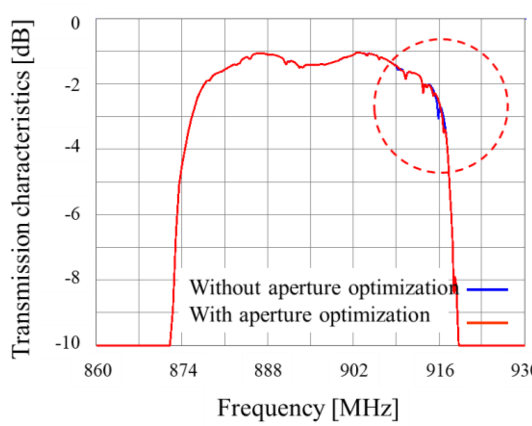

Fig. 7. Simulated transmission characteristics of the ladder filter with and without aperture optimization.

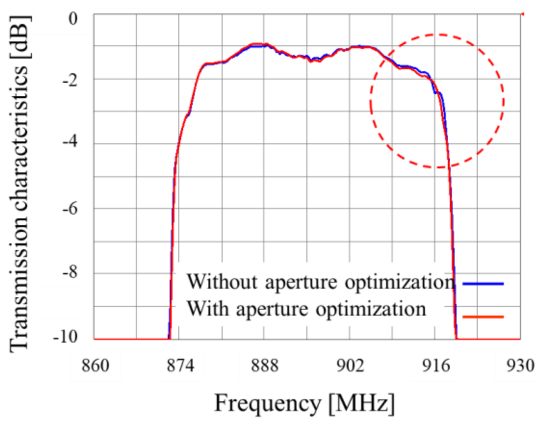

Fig. 8. Measured transmission characteristics of the ladder filter with and without aperture optimization.

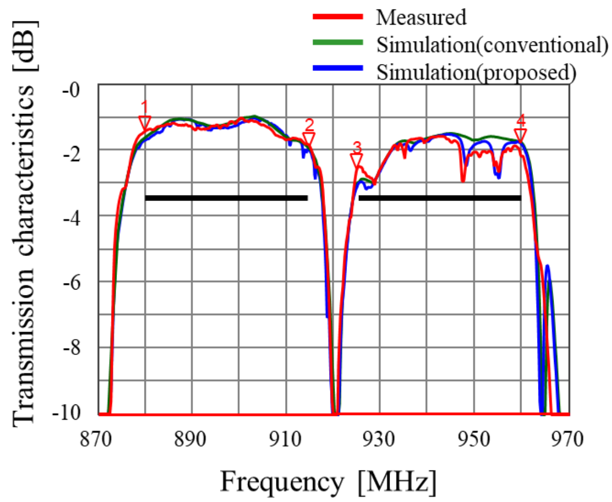

Fig. 10. Measured and simulated in band transmission characteristic of LTE Band8 duplexer before optimized.

equal apertrure length. Transvese modes excitation frequencies are strongly depend on IDT aperture length. By using the optimized non-equal aperture length like Fig. 6(b), transvrese modes are effectively spreaded and reduced. Figure 7 shows simulated ladder filter performance with and without aperture optimize. After optimizing the apreture length, transvsese mode on high edge of pass band can be reduced. Figure 8 shows measured transmission characteisticss. Measured characteristics also show reduction of transverse mode.

IV. DESIGN OF LTE BAND8 DUPLEXER

In this section, actual filter design for LTE Band 8 duplexer using proposed simulation method is demonstrated. The LTE Band 8 has a transmit (Tx) filter frequency band of 880 MHz to 915 MHz, an receive (Rx) filter frequency band of 925 MHz to 960 MHz, and the frequency difference between transmission and reception is very narrow like 10 MHz. It is more difficult to realize filters in the UMTS defined bands. To realize good cut-off characteristics with low insertion loss, it is essential to apply the TC-SAW with high Q and good TCF. Figure 9 shows a circuit topology of the Band 8 Duplexer. The Tx filter uses a ladder type filter, and the Rx filter uses DMS. For the Tx filter, the aperture length optimizing introduced in section III is applied. For the Rx filter, the IDT and the substrate structures are optimized to reduce the ripple due to the coupling mode with the SH mode generated in the DMS band as introduced in Chapter II.

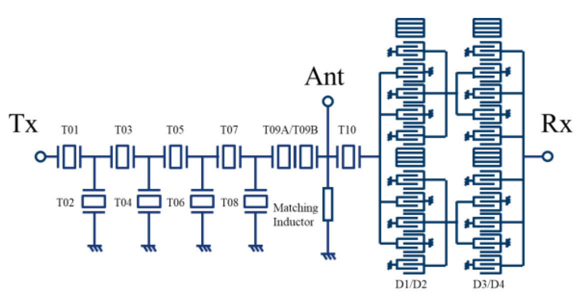

Fig. 9. Circuit topology of LTE Band8 duplexer.

Fig. 10 shows transmission responses of a designed duplexer before optimization. Various spurious resonances are observed in the measured characteristics. It is seen that simulated result obtained by the developed technique agrees well with the measurement not only for the main response but also spurious responses. Dips at 948 and 955 MHz are due to the coupling between SAW modes, and can be explained only by the extended COM model. Fig. 11 shows the response after optimization. Theoretically, expected spurious free responses are also obtained experimentally. Accuracy of the analysis can be verified also from this result. Here, the markers of 1 to 4 correspond to the frequencies of 880 MHz, 915 MHz, 925 MHz, and 960 MHz of the passband end of the band8, respectively. Measured TCF is around -25ppm/deg. Smooth characteristics with less ripple in the band are obtained. Figure 12 shows the measured results of attenuation and isolation. Good attenuation characteristics are obtained while configuring a good passband.

V. CONCLUSIONS

In this study, modeling and suppression method of spurious mode excited in TC-SAW structure. SH mode spurious mode simulation and transverse mode spurious suppression method is discussed. Actual filter designs for LTE Band 8 duplexer are demonstrated. After filter designs are optimized with introduced simulation methods, spurious free smooth passband characteristics are obtained. Physical size of this spurious free LTE Band 8 TC-SAW duplexer is 1.6×1.2 mm^2. We can also apply all any difficult band with this technology.

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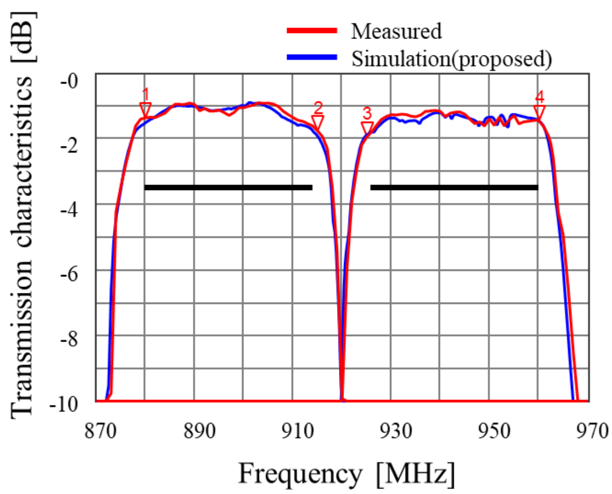

Fig. 11. Measured and simulated in band transmission characteristic of LTE Band8 duplexer after optimized.

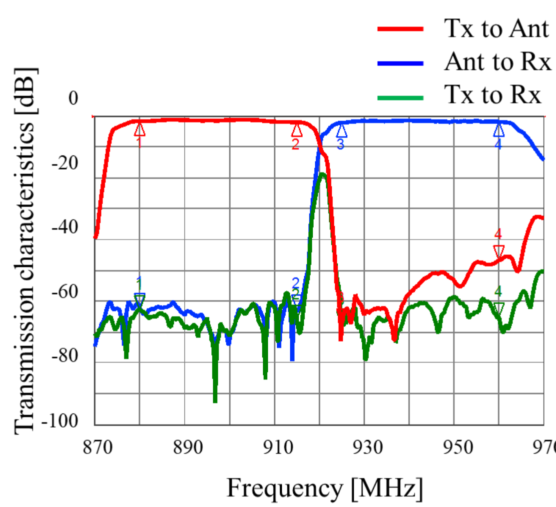

Fig. 12. Measured attenuation characteristic of TC-SAW LTE Band8 duplexer after optimized.