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A Consideration for Developing Tunable Ladder-type Acoustic Filters

ラダー型弾性波フィルタの帯域可変化に関する検討

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1. Introduction

Tunable capability over a wide range of frequencies is strongly demanded to RF filters for developing a reconfigurable RF front-end supporting multi-band and standard operation in a transceiver[1,2]. This paper describes a possible configuration for tunable filters based on RF surface or bulk acoustic wave (SAW/BAW) technologies. The frequency tuning for a ladder-type filter is made possible by attaching capacitors to the filter topology.

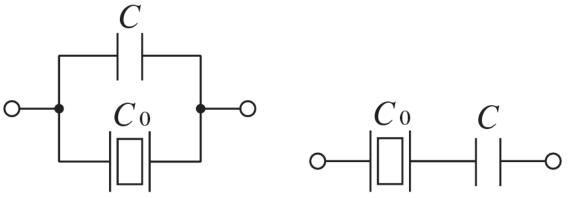
2. Control of the transmission zero's location

Fig. 1 shows a capacitor C connected to a resonator in either parallel or series. The simple BVD model predicts that when C is connected in parallel (see Fig. 1(a)), the resonance frequency f_r is unchanged from the intrinsic value of the resonator, whereas the anti-resonance frequency changes from the intrinsic value f_a to f_a' as,

$$f_a' = f_a\sqrt{1-\frac{1}{\gamma+1}\cdot\frac{C}{C_0+C}}\ , \tag{1}$$

where C_o and γ ($=((f_a/f_r)^2-1)^{-1}$) are the clamped capacitance and the capacitance ratio of the resonator, respectively. On the other hand, when C is connected in series as shown in Fig. 1(b), the anti-resonance frequency is unchanged, whereas the resonance frequency changes from f_r to f_r' as,

$$f_r' = f_r\sqrt{1+\frac{1}{\gamma}\cdot\frac{C_0}{C_0+C}}\ . \tag{2}$$



(a) parallel connection (b) series connection

Fig.1 Connection of capacitor to resonator.

The change in f_r and f_a shown in Fig. 1 suggests that employing the filter topology shown in Fig. 2, one would be able to change the location of lower passband edge by C_{pn} attached to the parallel arms. Similarly, the upper passband edge is controlled by C_{sn} in the series arms. Hence, the center frequency of the filter could be tuned continuously provided that both C_{pn} and C_{sn} are properly chosen.

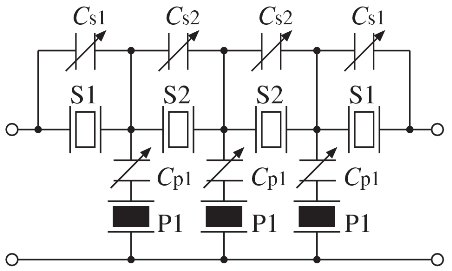


Fig.2 Configuration of tunable ladder-type filter.

The discussion clearly indicates that the tunable frequency range is limited by γ of the resonators employed; the resonators on a small γ substrate such as a Cu-grating/15°YX-LiNbO$_3$ (15-LN) substrate structure[3] is most effective in an increased tunable range.

Performances of the filter shown in Fig. 2 were investigated by simulation. Resonators and capacitors used in the simulation are those shown in Table I. The Q factors of the resonators and the capacitors were assumed to be 400 and 50, respectively, and γ was set at 3.3, a typical value for SAW resonators on the Cu-grating/15-LN substrate structure.

Table I. Design parameters.

(a) Resonators

	Resonance frequency [MHz]	Clamped capacitance [pF]
S1	913	3.2
S2	913	1.6
P1	783	8.0

(b) capacitors

	Design A	Design B	Design C
C_{s1} [pF]	7.5	4.0	2.1
C_{s2} [pF]	3.7	2.0	1.1
C_{p1} [pF]	14.5	7.2	3.3

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Fig. 3 shows the simulated result. It is seen that the center frequency is tuned over a range of +/- 18 MHz by changing the capacitances without badly affecting the passband and transition-band responses.

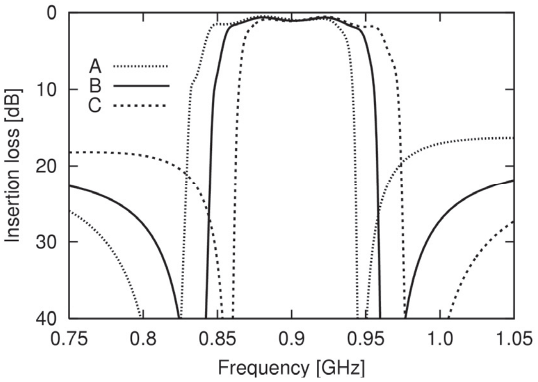

Fig.3 Simulated center frequency shift.

It should be noted here that the lower and upper passband edges can be controlled independently by changing C_{pn} and C_{sn} appropriately. Fig. 4 shows such an example; if C_{pn} is kept at constant, the upper passband edge changes with C_{sn} while the lower edge remains unchanged.

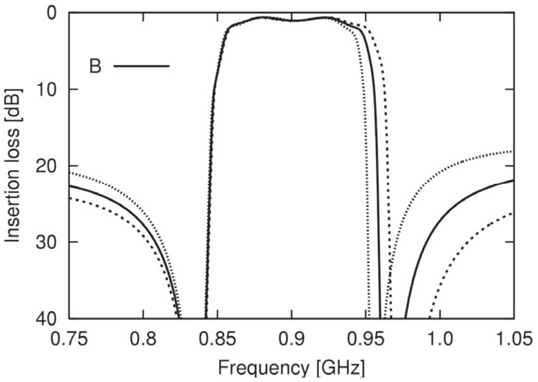

Fig.4 Control of upper passband edge.

3. Experimental verification

Two SAW filters with the configuration shown in Fig. 2 were fabricated on the Cu-grating/15-LN substrate structure, where the resonator parameters are those shown in Table I(a), and C_{pn} and C_{sn} are shown in Design B and C (see Table I(b)).

Fig. 5 shows the microscope image of the fabricated filter. IDTs resonating at 1,120 MHz were used as the capacitors.

Fig. 6 shows the measured frequency response. The overall result is in good agreement with the simulation. However, slight deterioration in the out-of-band rejection is observed, which is believed to be caused by the resonance of the IDT capacitors. It is concluded that the proposed method is one of the solution methodologies for developing tunable filters.

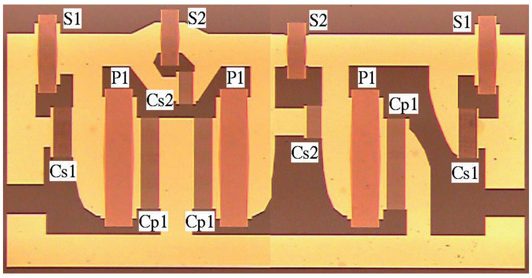

Fig.5 Microscope image of fabricated filter.

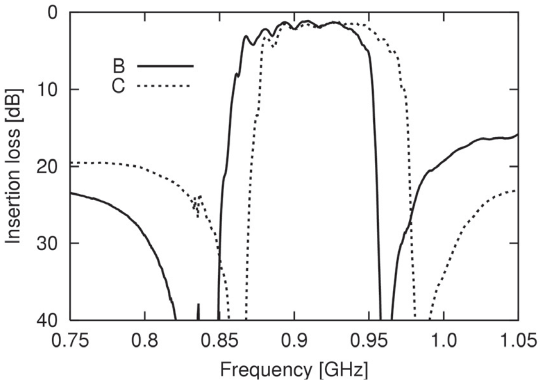

Fig.6 Fabricated device response.

4. Conclusion

This paper proposed a method of developing tunable ladder-type acoustic filters. The filter topology, in which capacitors are newly connected to respective resonators, was discussed both theoretically and experimentally. The next step is to develop practical tunable filters by integrating MEMS-based varicaps with SAW resonators.

Acknowledgment

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