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Ultra-Wideband Longitudinally Coupled Resonator Filters On Lithium Niobate Using Periodically Slotted SiO_2 As Acoustic Coupler

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1. Introduction

Wideband and high-frequency acoustic filters are in great demand for 5G use, especially for those new frequency bands with extremely large bandwidths (13%~24%) in sub 6 GHz.

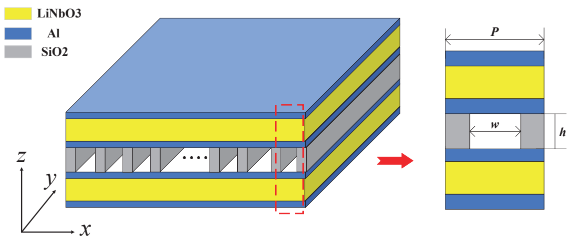
Longitudinally coupled resonator filters (LCRFs) are attractive because they offer wider bandwidth, smaller size and better out-of-band rejection than those with ladder and lattice filters using one-port resonators. LCRFs composed of $LiNbO_3$-based thickness shear BAW resonators (TSBARs) [1-2] seem promising because not so small acoustic impedance Z_a is required for the coupling layer[1]. The authors indicated that flat passband with fractional bandwidth more than 24% can be achievable when SiOC is used as the coupler[3].

This paper discusses applicability of periodically slotted SiO_2 as the coupler for ultra-wideband LCRFs. The simulation results show that -3 dB fractional bandwidth more than 32% can be achievable by employing lower-order three resonances.

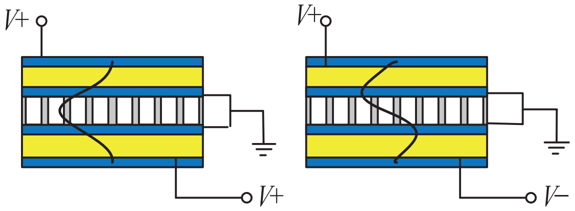
2. Basic operation design

Fig. 1(a) depicts the configuration of TSBAR-based LCRF under concern, where two -18°YX-$LiNbO_3$ plates of 1 μm thickness with Al electrodes of 0.1 μm thickness are stacked vertically. Periodically slotted SiO_2 is sandwiched in between these resonators as the coupler. Here the slots are aligned parallel to the y-axis and assumed to be vacuum. Note that when the slot period P is much smaller than the lateral wavelength, the slotted SiO_2 looks like a uniform layer, and its properties are controlled by h and w/P where h and w are the SiO_2 thickness and width, respectively.

Let us consider the case when two outer electrodes are connected to the input and output ports while two inner electrodes are short-circuited and grounded. In this situation, these two resonators are acoustically coupled but electrically isolated. The resonance modes are categorized into two types: even and odd modes. They can be excited and detected selectively by applying voltages to two electrical ports as shown in Figs. 1(c) and (d).



(a) bird's view (b) cross-sectional view



(c) even mode (d) odd mode

Fig. 1 LCRF configuration under concern.

First, the unit cell (see Fig. 1(b)) is analyzed by the periodic 2.5D FEM, where the periodic boundary condition is applied to both the x- and y-directions and P is set very tiny (10 nm) at first.

Fig. 2 shows the calculated admittances for even and odd modes Y_e (blue) and Y_o (red) when the h and w/P are set at 800 nm and 0.8, respectively. Two even modes and one odd mode exist in the frequency range.

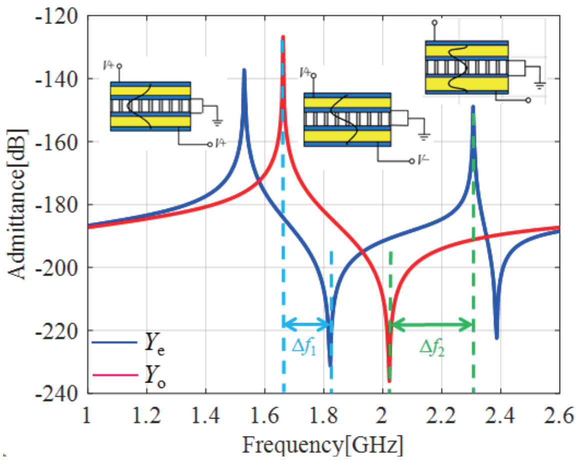


Fig. 2 Admittance of even and odd resonances

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3. Coupler design

Basic design principle for multi-mode resonator filters is (a) to adjust the resonance f_{ro} of odd mode to coincide with the anti-resonance f_{ae} of even mode and/or the resonance f_{re} of even mode to coincide with the anti-resonance f_{ao} of odd mode, and (b) the clamped capacitance C_0 of the resonators is close to $1/2\pi f_r R_0$, where R_0 is the circuit impedance[4].

Here we define (a) Δf_1 as the separation between the anti-resonance frequency of the first-order even-mode and the resonance frequency of the first-order odd-mode and (b) Δf_2 as the separation between the anti-resonance frequency of the first-order odd-mode and the resonance frequency of the second-order even-mode (see Fig. 2).

Fig. 3 shows how Δf_1 and Δf_2 change with h and w/P. It is seen that Δf_1 decreases monotonically with w/P and increases with h while Δf_2 exhibits opposite dependencies. Thus, both Δf_1 and Δf_2 can be set zero when h ~799 nm and w/P~0.76.

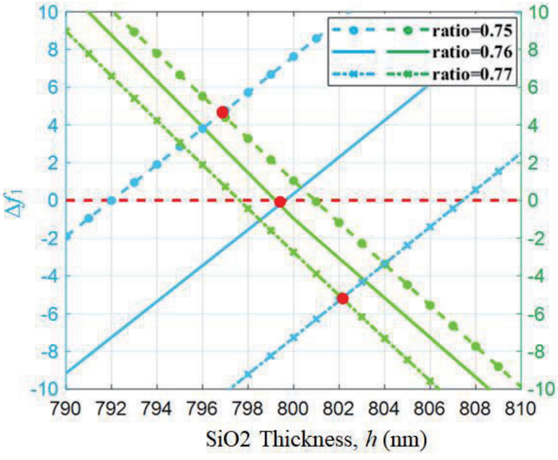

Fig.3 Variation of Δf_1 and Δf_2 with h and w/P.

Fig. 4 shows the Y_e and Y_o of properly designed LCRF. It is seen that Δf_1 and Δf_2 are at 1.667 GHz, and 2.029 GHz, respectively, and k^2 of these three resonances are estimated as circa 24.6%, 18.4% and 36.6%, respectively.

Fig. 5 shows the transfer function S_{21} of the designed filter. The passband is extremely wide, and the bandwidth is about 600 MHz which corresponds to the -3 dB fractional bandwidth of 32%, which is wider than the requirement of N77 (24%). A spurious peak is seen at 2.5 GHz, which is due to the third-order even mode (see Fig. 4).

The authors also investigated influence of P to the device performances. The result indicated that P should be set lower than 1.2 μm to locate spurious modes caused by the Bragg reflection in the coupled layer far from the main resonance.

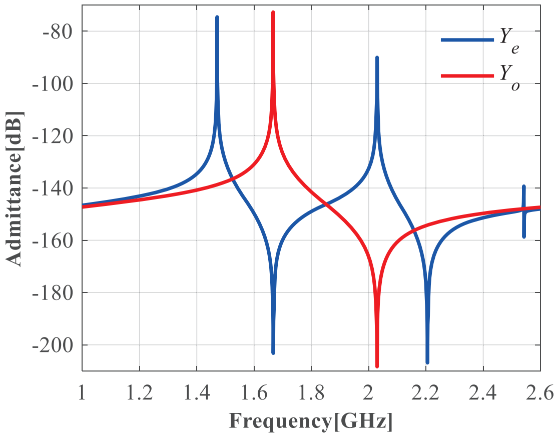

Fig. 4 Y_e and Y_o of the designed LCRF

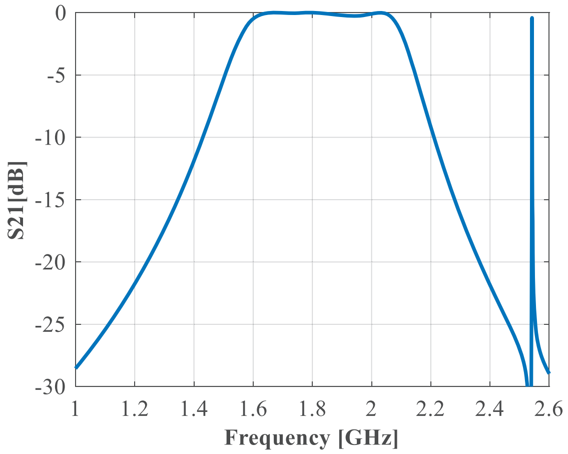

Fig.5 Calculated transfer function S_{21}.

4. Conclusion

This paper demonstrated applicability of periodically slotted SiO_2 as the coupler for ultra-wideband LCRFs. It was shown that -3 dB fractional bandwidth more than 32% is achievable by employing lower-order three resonances.

Acknowledgment

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References

1. M. Gorisse, et al., Proc. IEEE Freq. Contr. Symp. (2019) 10.1109/FCS.2019.8856017
2. T. Wu, et al, Jpn. J. Appl. Phys., **60**, 7 (2021) SDDC06.
3. W. Li, et al, Proc. IEEE. Ultrason. Symp. (2022) 10.1109/IUS54386.2022.9957983
4. J. Liu. et al, IEEE Trans. Ultrason. Ferroelectr. Freq. Contr., **61**, 5 (2014) pp. 881-885.