Double–Resonance SAW Filters

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1. Introduction

We study a surface acoustic wave (SAW) device with hiccup-type double resonance (DR) on leaky substrates. Similar device previously studied [1] showed poor performance due to loss in metallized gaps.

We present a novel SAW filter structure that features

- Narrow bandwidth (BW) (1..2%) on leaky-wave subtrates
- Low insertion loss (IL) (1...1.5 dB), steep filter skirts
- Unbalanced-balanced (balun) operation, excellent characteristics

2. Double Resonance Physics

A. Double–Resonance Structure

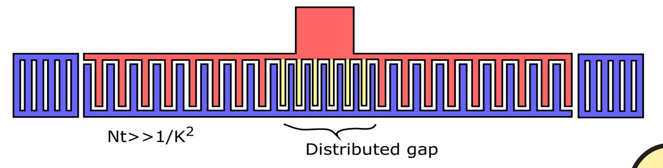

Fig. 1: 1-port double resonance device. Yellow fingers constitute the distributed gap.

Resonator structure:

1. leaky-wave substrate
2. distributed gaps
3. long transducers, N>>1/K²

- **Narrow aperture** reduces resistive losses
- **Distributed gap** reduces propagation loss and conversion to BAW [2]
- Compared to standard CRF (short IDTs, metallized gaps), SAW energy is concentrated in the "gap" region (see Fig. 3)

⇒Losses in the gap must be minimized to ensure desired performance. Previous experiments with metallized gaps were not successful [1].

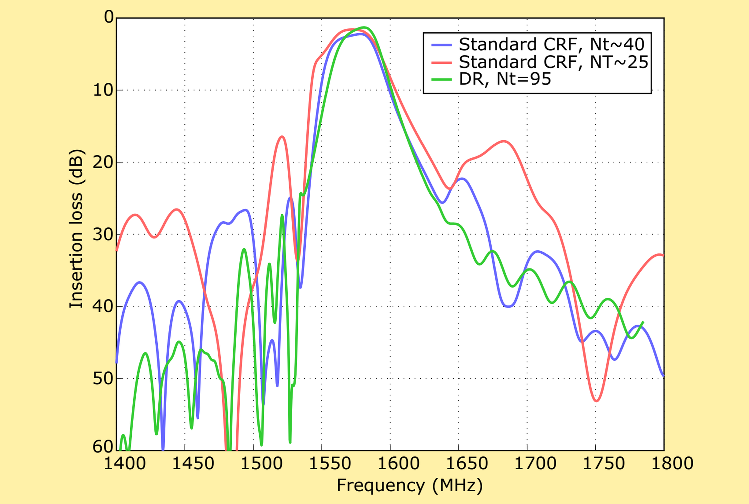

Fig. 2: COM simulations of standard 2-IDT CRFs and 2-IDT double-resonance filter.

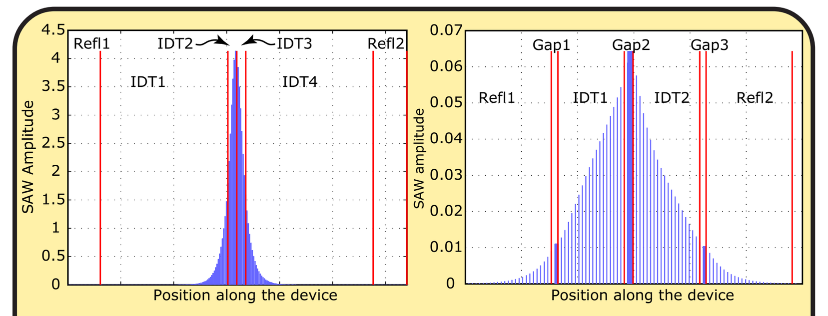

Fig. 3: Simulated (COM) amplitude distribution along 2-IDT device: (a) double-resonance filter (95 fingers), (b) conventional CRF (20 fingers).

B. Resonances in the DR Structure

Two independent resonances arise in the structure (Figs. 4-6):

1. "main" resonance in long IDTs
2. "side" resonance in short IDTs (distributed gap)

- Long IDTs have strong reflectivity ⇒ SAW is transmitted only through the resonance in the gap

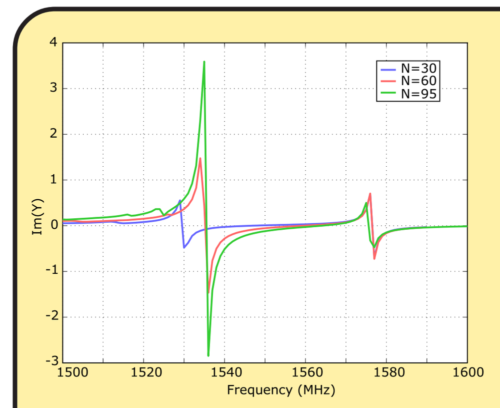

Fig. 4: Long IDTs determine the strength of main resonance. FEM simulation.

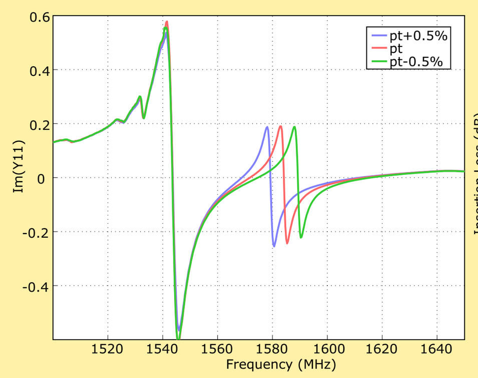

Fig. 5: Pitches of short IDTs determine the position of side resonance. Experimental result.

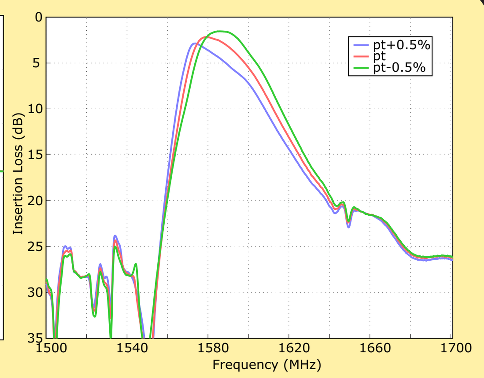

Fig. 6: Effect of short IDT pitch on 2-IDT filter response. Experimental result.

Self-matching (Fig. 7):

- f_{ar} of main resonance coincides with f_0 of side resonance
- Main resonance acts as matching inductance for side resonance

Conditions for self-matching:

1. $K^2 \approx \frac{|\kappa|}{\pi}$
2. N of long IDTs and pitch of short IDTs appropriately chosen

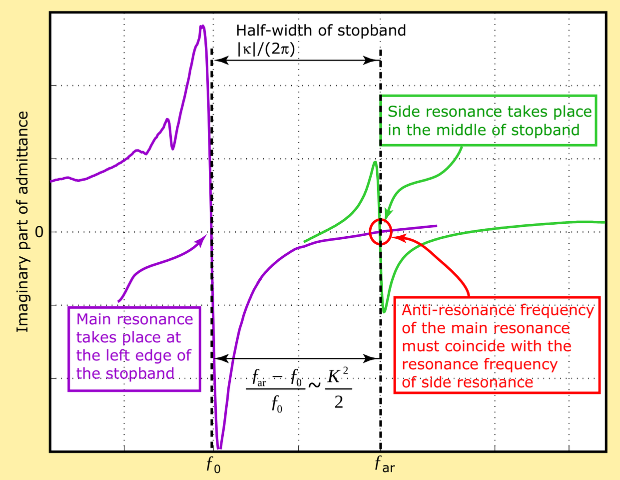

Fig. 7: Self-matching of the side resonance in DR structure.

C. Advantages of the DR Structure

- High-Q side (hiccup) resonance on leaky-wave substrate
- Self-matching of the side resonance reduces loss
- Narrow-bandwidth devices on leaky-wave substrates
- Improved suppression on the high-f side of passband

3. Experimental Results of DR Filters

- Substrate: 42°-$LiTaO_3$ (leaky-wave)
- f_0=1575 MHz (experimental curves may be shifted)
- Specifications are for a narrow-band GPS filter

A. 2–IDT, Single–Ended Filter

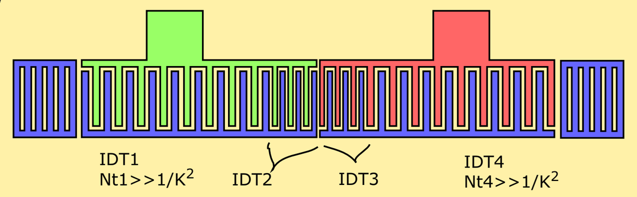

Fig. 8: Topology of 2-IDT DR filter.

Aperture (μm)	110
Fingers in IDT1 and IDT4	95
Fingers in IDT2 and IDT3	7
System impedances (Ω)	50/50
Minimum IL (dB)	1.7
Absolute 2.5-dB BW (MHz)	21 (1.3%)
Relative 3-dB BW (MHz)	29 (1.8%)

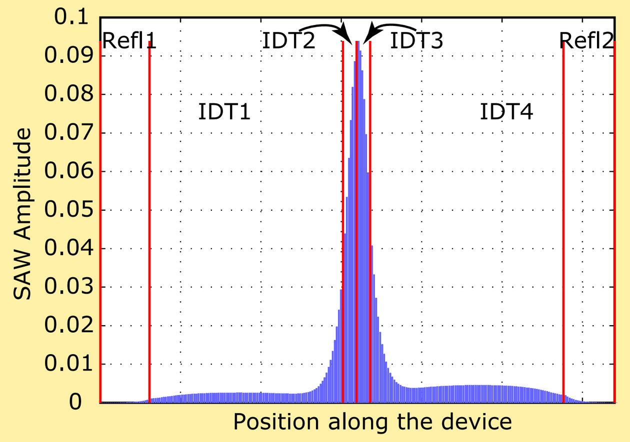

Fig. 9: Simulated (COM) amplitude distribution along the 2-IDT DR filter.

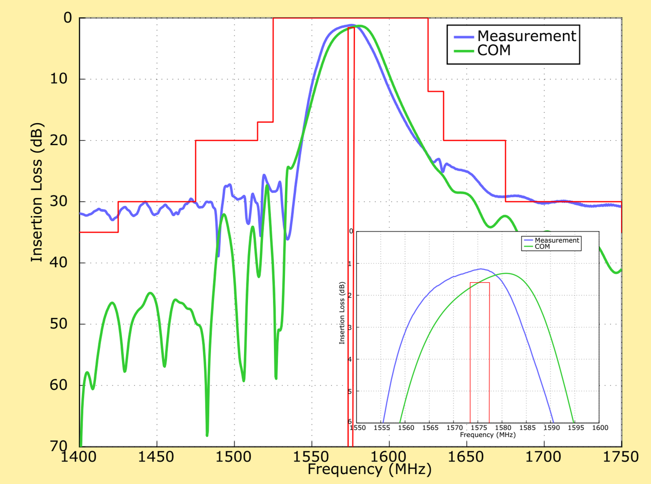

Fig. 10: Frequency response of 2-IDT DR filter: simulation and measurement. Measured curve matched with 0.8 pF || input and output.

B. 3–IDT, Balun Filter

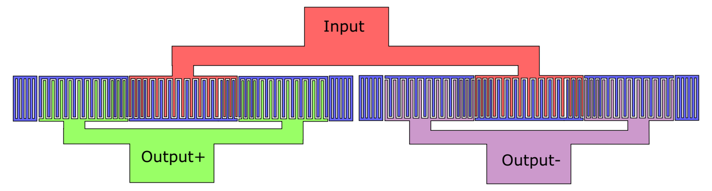

Fig. 11: Topology of 2-track, 3-IDT balun DR filter.

Aperture (μm)	42 / track
Fingers in side IDTs	95
Fingers in middle IDT	145
Fingers in short IDTs	7
System impedances (Ω)	50/100
Minimum IL (dB)	1.07
Absolute 2.5-dB BW (MHz)	25 (1.6%)
Relative 3-dB BW (MHz)	36 (2.3%)
Phase balance (°, 2.5-dB band)	1...3.5
Amplitude balance (dB, 2.5-dB band)	0...2.1

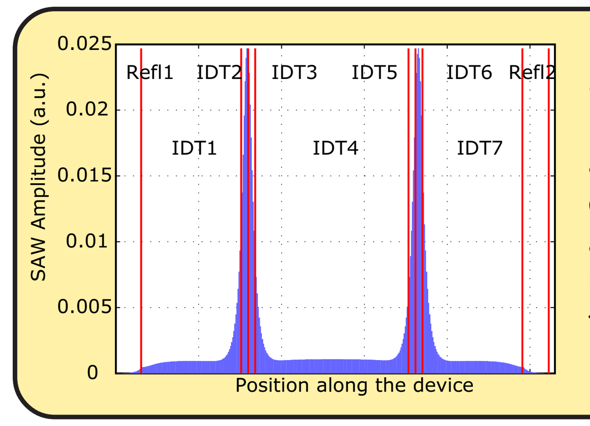

Fig. 12: Simulated (COM) amplitude distribution along the 3-IDT filter track.

Frequency Response of 3–IDT Filter

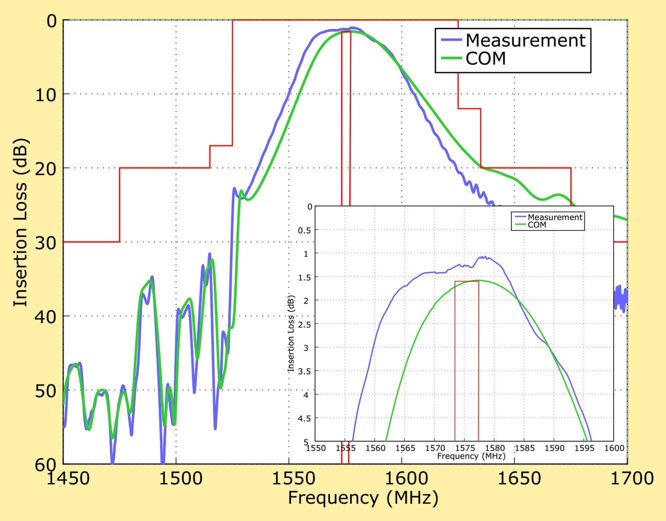

Fig. 13: Frequency response of 3-IDT filter: measured response of 2-track balun device, simulated response of 1-track, single-ended device. Measured curve

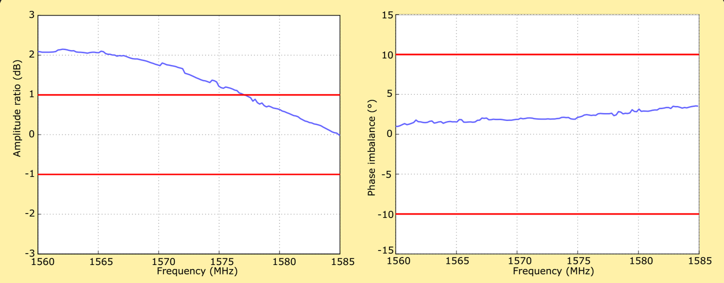

Fig. 14: Measured amplitude (left) and phase (right) balance of 3-IDT balun filter.

- Excellent agreement between simulation and measurement
- Flat balance characteristics
- Narrow band, low insertion loss

4. Discussion

- Novel device type on leaky-wave substrates
- Operation principle different from standard CRF
- Distributed gaps are essential to avoid loss in the gap
- Excellent for applications demanding narrow band (1..2%) and low loss

Acknowledgement

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References

[1] V. P. Plessky, T. Thorvaldsson, and S. Kondratiev, "Otsikko tähän", in *Proc. of the 1996 IEEE Ultrasonics Symposium*, pp. 25-28.
[2] J. Meltaus, V. P. Plessky, S. Härmä, and M. M. Salomaa, "Low-Loss, Multimode 5-IDT SAW Filter", *IEEE Trans. Ultrason. Ferroelect. Freq. Contr.* 52 (6), pp. 1013-1019 (2005).