# Compact Low Pass Filter with Ultra-Wide Pass and Stopbands Using Stepped Impedance Resonators and Novel Techniques

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***Abstract*** **— The design procedure of a compact ultra-wideband (UWB) stepped impedance resonator (SIR) low pass filter (LPF), is presented in this paper. A SIR LPF with 15.5 GHz cutoff frequency miniaturized by meander line technique is designed and it is shown that offsetting the stepped impedance resonators, as well as indenting the tap location greatly improve rejection bandwidth. By cascading multiple filters the passband is increased while maintaining good rejection bandwidth. The proposed filter is simulated in EM software, fabricated, and tested on a high dielectric ceramic. The results show an improved stopband and passband performance compared with similar topologies with a drastic reduction in filter size.**

***Keywords*** **— LPF, Passive Circuits, Stepped Impedance, UWB.**

## I. INTRODUCTION

Filters are important parts of any microwave transmit/receive system. As technology continually reduces the size of many systems, compact size and high performance microwave filters are in high demand. Designs currently push for LPF with wider passbands in order to reduce cost by reusing filters in multiple channels. Stepped impedance resonators (SIR) are one way to dramatically reduce size [1]. Many common filter topologies (e.g. λ/2, λ/4 resonators) have spurious or harmonic re-entrances between $2f_o$ and $3f_o$, where $f_o$ is center frequency. At frequencies above 10GHz λ/2 designs without vias are of interest as they eliminate error caused by via driller tolerance. This makes suppression of 2$^{nd}$ harmonic of interest. Many systems require attenuation of these re-entrances. Implementation of a low pass filter with wide passband to attenuate these harmonics becomes important, but improved rejection characteristics with wide passband generally comes with the price of increased insertion loss (IL) and increased size [2]. Wider passband also increases the re-entrance of harmonics, further increasing the desired stopband. This makes ultra-wide stopband filters of compact size attractive for communication systems. Stepped impedance resonators, in addition to being compact, also suppress up to 3rd order harmonics. Characterization equations are derived for T-Shaped SIR in recent literature [3]. The T-Shaped equations in [3] are modified to model a SIR of type shown in Fig. 1.

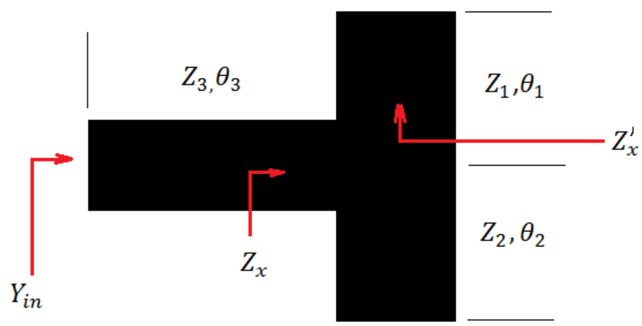


Fig. 1. Simple stepped impedance resonator.

Modifying the SIR to have $Z_1$=$Z_2$, $\theta_1$=$\theta_2$, and to have $Y_{in}$ = 0 at passband center frequency when electrical lengths are as shown in Fig. 1 we must have

$$\frac{-j\,Z_x \tan\theta_3}{Z_3} = 1 \tag{1}$$

Where $Z_x$ is the parallel combination of two identical open circuit stubs of impedance $Z'_x$, where $Z'_x$ is

$$Z_x' = -jZ_1 \cot\theta_1 \tag{2}$$

And

$$Z_x = \frac{Z_1 \cot\theta_1}{2} \tag{3}$$

Now substituting (3) into (4)

$$\frac{-jZ_1 \cot\theta_1 \tan\theta_3}{2Z_3} = 1 \tag{4}$$

The filter designer can now set the limits on $Z_1$ and $Z_3$, and has two degrees of freedom to vary $\theta_1$ and $\theta_3$. A novel technique of offsetting SIR as shown in Fig. 2 can increase the rejection bandwidth [4]. By tapping the high to low impedance transition in addition to offsetting the SIR the rejection bandwidth can further be increased. By adjusting the SIR offset distance and tap depth (See Fig. 3) the rejection roll off, as well as, rejection bandwidth are tuned for

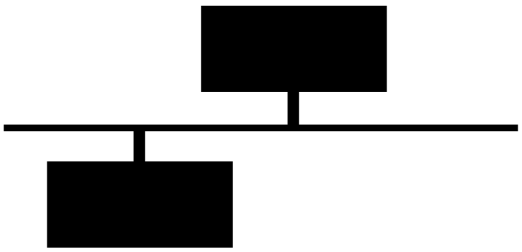

Fig. 2. Offset stepped impedance resonators (SIR).

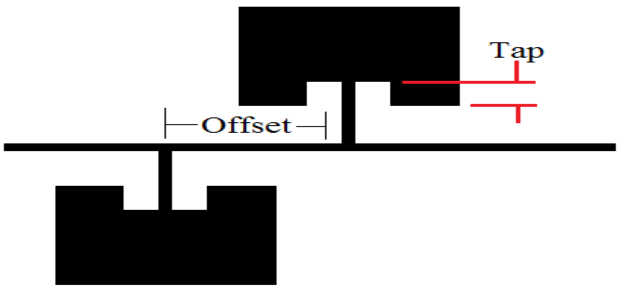


Fig. 3. Offset and tapped SIR.

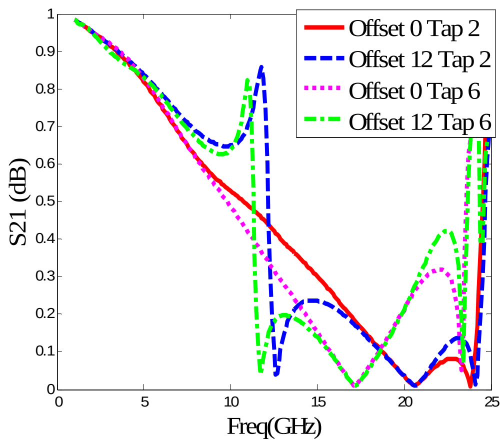


Fig. 4. Effects of offset and tap depth.

requirements based on filter design criteria. As the SIR offset is increased the rejection roll off steepens. Varying tap depth can increase or decrease the rejection bandwidth. Figure 4 displays a brief summary comparing the effects of resonator offset and tap distances. For example, the red curve corresponds to an offset of 0 mils and a tap depths of 2 mils.

## II. Filter Design

Expanding on previously published work, and the above mentioned tuning techniques a compact high performance LPF is designed [5]. These design techniques provide a 3x reduction in size compared to LPF using only SIR (Similar layout to Fig. 2) required to gain the same performance [5].

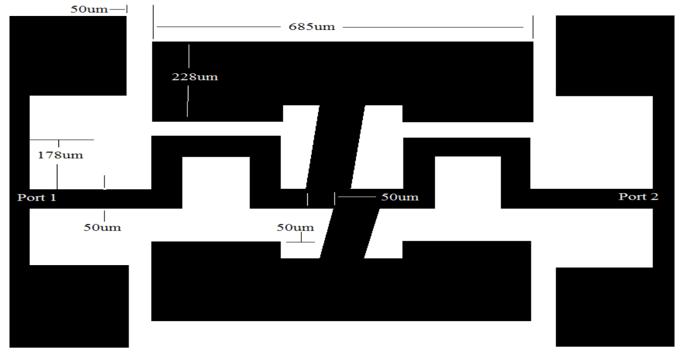


Fig. 5. LPF topology.

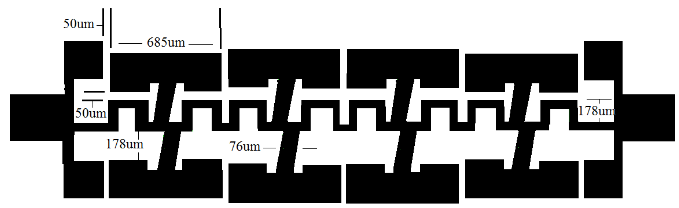


Fig. 6. Cascaded LPF topology.

One can see how the steepness or roll-off and passband width are affected. After selecting the corresponding $Z_1$,$Z_3$, $\theta_1$ and $\theta_2$ values tuning techniques yield a filter topology illustrated in Fig. 5. Using the filter topology the designer can treat an individual filter as a "pole", and by cascading multiple filters increase the filter order, and obtain improved rejection characteristics, as will be discussed in the next section. Figure. 6. displays the topology of four cascaded filters. The filter has tap depths of 50 µm, SIR offset of 50 µm, and the spacing between adjacent filters is 50 µm. These values are post-optimization.

## III. Simulation Results

Designing a filter utilizing the techniques presented in the previous sections and then cascading filters to further improve performance provides the final topology in Fig. 6. The filter is designed and simulated on Dielectric Laboratory's PG material. PG has an $\varepsilon_r$ value of 13.2 with a thickness of 0.381mm for this design. It is simulated in a Sonnet EM environment [6]. Figure 7 compares the simulated results of the single filter of Fig. 5 vs. the multistage in Fig. 6. The multistage filter provides much greater rejection than the single filter. The harmonic around 30GHz in the cascaded scenario is caused by a higher order box mode, and is predicted by Sonnet Software. It is noted that the final multistage filter simulates a 3dB point 500MHz higher than the desired 15.5GHz. This is done deliberately in hopes of accounting for a post manufacturing shift.

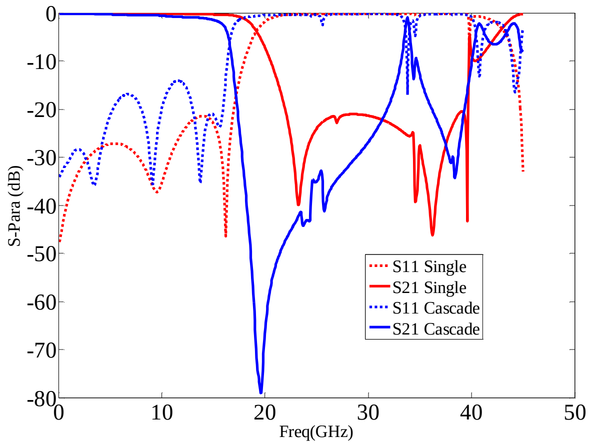


Fig. 7. Single vs cascade filter performance.

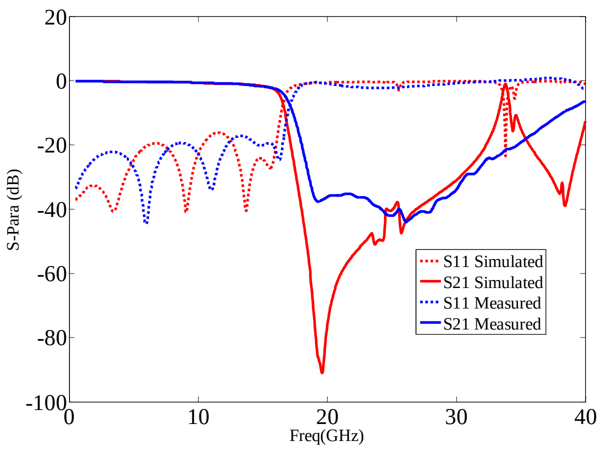


Fig. 8. Measured vs simulated comparison.

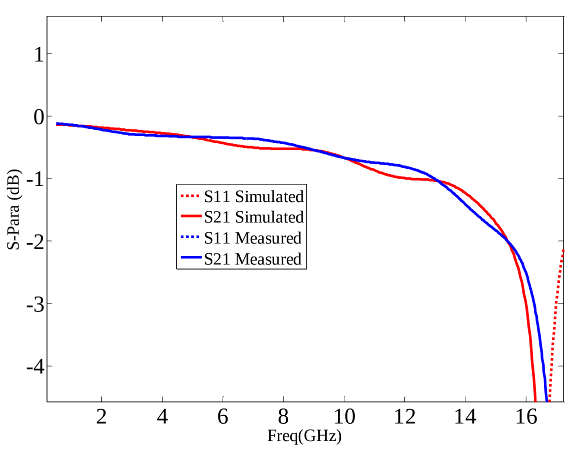


Fig. 9. Passband slope and ripple.

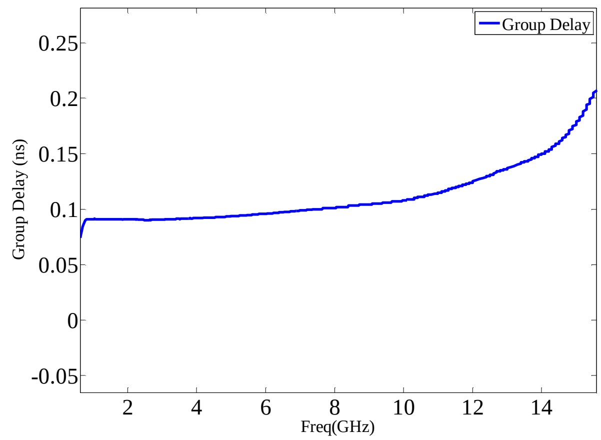


Fig. 10. Passband group delay.


Fig. 11. Size reference of manufactured filter.

## IV. Measured Results

The filter's measured performance is compared with simulated in Fig. 8. A zoomed view of the passband and group delay plot are shown in Fig. 9. and Fig. 10. respectively. Figure 11 displays a photo of the manufactured filter. From Fig. 8. one can see good agreement between measured and simulated results, and that the Sonnet box resonance was in fact just that. The filter maintains better than -20dB rejection out through 35GHz. Looking at Fig. 9. there is ~1.9dB passband slope with better than 0.4dB ripple. The group delay in Fig. 10. is ~0.2ns max throughout passband.

## V. CONCLUSION

After investigation of novel tuning techniques for low pass filters, a novel design for a compact ultra-wide pass and stopband low pass filter is realized. The filter passes frequencies through 15.5GHz, and improves rejection to −20dB through 35GHz. The manufactured filter is compact in size, utilizes tapped and offset SIRs, and is surface mount compatible. It has results that agree well with simulations.


## ACKNOWLEDGEMENT

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