# A WIDE STOPBAND TAPPED SQUARE SPLIT RING STEPPED IMPEDANCE INTERDIGITAL BANDPASS FILTER

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*Abstract* — **In this paper, we present a new microstrip stepped impedance interdigital bandpass filter with tapped square split ring resonators (T-SSRR). The quarter wavelength stepped impedance resonators (λ/4-SIR) allow a higher $f_1/f_0$ ratio as compared with the conventional unit impedance resonator (UIR), thus extending the rejection band. Moreover, the T-SSRR which is shown to be a wide band bandstop filter with three transmission zeros, suppress the spurious passband and extend the stopband further. To verify the proposed structure usefulness, two prototype 3rd order λ/4-SIR bandpass filters, with and without T-SSRR, have been designed at 525MHz with 6.5% bandwidth. Demonstrated is a good spurious suppression of -30dB at $f_1$, and the rejection band is wider than $5.8f_0$, with the fundamental passband almost unaltered.**

*Index Terms* — Microstrip, microwave filter, spurious response, square split ring resonator, stepped impedance resonator.

## I. INTRODUCTION

WIDE STOPBAND and high selectivity microwave filters are important components in the RF front-end of wireless communication system. Coupled-line structures are commonly used because of their low cost, and easy synthesis. But it is well-known that spurious responses locate at harmonic frequencies of these structures [1]-[2], which seriously degrade the filter performance. One of the traditional coupled-line structures, the parallel-coupled-line, has received special attention to overcome the problem of spurious responses in recent years [3]-[5]. The stepped impedance resonator bandpass filter in [3] maximized the ratio between higher order and fundamental resonance using half wavelength SIR, with tapped-line input two transmission zeros can be created to suppress the higher order resonance successfully. In [4], a substrate suspension method has been proposed to equalize the unequal even and odd mode phase velocity, so the unwanted passband at $2f_0$ can be suppressed completely. Periodic grooves structure has also been reported to meet the Bragg condition to overcome the previously mentioned limitations [5].

Another traditional coupled-line structure, the interdigital, takes the advantage of compact size and easy orientation as compared with parallel-coupled-line. The resonators are quarter wavelehgth with one open circuit end and one short circuit end in an alternative way, and the size is just about one-third of the previous parallel-coupled structure. Because of the groundings, this structure is 2nd harmonic free, and the first spurious passband locates at $3f_0$. However, the studies on improving this filter performance are rare [6]-[7]. The work in [6] suppressed this spurious passband by using defected ground structure (DGS) while the unequal length embedded spurlines in [7] was able to create two transmission zeros for stopband extension. With SIR applied, good rejection level of -30dB has been obtained up to $4f_0$.

In this work, we aim at designing stopband improved interdigital bandpass filter, by using λ/4-SIR [8] and T-SSRR together. Using SIR, $f_1/f_0$ can be tuned by changing the ratio of the low impedance and high impedance sections. The fundamental and first spurious are relocated to low and high frequencies respectively and thus a wider stopband can be obtained. On the other hand, split ring resonator can be applied to suppress the spurious response to wider the rejection band. Circular split ring resonator has been recently discussed for bandpass and bandstop filter design respectively [9]-[10]. Here, new tapped square split ring resonator (T-SSRR) is used. It is shown the response of this new structure is a wide bandstop one with three transmission zeros. Using this element at the tapped-line input and output of the filter, together with SIR, wide stopband performance can be achieved.

Besides this introductory section, section II analyzes the basic characteristic of SIR and T-SSRR, and presents the new filter structure in interdigital architecture using these two techniques. Section III shows the simulation and experimental results. The conclusion is then drawn in Section IV.

## II. FILTER DESIGN

### A. SIR

Fig. 1 shows a λ/4-SIR, which is a quarter wavelength resonator with one low impedance section and one high impedance section, one of its terminals is short circuit and the other end is open circuit. Comparing with the conventional UIR, SIR allows the tuning of fundamental and higher order resonances by the length and width of the low impedance and high impedance sections. The impedance ratio $R$ is defined as

$$R = \frac{Z_2}{Z_1} \tag{1}$$

With the input admittance of this resonator given by [8]

$$Y_{in} = jY_2 \frac{Y_2 \tan\theta_1 \tan\theta_2 - Y_1}{Y_2 \tan\theta_1 + Y_1 \tan\theta_2} \tag{2}$$

it can be found that maximum ratio of the first spurious $f_1$ to the fundamental $f_0$ is obtained when $\theta_1 = \theta_2 \equiv \theta_0$, and the resonator ratio is calculated as

$$\frac{f_{1SIR}}{f_{0SIR}} = \frac{\pi}{\tan^{-1}\sqrt{R}} - 1 \tag{3}$$

when $R = 1$, $f_{1SIR} = 3f_{0SIR}$, so the first spurious response of a conventional interdigital bandpass filter locates at around $3f_0$. By tuning $R$, this resonanee ratio can be changed, it is greater than 3 when $R$ is lower than 1, and lower than 3 when $R$ is larger than 1. Moreover, the SIR resonance $f_0$ and $f_1$ normalized with respect to that of UIR are given by

$$\frac{f_{0SIR}}{f_{0UIR}} = \frac{4\tan^{-1}\sqrt{R}}{\pi} \tag{4}$$

$$\frac{f_{1SIR}}{f_{1UIR}} = \frac{4(\pi - \tan^{-1}\sqrt{R})}{3\pi} \tag{5}$$

Fig. 2 graphically displays $f_{0SIR}/f_{0UIR}$ and $f_{1SIR}/f_{1UIR}$ against $R$. It can be seen that as long as $R$ is less than 1, the SIR $f_0$ shifts to a lower frequency when eompared with that of the UIR while $f_1$ moves to a higher frequency value. As a result, the rejection band of filters using SIR can be greater than conventional UIR ones, and the smallest value of $R$ should be ehosen.

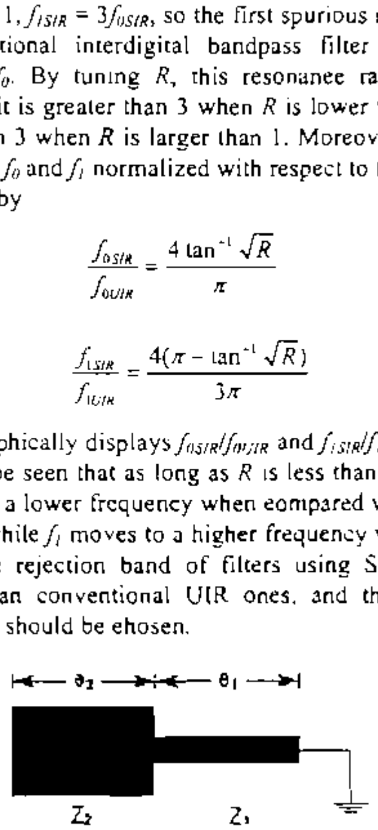


Fig. 1. Structure of (a) λ/2-SIR, (b) Grounded λ/4-SIR

*B. T-SSRR*

Although SIR extends the rejection band, the spurious passband still exists. Also, there are upper and lower limits in the strip width depending on the substrate parameters, and the resolution of the fabrication process. In order to extend the stopband further, the spurious response must be suppressed. Here T-SSRR bandstop filter is introduced in Fig. 3. It consists of two square open loops, one at the outer and one in the inner with gaps at opposite direction, the width of the rings are the same and there is a 50Ω transmission line section with the rings as shown in the figure.

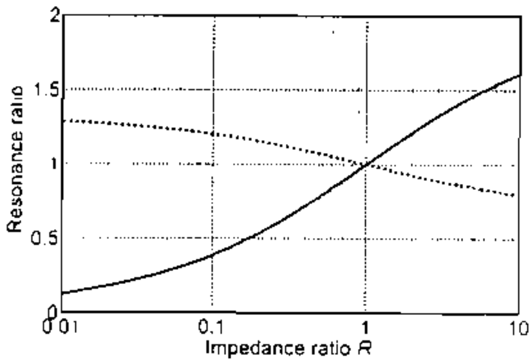


Fig. 2. Relationship between resonance and impedance ratios. $f_{0SIR}/f_{0UIR}$ (solid), $f_{1SIR}/f_{1UIR}$ (dot).

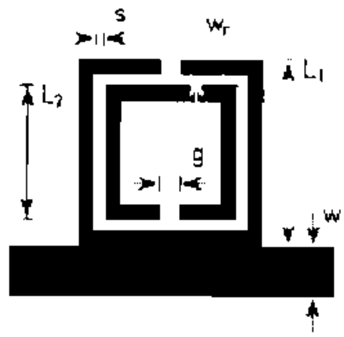


Fig. 3. Layout of proposed tapped square split ring resonator (T-SSRR).

As an example, the bandstop response of this new structure has been simulated using *IE3D* [11] with circuit dimensions as: $w$ = 3.526mm (50Ω), $g$ = 1.45mm, $w_r$ = 1.125mm, $s$ = 0.8mm, $L_1$ = 13.5mm, and $L_2$ = 9.65mm. The substrate employed has $\varepsilon_r$ = 3.38 and thickness = 1.524mm. The result in Fig. 4 clearly shows a bandstop response, three transmission zeros are observed at 2.31GHz, 2.84GHz, and 3.16GHz respectively. The 3dB frequencies are 2.2GHz and 3.2GHz, corresponding to a bandwidth of 37%. Sharp cutoffs, low return loss are seen at the cutting edge and stopband respetively, with low insertion loss below 1GHz, thus this structure is suitable for high order spurious suppression, such as $3f_0$ or higher.

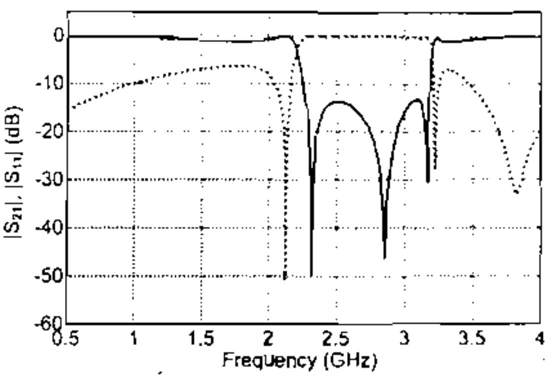


Fig. 4. Response of the T-SSRR: $|S_{21}|$ (solid) and $|S_{11}|$ (dot).

*C. Filter Topology*

The filter topology using λ/4-SIR and T-SSRR is illustrated in Fig. 5. Three λ/4-SIRs are arranged in interdigital architecture, it forms the main structure of a 3rd order bandpass filter. the fundamental and first spurious frequency can be estimated by Eq. (3)-(5), while the bandwidth is mainly controlled by the separation of the resonators. Furthermore, T-SSRR are cascaded at the input and output ports for spurious passband suppression. Using this new T-SSRR SIR interdigital structure, wide stopband and compact size filter is realized.

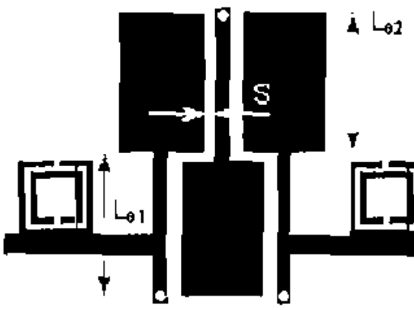


Fig. 5 Layout of T-SSRR λ/4-SIR interdigital bandpass filter

### III. SIMULATION AND MEASUREMENT

To examine the proposed structure, SIR filters with and without T-SSRR have been designed on Rogers RO4003 with substrate parameters given in Section II-B at $f_0$ = 525MHz with 6.5% fractional bandwidth, the attenuation of the rejection band should be better than -30dB. The groundings are provided by via holes. To avoid conductor overlapping and unwanted coupling, the low impedance section is slightly shorter than half of the total length with $L_{\theta 1} = 1.04L_{\theta 2}$.

To design the filter in Fig. 5, the SIRs without T-SSRR are first considered. The impedance ratio is $R$ = 0.29 with $L_{\theta 1} + L_{\theta 2}$ = 54.7mm, the spacing $S$ is 2.24mm to achieve 6.5% bandwidth. The simulated result from *IE3D* shows a center frequency at 525MHz with first spurious passband centered at 2.84GHz ($5.4f_0$) as in the dot line of Fig. 6. Compare with a UIR at 525MHz, this SIR achieve a length reduction of about 40%. Secondly, the T-SSRR are designed to suppress the spurious passband around $5.4f_0$, the dimension is same as the one introduced in Section II-B with the stopband from 2.2GHz to 3.2GHz. From the simulated results in Fig. 6, one can see that the spurious passband has been suppressed successfully. The peaks at $5.4f_0$ is lower than -40dB, with good rejection level of -30dB till 3GHz.

The measurement results are presented in Fig. 7, the center frequency shifts slightly to 517MHz and the bandwidth and insertion loss were measured to be 7.4% and less than -1.24dB respectively. The spurious response was suppressed to -30dB, and thus the rejection band of this filter is over 3GHz ($5.8f_0$). The difference between simulation and measurement may due to fabrication tolerance. The bandpass performance in Fig. 7(b) shows that the main passband with and without T-SSRR is almost the same. The measured performance of the filters are recorded in Table I.

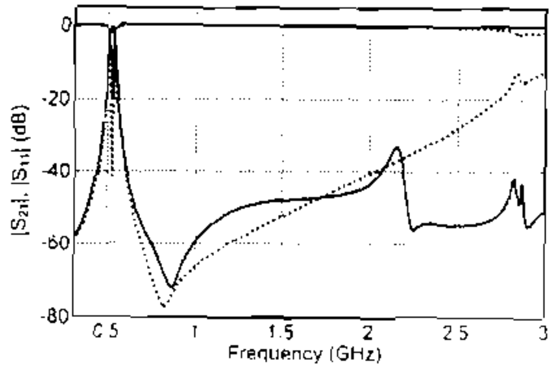


*Fig. 6. Simulated results of the λ/4-SIR interdigital bandpass filter (dot) and T-SSRR λ/4-SIR interdigital bandpass filter (solid).*

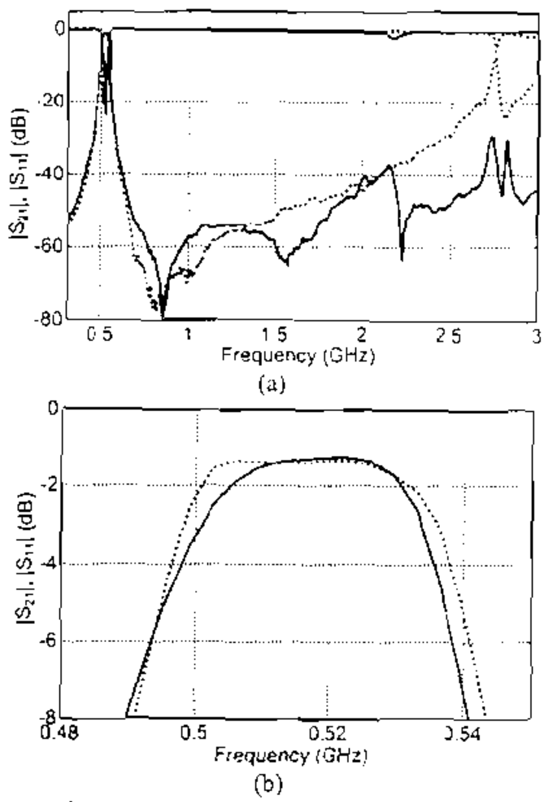


Fig. 7. Measurement results of the λ/4-SIR interdigital bandpass filter (dot) and T-SSRR λ/4-SIR interdigital bandpass filter (solid); (a) passband and stopband view and (b) passband view.

Shown in Fig. 8 is the photograph of the fabricated microstrip T-SSRR λ/4-SIR interdigital bandpass filter. The circuitry size is about 8×5.5cm². Comparing with a conventional 525MHz interdigital filter, this new structure offers a resonator length reduction of about 40%, and -30dB rejection band over $5.8f_0$.

TABLE I
MEASUREMENTS SUMMARY

| | SIR | SIR T-SSRR |
|---|---|---|
| $f_0$ (MHz) | 515 | 517 |
| Passband loss (dB) | -1.28 | -1.24 |
| BW (%) | 8.3% | 7.4% |

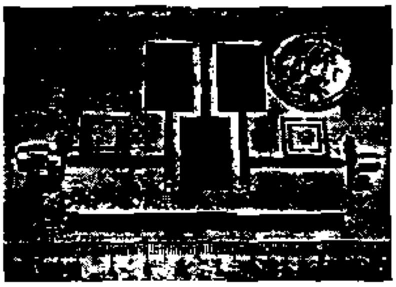

Fig 8. Photograph of the microstrip T-SSRR λ/4-SIR interdigital bandpass filter.

## IV. CONCLUSION

In this paper, a new T-SSRR λ/4-SIR interdigital bandpass filter has been proposed and tested successfully. The SIR extends the stopband by moving the fundamental and spurious resonance to a lower and higher frequency respectively. The three transmission zeros T-SSRR bandstop filter suppresses the spurious response and extends the rejection band significantly. A 3rd order filter centered at 525MHz has been designed, a wide -30dB stopband over $5.8f_0$ has been simulated and measured successfully


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