# Design of Tri-Band Filter Based on Stub Loaded Resonator and DGS Resonator

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***Abstract*—A tri-band bandpass filter using stub loaded resonator (SLR) and defected ground structure (DGS) resonator is proposed in this letter. The DGS resonator on the lower plane constructs the first pass-band, and the SLR on the upper plane forms the second and third pass-bands, in which a DGS loop is properly used to provide the coupling between the SLRs. The three pass-bands are combined together with a common T-shaped feed line, and a reasonable tuning method is adopted to tune the three pass-bands with smooth responses. A compact tri-band filter with three pass-bands centered at 2.45, 3.5, and 5.25 GHz is designed and fabricated. The measurement results agree well with the full-wave electromagnetic designed responses.**

***Index Terms*—Defected ground structure (DGS) resonator, stub-loaded resonator (SLR), tri-band filter, T-shaped feed line.**

## I. Introduction

To meet the increasing communication requirements, many wireless communication systems have been developed and widely used in people's daily life, such as GSM (800/900 MHz), WCDMA (2.1 GHz), WLAN (2.4/5.2 GHz) and Wimax (3.5 GHz). To incorporate two or more desired communication bands in a single unit and filter unwanted frequencies, filters with a multi-band response have attracted more and more interest in modern microwave filter design.

Many different methods on designing multi-band filters have been explored and reported. In [1], a dual-band BPF is achieved by cascading open-stub structures, and a dual-band response can also be achieved by embedding a resonator in another one, such as depicted in [2]. A widely used method for designing a multi-band filter is making use of multi-mode resonators, such as stepped impedance resonator (SIR) [3]–[6] and stub loaded resonator (SLR) [7]–[9]. The two-section SIR can achieve dual-band response by tuning its geometric parameters [4], [5], and the tri-section SIR is easy to determine the resonant frequencies of tri-band filter [5], [6]. With more design flexibility, SLR is also attractive in dual-band [7], [8] and tri-band [9] filter design. In [7], the open stub loaded SLR is presented and analyzed, with which a dual-band BPF is designed. And the short stub loaded SLR for WLAN application is analyzed in [8]. In [9], a tri-band filter using short and open stubs loaded resonator is presented, the three resonant modes are determined by the stub parameters.

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Except for the utilization of multi-mode resonators, another way is assembling several RF passages together [10]–[12]. In [10], cascaded multi-band resonators with proper coupling structure form the dual- and triple- bandpass responses. And a dual-band filter incorporating SIR and DGS resonator with the same feed structure is presented in [11]. In [12], the tri-band response is achieved by the SIR and a half-wavelength resonator, which are combined with the same feed structure.

In this letter, a tri-band filter achieved by combining two RF passages together is presented. The SLR forms the passage 1 with the 3.5/5.25 GHz pass-bands realized by its odd mode and even mode, respectively. The DGS resonator forms the passage 2 with a wide bandwidth pass-band at 2.45 GHz. Based on the geometric property, the three resonant frequencies can be designed independently, which facilitates the tri-band filter design. A common T-shaped feed structure is designed and applied to provide external couplings to the two passages. With the analysis and adjusting of the open ended stub, three smooth pass-bands are achieved. Finally, a compact tri-band filter is optimally designed, fabricated and characterized.

## II. Analysis of The Tri-Band Filter

The whole geometric structure of this filter is shown in Fig. 1. As depicted in this figure, the SLRs combined with interdigital feed lines form the RF passage 1, and the DGS resonators with parallel feed lines realize the RF passage 2. In the passage formed by SLRs, a DGS loop is used to provide a tight coupling between the even modes as well as that of the odd modes, respectively. It is seen from Fig. 1 that there is no cross-coupling between the SLR and the DGS resonator, and the coupling structure of this filter can be expressed as Fig. 2. The $R1$ and $R2$ in this figure represent the SLR and the DGS resonator, and the superscript $e$ and $o$ of the SLR denote the even and odd resonant mode, respectively. Due to the coupling property of this filter, the two passages are independent and can be analyzed separately.

With the feature of tuning the even mode without affecting the odd mode, the symmetrical SLR is widely used as the building block in multi-band filter design. In RF passage1, the SLR is used as the building block to realize a dual-band response. Detailed analysis has been accomplished in [7], which is based on even- and odd-mode analysis. In the SLR, the admittance $Y_1$ and $Y_2$ of the stub $L_1$ and $L_2$ are determined by the stub widths $W_1$ and $W_2$. In this letter, the even mode and odd mode resonant condition are expressed as

$$Y_{\rm in,odd} = \frac{Y_1}{j\tan(\beta_1 \cdot L_1)} = 0 \quad (1)$$

$$Y_{\rm in,even} = jY_1 \frac{2Y_1 \tan(\beta_2 \cdot L_1) + Y_2 \tan(\beta_2 \cdot L_2)}{2Y_1 - Y_2 \tan(\beta_2 \cdot L_1/2)\tan(\beta_2 \cdot L_2)} = 0 \quad (2)$$

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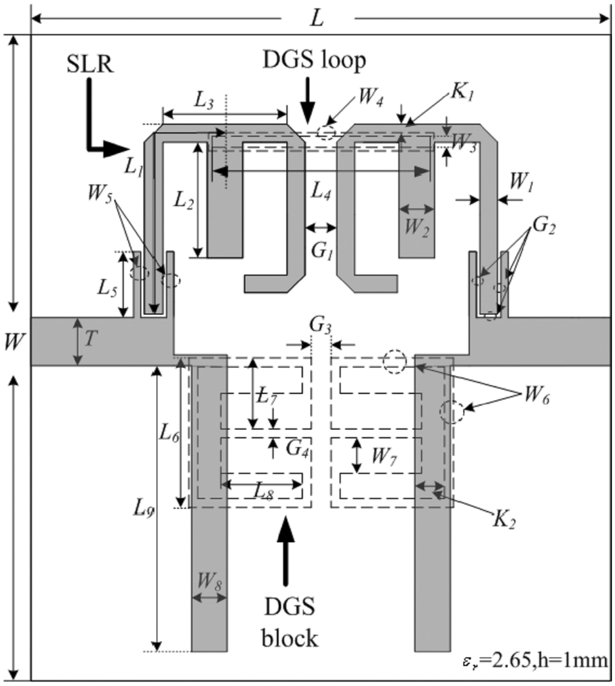


Fig. 1. Configuration of the proposed filter.

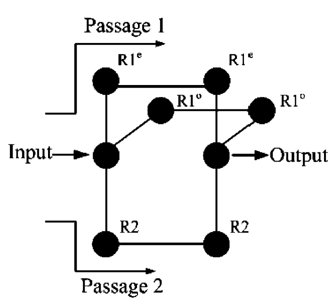


Fig. 2. Coupling structure of the proposed tri-band filter.

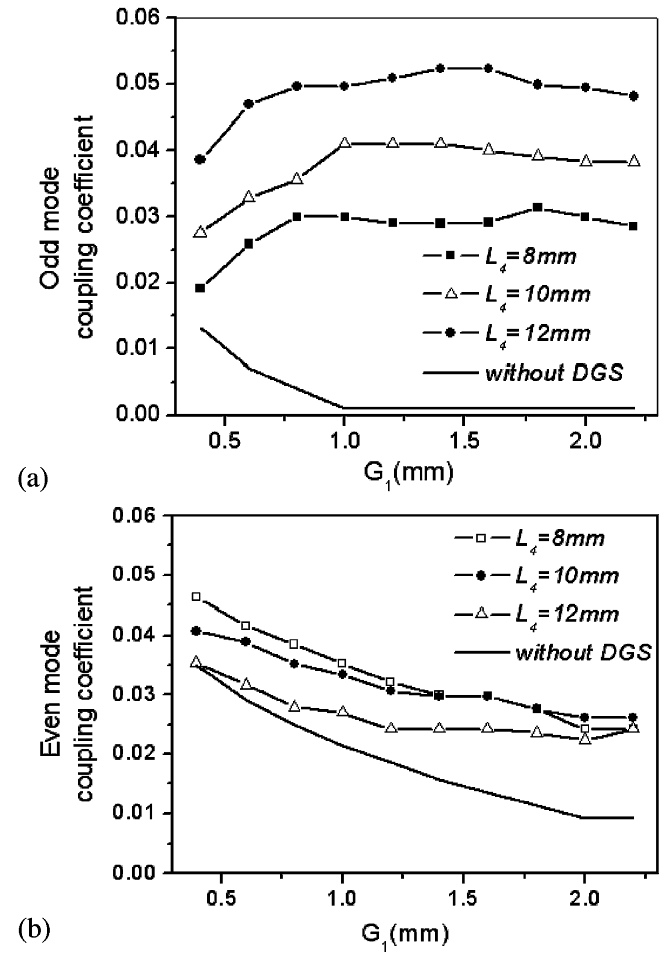


Fig. 3. Coupling coefficients of the (a) odd mode and (b)even mode. Parameters of the loop are $W_3 = 0.6$ mm, $W_4 = 0.2$ mm, $K_1 = 0.5$ mm.

where $\beta_1$ and $\beta_2$ represent the phase constant of the 3.5 GHz (odd mode) and 5.25 GHz (even mode) modes, respectively. Once the admittances are determined by the stub widths, the stub length $L_1$ and $L_2$ can be solved from (1) and (2).

The external couplings of the two resonant modes are provided by the interdigital feed lines, which are controlled by the length $L_5$ and the gap width $G_2$ of the feed line. As in the coupling coefficients extraction, the coupling coefficient of the odd mode is found to be very small without the assistance of the DGS loop, which is less than 0.007 with $G_1$ larger than 0.6 mm. In order to improve the coupling strength of the odd mode, a DGS loop is adopted. The loop is placed under the location where the SLR has the maximum current density at the two resonant modes, which intends to couple the energy from one SLR to the other. As shown in Fig. 3, proper coupling strength of the two modes can be achieved with the DGS loop. To decrease the affect on the resonant modes, the loop should have a small width and short length. Finally, the parameters of the SLR are calculated and optimized as $L_1 = 13.5$ mm, $L_3 = 7$ mm, $L_2 = 6.5$ mm, $W_1 = 1$ mm and $W_2 = 2$ mm. The external quality factors of the odd and even modes are determined as $Q_1 = 31.2$ and $Q_2 = 34.4$ with $L_5 = 3.7$ mm, $W_5 = 0.4$ mm and $G_2 = 0.2$ mm. In this letter, $L_4$ is chosen as 12 mm to realize the coupling coefficients $M_1 = 0.055$ and $M_2 = 0.023$ for the two modes, respectively.

In the RF passage 2, the DGS resonator is used as the building block to realize the bandpass response of 2.45 GHz. As shown in Fig. 1, the DGS building block used in this letter is realized by etching the folded SIR-shaped slot in the ground. Due to the folded structure and SIR-shape, this block not only realizes the desired resonant frequency in a compact size but also has the effect of harmonic resonance suppression. The resonant frequency of 2.45 GHz is realized by $L_6 = 8.4$ mm, $L_7 = 4$ mm, $L_8 = 4.6$ mm, $W_6 = 0.5$ mm, $W_7 = 2$ mm and $G_4 = 0.4$ mm, and the harmonic resonant mode is higher than 6 GHz which doesn't affect the pass-bands in passage 1. The coupling coefficient $M_3 = 0.084$ is realized with $G_3 = 1.1$ mm. The external coupling of the DGS block is mainly controlled by the slot-coupling of the overlapped section, which is adjusted by the relative position $K_2$ of the DGS resonator. And this slot-coupling structure can achieve tight coupling, which is helpful to design a bandpass filter with wide bandwidth. In this design, a $Q_e$ of about 13 is realized by $K_2 = 1.7$ mm.

The external couplings of the two passages are accomplished by a common T-shaped structure. Due to the geometric property, the two passages will affect each other. In order to decrease the affect and get a good transmission response, the stub length $L_9$

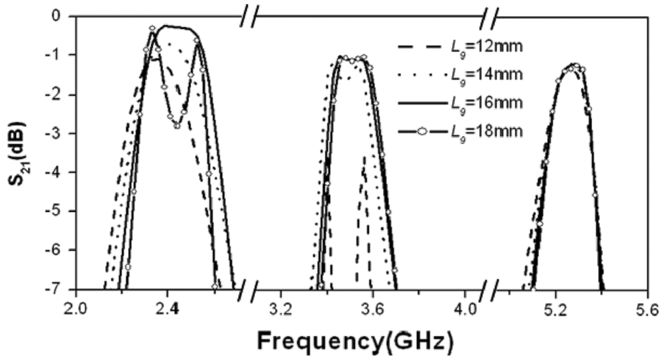


Fig. 4. Closer looks of the tri-band performance with different $L_9$. The other parameters are listed above.

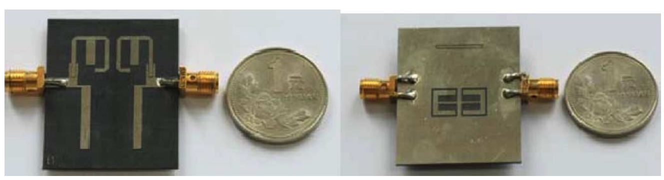

Fig. 5. Photographs of the tri-band filter. (a) Top view, (b) Bottom view.

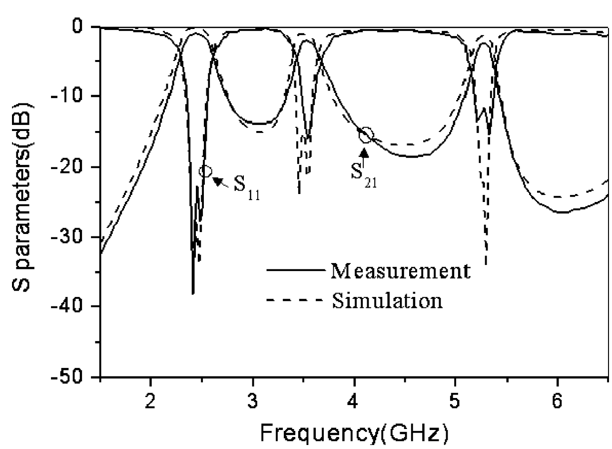


Fig. 6. Simulated and measured results of the tri-band filter.

is adjusted, which is used to tune the external quality factors of the three bands. To describe this effect, the $S_{21}$ with different $L_9$ is shown in Fig. 4. A good tri-band response is achieved with $L_9 = 16$ mm. When $L_9$ is equal to 16mm, the extracted quality factors for the three bands are 12.4, 23.2 and 41.7, respectively, which have little variation with their former values. At last, the geometric parameters of open stub are determined as $L_9 = 16$ mm and $W_8 = 2$ mm.

## III. Fabrication and Measurement

Based on the detailed analysis expressed in the above section, the proposed tri-band filter is designed and fabricated. The other parameters are $L = 32$ mm, $W = 39.5$ mm and $T = 2.7$ mm. The simulation is based on a substrate with a relative dielectric constant of 2.65 and height of 1 mm. The simulation is accomplished by the Zeland IE3D software, and the measurement is performed on an Agilent 8917ES network analyzer.

The fabricated filter with top and bottom views are shown in Fig. 5, and the simulated and measured transmission responses are shown in Fig. 6, which are in good agreements. The simulated results are centered at 2.45/3.5/5.25 GHz, with 3 dB fractional bandwidths of 13.5%, 7% and 3.5%, respectively. In the measurements, the three pass-bands are centered at 2.44/3.53/5.26 GHz, with the fractional bandwidths of 12.3%, 6.2% and 3.3%, respectively. Since there has no cross-coupling among the three resonant modes, the rejection between adjacent bands is about 15 dB. The measured insertion losses at the pass-band center frequencies are 0.9, 1.7, and 2.1 dB, respectively. The return losses of the three bands are larger than 13 dB.

## IV. Conclusion

A tri-band filter based on SLR and DGS resonator is presented in this letter. The SLR generates one RF passage with dual-band response, and the DGS resonator forms another RF passage with a bandpass response. Both the resonant and coupling properties of the two RF passages are carefully analyzed. A pair of T-shaped microstrip feed line is carefully designed to provide proper external couplings to the two passages with little affect on each other. Based on the analysis, a filter with tri-band performance centering at 2.45/3.5/5.25 GHz is designed, fabricated and measured. The measured results exhibit a good tri-band property and good coherence with the simulated results.

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