

Compact Dual Band Bandstop filters using Stepped Impedance Resonators

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Introduction:

Bandstop filters are used to reject unwanted frequency components. Mixers and Power amplifiers will have double sideband spectral regrowth due to intermodulation and distortion. Dual band reject filters can be used to reject these frequencies. Another added advantage is the low pass band insertion loss when compared to the bandpass filters, because the resonators will resonate in the stopband than in the passband. There are two popular approaches to implement the dual band response : one which uses Zolotarev function and the other which uses Chebyshev or Maximally flat function with simple frequency variable transformations. Topologies for single band reject filter is discussed in [2]. Parallel-connected different-length open stubs have recently been presented as composite shunt resonators to obtain dual-band performance [4]. However, further size reduction that is achievable by applying stepped-impedance resonators (SIRs) [5] ,[6] in filter design. Circuit synthesis for the DBBSF(Dual band band reject filter) topology used here is presented in [3] and the transformation from Low pass filter to a band reject filter and the equivalent circuit for Dual band response is explained.

This report presents the design of DBBSF whose center frequency and bandwidth is controllable. This topology achieves size reduction by using single SIR instead of two parallel connected stubs. The design equations are presented here. A DBBSF with center frequencies 2.45Ghz and 5.2Ghz is designed , fabricated and results are presented.

Synthesis of the DBBSF :

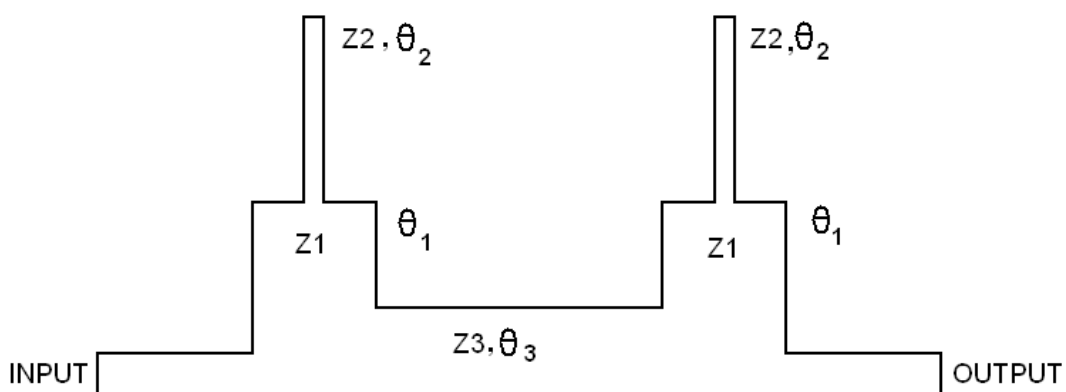


Fig 1: Schematic of DBBSF of order 2 using SIR's

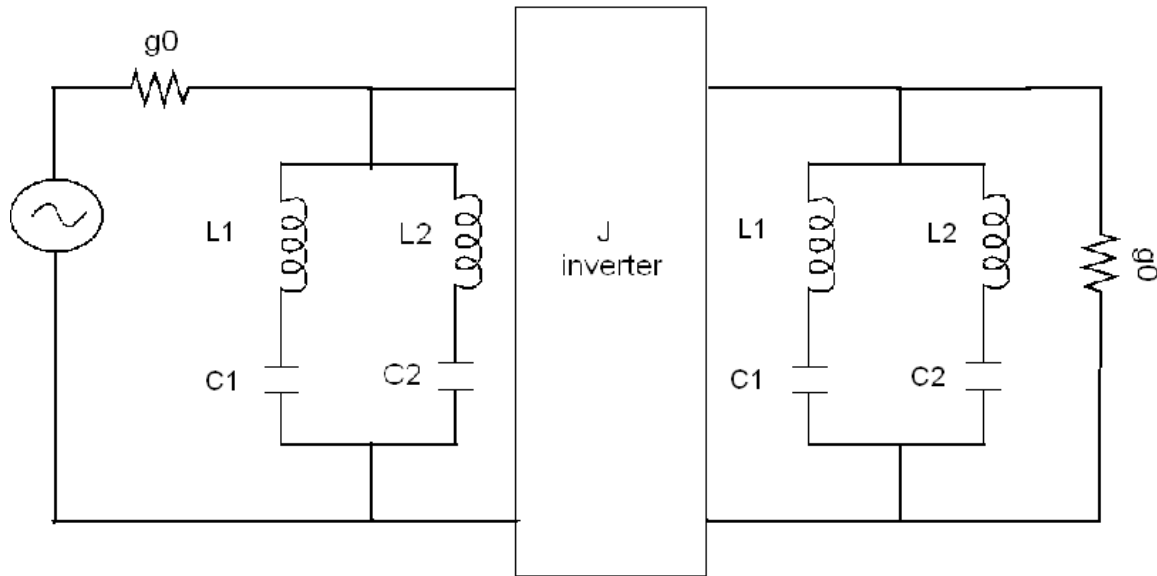


Fig 2: Equivalent Circuit for Fig 1 using series LC resonators and a J inverter.

DBBSF's have two parallel connected different length open stubs which are quarter wavelength long at the respective midband frequencies. A topology that replaces these parallel connected stubs with SIR's is shown here in Fig 1. Fig 2 shows the equivalent circuit of Fig 1 in which the composite shunt resonator structure is used to get the two antiresonance frequencies. At the first resonant frequency when series resonator formed by L1 and C1 resonate, series resonator formed by L2 and C2 behaves as an open circuit as their impedance is much larger than that offered by the former. At the second stop band frequency series resonator formed by L2 and C2 will resonate, and the series resonator formed by L1 and C1 will behave as open circuit. Thus this represents a DBBSF.

Fig 3 shows the equivalence between an open circuited SIR and two parallel connected series resonators.

The input impedance of the SIR is got by applying simple network theory principles to a cascade of an open circuited line and another short circuited line.

$$Z_{SIR} = j Z_1 (Z_1 \tan \theta_1 - Z_2 \cot \theta_2) / (Z_1 + Z_2 \tan \theta_1 \cot \theta_2) \quad \text{----- (1)}$$

The input impedance of the composite series LC resonators connected in parallel is given as

$$Z_c = \frac{j \sqrt{L_1 L_2} (\omega^2 - \omega_1^2) (\omega^2 - \omega_2^2)}{\omega \omega_1 (\sqrt{C_1 L_2} (\omega^2 - \omega_2^2) + \sqrt{C_2 L_1} (\omega^2 - \omega_1^2))} \quad \text{----- (2)}$$

The resonant conditions are characterized by the condition $Z_{SIR} = 0$.

Additional equations are got by solving for the reactance slope parameter at the respective stop band frequencies [7]. The reactance slope parameter must be equal for both the topologies at each resonant frequency. Hence we get the following equations (3)-(6), after applying reactance slope parameter to the equations (1) and (2) and equating them.

$$Z_1 \tan \theta_1 - Z_2 \cot \theta_2 = 0 \quad \text{----- (3)}$$

$$Z_1 \tan(\text{rf } \theta_1) - Z_2 \cot(\text{rf } \theta_2) = 0 \quad \text{----- (4)}$$

$$\frac{Z_1 (Z_1 Z_2 \theta_2 + Z_1^2 \theta_1 \sin^2 \theta_2 + Z_2^2 \theta_1 \cos^2 \theta_2)}{2 (Z_1 \cos \theta_1 \sin \theta_2 + Z_2 \sin \theta_1 \cos \theta_2)^2} = \frac{1}{g_1 \Delta f} \quad \text{----- (5)}$$

$$\frac{rf Z_1 (Z_1 Z_2 rf \theta_2 + Z_1^2 rf \theta_1 \sin^2(rf \theta_2) + Z_2^2 rf \theta_1 \cos^2(rf \theta_2))}{2(Z_1 \cos(rf \theta_1) \sin(rf \theta_2) + Z_2 \sin(rf \theta_1) \cos(rf \theta_2))^2} = \frac{1}{g_1 \Delta_s} \quad \text{-----(6)}$$

rf is the ratio of frequencies ω_2 to ω_1 . Δ_f and Δ_s are the fractional bandwidths. We note that the electrical lengths θ_1 and θ_2 are specified at the first stopband frequency ω_1 . The roots of the equations (3) to (6) can be calculated using MATLAB or any root searching program. The MATLAB code used to calculate the four design parameters Z_1 , Z_2 and θ_1 , θ_2 is given in appendix.

The dual band performance is got by adding a J inverter which is shown in Fig 4. This employs two open stubs with a transmission line in between [8] [9].

The electrical lengths and impedances are got by setting $A=0$ and $B=+j/J$ or $-j/J$ in the ABCD matrix.

This gives $\theta_3=\theta_4= n\pi/(r_f+1)$ where n is any natural number.

$$Z_3 = \frac{1}{J \sin(\theta_3)} \quad \text{-----(7)}$$

$$Z_4 = \frac{\tan^2(\theta_3)}{J \sin(\theta_3)} \quad \text{-----(8)}$$

Here again the electrical lengths are specified at the first stop band frequency and the impedances are normalized to Z_0 . The SIR's have input admittances close to infinity at the resonant frequencies, and the open stubs have a much lower input admittance at the resonant frequencies, hence in practice they can be removed from the design to save space at a cost of reduction in bandwidth. The loss in bandwidth can be attributed to the removal of these open stubs.

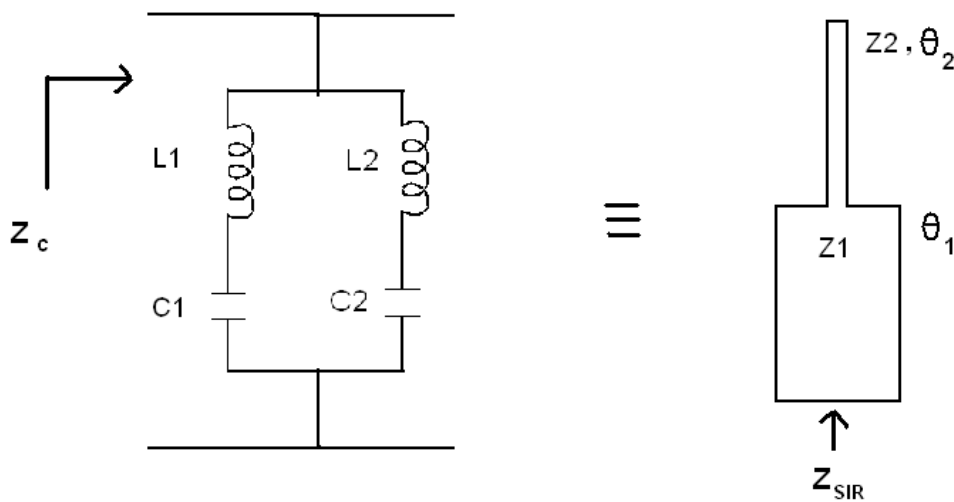


Fig 3: Equivalence between shunt connected series LC resonators and open ended SIR

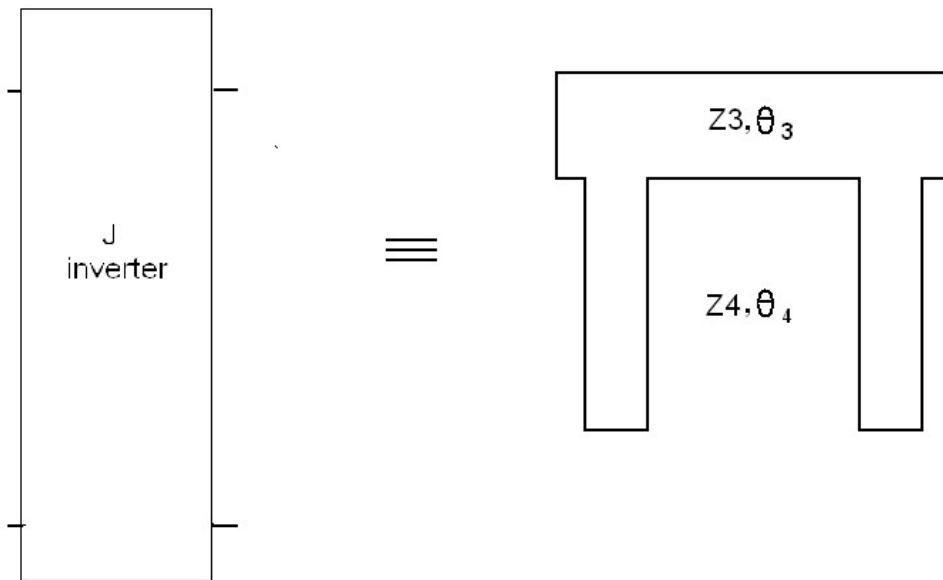


Fig 4: Dual band admittance inverter

Illustrative example : DBBSF for 2.45Ghz and 5.2 Ghz.

A second order DBBSF was simulated, fabricated and tested on an FR-4 substrate with $\epsilon_r=4.4$ and $\tan\delta=0.02$. The thickness of the substrate was 1.58mm and conductor thickness is 16um. The stop band frequencies used are 2.45 and 5.2 Ghz. The fractional bandwidths Δ_f and Δ_s are 70% and 35% respectively. This is chosen to keep the ratio of bandwidths (r_b) 0.5. It is observed through graphs obtained by solving equations (3)-(6), that more compact design is got by keeping $r_f r_b=1$. The equations (3) -(6) were solved using the matlab code given in appendix. This gives the following values

$Z1=50.199 \Omega$ and $\theta1=57.645^\circ$ (Width= 2.94mm Length=10.73mm)
 $Z2=125.106 \Omega$ and $\theta2=57.64^\circ$ (Width=0.331mm and Length=11.434mm)
 The values for the J inverter is given by equations (7) and (8) as
 $Z3=59.187 \Omega$ and $\theta3=57.6^\circ$ (Width=2.213mm and Length=10.86mm)

The open stubs were omitted from the J inverter to give a compact design, however the bandwidth is reduced due to this. After substituting the above values the center frequencies were got at 2.4Ghz and 5Ghz. This is because the electrical lengths have been calculated at 2.45Ghz. So the length of the SIR ($\theta2$) was reduced by 1mm i.e. 5.04° , this gave center frequencies at 2.45Ghz and 5.2Ghz as desired.

Agilent ADS was used for all the simulations. The layout of the DBBSF is shown in Fig 5. Fig 6 shows the fabricated design. The s11 and s21 parameters are shown in Fig 7 and Fig 8 respectively.

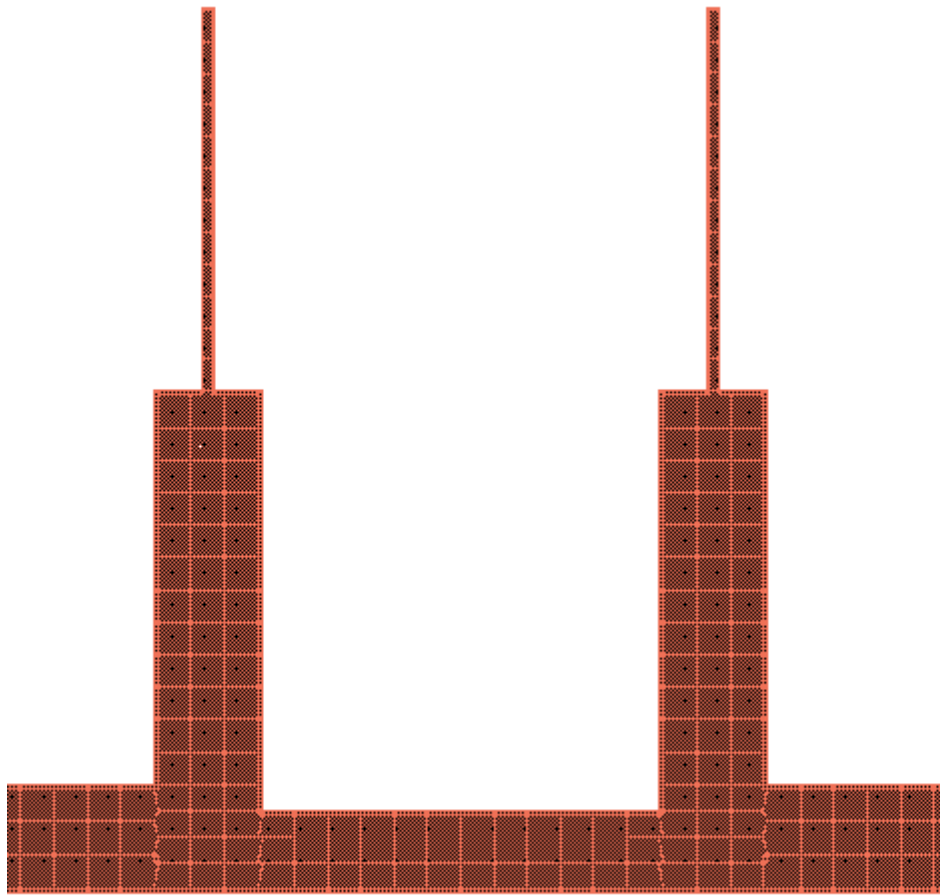


Fig 5: Layout of the DBBSF in Agilent ADS.

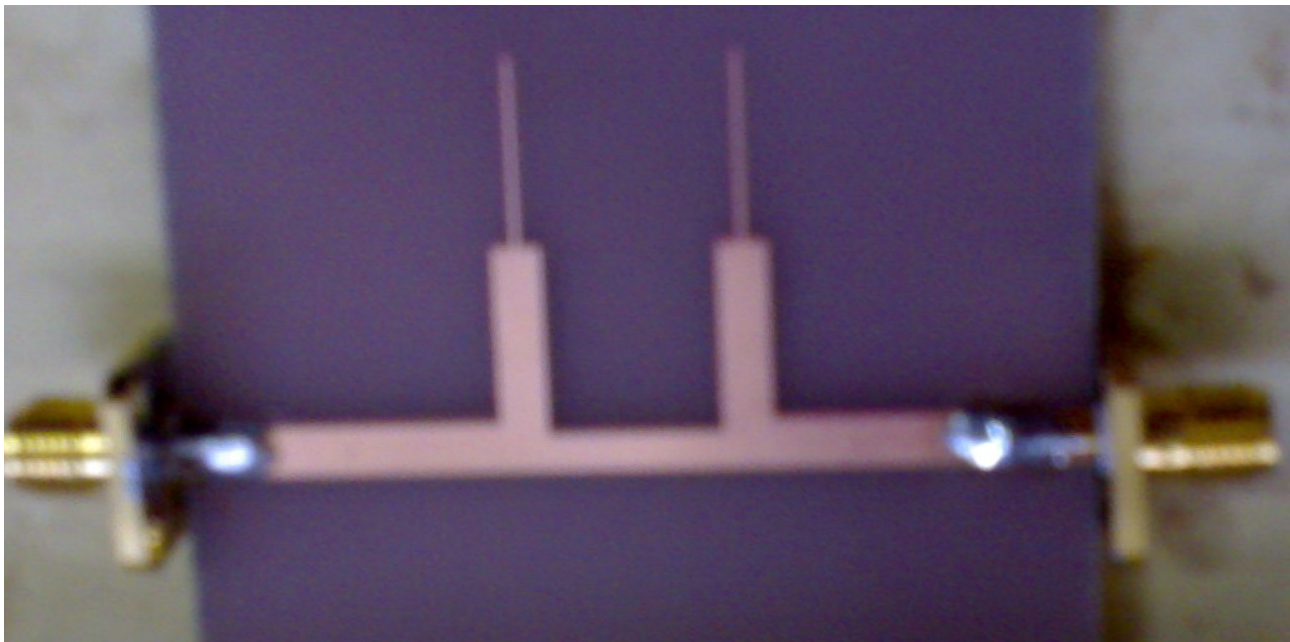


Fig 6: Photograph of the fabricated dual band bandstop filter.

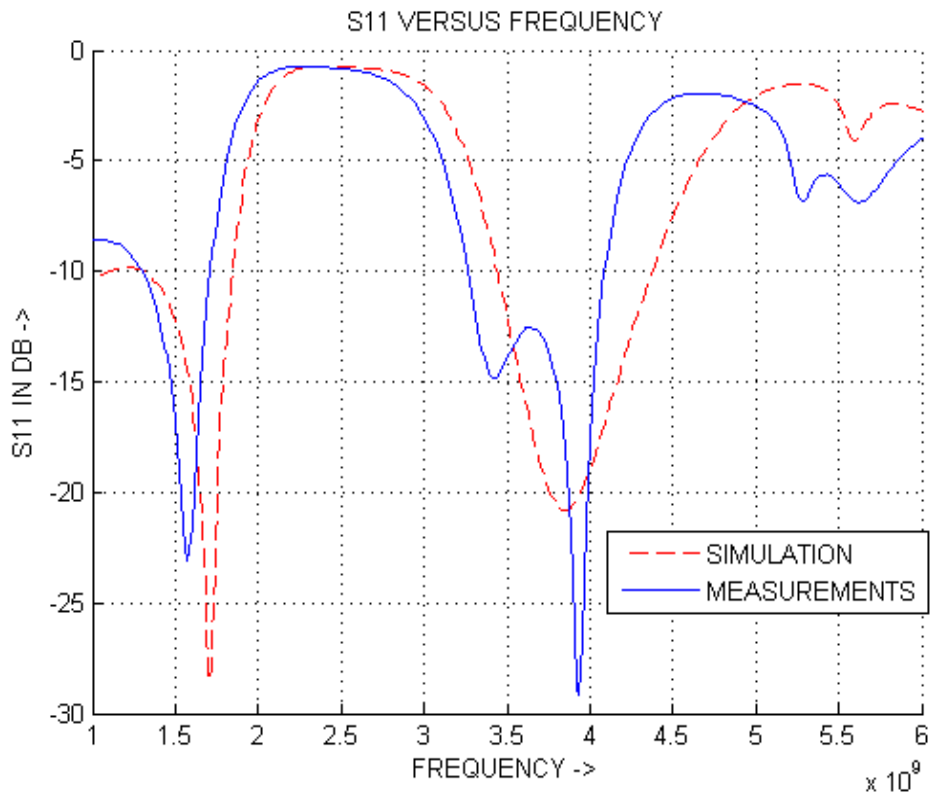


Fig 7: S11 versus frequency showing measured and simulated results.

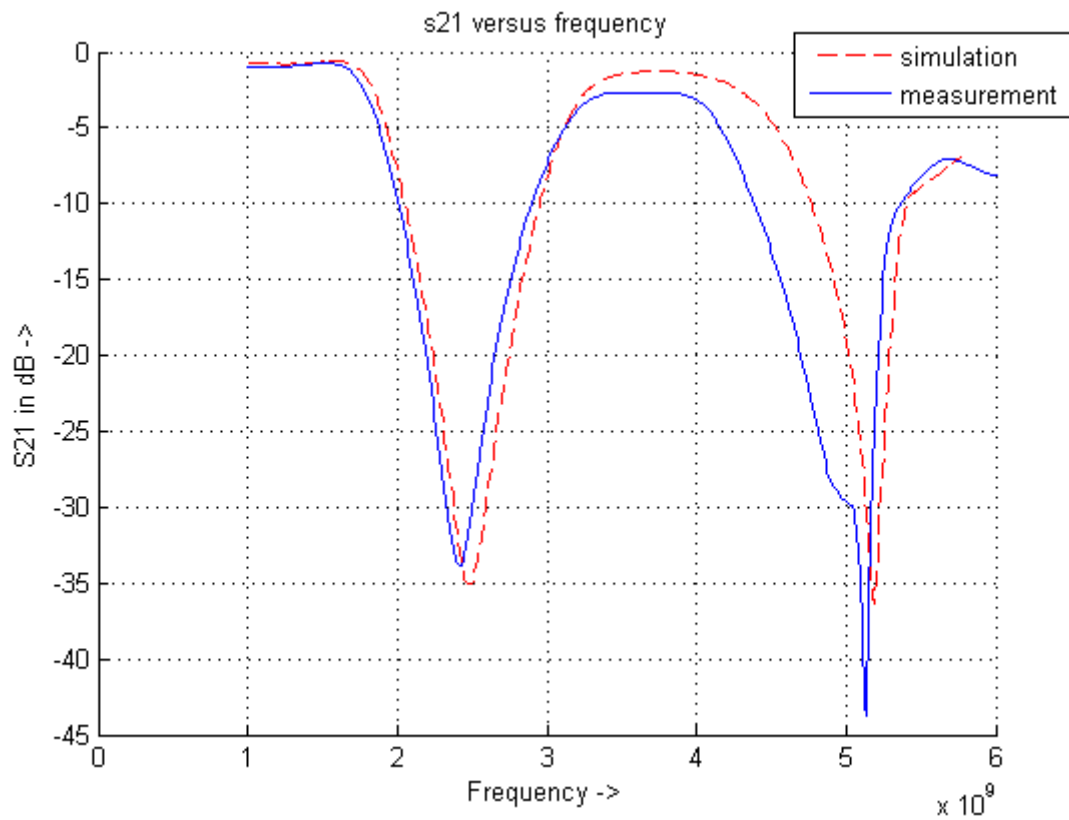


Fig 8: S21 versus frequency showing measured and simulated results.

Results:

Center frequencies : 2.42 Ghz and 5.13Ghz.

Fractional Bandwidths(calculated at -10dB points) : 41% at 2.42 Ghz and 19% at 5.13 Ghz.

Rejection level at 2.42 Ghz : 34dB

Rejection level at 5.13 Ghz : 43dB

Pass band insertion loss : 2.42 dB.

Circuit dimensions : 35 mm by 25.15 mm.

REFERENCES:

- [1] Compact Dual-Band Bandstop Filters Using Stepped-Impedance Resonators Kuo-Sheng Chin, Member, IEEE, Jun-Hong Yeh, and Shuh-Han Chao
- [2] Microwave Engineering, D M Pozar , 3rd Edition.
- [3] Dual-Band-Rejection Filter for Distortion Reduction in RF Transmitters, Uchida et. Al
- [4] Z. Ma, K. Kikuchi, Y. Kobayashi, T. Anada, and G. Hagiwara, "Novel microstrip dual-band bandstop filter with controllable dual-stopband response," in Proc. Asia-Pacific Microw. Conf., Dec. 2007, pp. 1177–1180.
- [5] C. Quendo, E. Rius, and C. Person, "Narrow bandpass filters using dual-behavior resonators," IEEE Trans. Microw. Theory Tech., vol. 51, no. 3, pp. 734–743, Mar. 2003.
- [6] Y.-Z. Wang and M.-L. Her, "Compact microstrip bandstop filters using stepped-impedance resonator (SIR) and spur-line sections," Proc. Inst. Elect. Eng., vol. 153, pp. 435–440, Oct. 2006.
- [7] G. L. Matthaei, L. Young, and E. M. T. Johns, Microwave Filters, Impedance Matching Networks, and Coupling Structures. Norwood, MA: Artech House, 1980.
- [8] C.-M. Tsai, H.-M. Lee, and C.-C. Tsai, "Planar filter design with fully controllable second passband," IEEE Trans. Microw. Theory Tech., vol. 53, no. 11, pp. 3429–3439, Nov. 2005.
- [9] H.-Y. Anita Yim and K.-K. Michael Cheng, "Novel dual-band planar resonator and admittance inverter for filter design and applications," in IEEE MTT-S Int. Dig., 2005, pp. 2187–2190.

APPENDIX:

Matlab code : To solve the nonlinear equations (3) -(6) :

A function is written , incorporating the constants in the equations by substituting them as shown below.

```
function F=myfun(z)
```

```
F=[z(1)*tan(z(3))-z(2)*cot(z(4));
```

```
z(1)*tan(2.1224*z(3))-z(2)*cot(2.1224*z(4));
```

```
z(1)*(z(1)*z(2)*z(4)+z(1)*z(1)*z(3)*sin(z(4))*sin(z(4))+z(2)*z(2)*z(3)*cos(z(4))*cos(z(4)))/  
(2*power((z(1)*cos(z(3))*sin(z(4))+z(2)*cos(z(4))*sin(z(3))),2))-1.010152;
```

```
2.1224*(z(1)*(z(1)*z(2)*z(4)+z(1)*z(1)*z(3)*sin(2.1224*z(4))*sin(2.1224*z(4))+z(2)*z(2)*z(3)*  
cos(2.1224*z(4))*cos(2.1224*z(4)))/(2*power((z(1)*cos(2.1224*z(3))*sin(2.1224*z(4))  
+z(2)*cos(2.1224*z(4))*sin(2.1224*z(3))),2))-1.0101626];
```

To solve these the `fsolve()` function in the optimization toolbox is used. The following commands have to be typed on to the prompt.

```
Z = [45; 45;.9;.9];          % Make a starting guess at the solution
options=optimset('Display','iter'); % Option to display output
[x,fval] = fsolve(@myfun,z,options) % Call optimizer
```

This gives the solution with limits specified in 'optimset' structure.