New Compact Dual-Band Bandpass Filter Using Stepped Impedance Resonator and U-Shaped Microstrip Structure

Y. E Masrukin[1], N. Hassim[2], Z. Zakaria[1], N. S. A. S Ali[1], M. S. A. M Noh[2]
[1]*Centre for Telecommunication Research and Innovation (CeTRI), Faculty of Electronic and Computer Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.*
[2]*Faculty of Engineering Technology (FTK)*
Universiti Teknikal Malaysia Melaka (UTeM), Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
yully_erwanti@yahoo.com

***Abstract*—This paper presented a design to realize a compact dual-band bandpass filter using a pair of coupled symmetric stepped impedance resonator (SIRs) and U-shaped microstrip structure for wireless communication applications. To obtain its compact size, the symmetric SIR was bent like an L-shape. The U-shaped microstrip structure was designed and integrated into the SIR to achieve notch bandstop response so as to produce the specified dual-band bandpass filter. For the resonant frequency and attenuation, the U-shaped microstrip structure was designed at 3GHz and greater than 60dB respectively. Based on the simulation and experimental results, it was verified that this proposed design produced two passbands centered at 2.5GHz and 3.5GHz with the fractional bandwidth of more than 16%. The return loss and insertion loss are better than 15dB and 1dB respectively. The simulated and measured results are both presented and showed a good agreement. This proposed dual-band bandpass filter is beneficial in modern wireless communication and many other applications such as WiMAX and WLAN.**

***Index Terms*—Bandpass; Dual-Band; Microstrip Structure; Stepped Impedance Resonator.**

I. INTRODUCTION

In the past few decades, designing the multi-band bandpass filter have been studied extensively because of the high demand in recent impositions leading to the growth of multi-purpose RF front-ends that might support several services simultaneously [1] such as the Worldwide Interoperability for Microwave Access (WiMAX) which can operate at the specifications of 3.5GHz and 5.8GHz.

A considerable amount of literature has been published and focused on designing the dual-band bandpass filter as in [2]-[7]. Lee *et al*. [2] highlight the design of dual-band bandpass filter by integrating the open and short circuit stubs. The advantages of this design were, it had no restriction in bandwidth and the ability to vary the stub length depending on the necessity and required a result in a miniaturized circuit. However, the LTCC procedure had led the insertion losses to be higher than -6dB and -5.3dB for the 2.42GHz and 5.24GHz respectively. In 2011, Ma *et al.* [3] published a compact dual-band bandpass filter paper which used tri-section stepped impedance resonators (SIRs) for Wireless Local Area Network (WLAN). This filter used SIR and one stub between couple lines to produce two reasonable passbands. Nevertheless, this design was bigger in size and achieve a lower 3dB fractional bandwidth of 6.3% and 3.4% at 2.4GHz and 5.2GHz respectively.

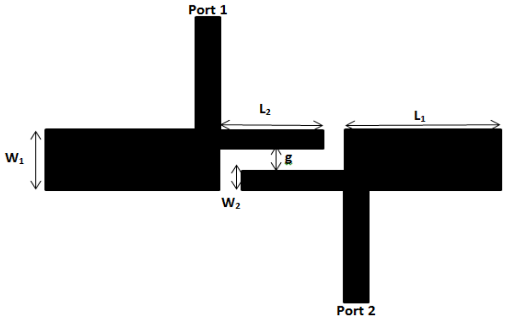
A new idea of a circuit structure for designing dual-band BPF was performed by Kuo *et al.* [4] by composing two two-port networks in shunt connection, a coupled-line section of $\lambda/4$ long together with a transmission line segment of identical length. This structure had improved the frequency selectivity and produced the transmission zeroes in the rejection bands. Conversely, this design contributed to the smaller bandwidth for the two passbands and needed a large area due to its bigger size.

In a different study, Chu *et al.* [5] presented a new technique using meandering scheme SIRs with a new coupling scheme to generate a small dual-band narrow BPF. In order to realize the SIR, the high-impedance section has been cascaded with the low-impedance sections. Next, integrating and connecting these impedances to have a pin structure to produce a compact design. Nonetheless, surprisingly, the finding is contrary to a study conducted by Zhang *et al.* [6]. In the similar frequency and requirements, the finding exhibits the circuit dimension was minimized 50% lesser compared with the conventional direct coupling structure in [7].

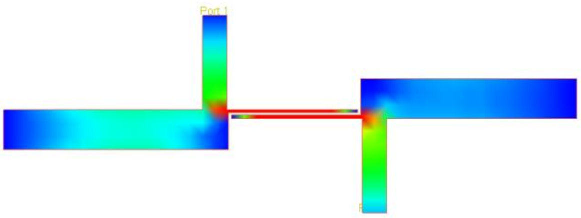
Therefore, this study attempted to introduce and develop a compact design of dual-band bandpass filter centered at 2.5GHz and 3.5GHz by integrating a pair of coupled asymmetric stepped impedance resonators (SIRs) and a U-shaped microstrip structure. This presented approach was a way to enhance the technique in [8] in designing the dual-band BPF. By coupling the two resonant modes of the asymmetric SIR, the wideband bandpass filter was achieved. Meanwhile, the band rejects response was realized by designing a U-shaped microstrip structure with high attenuation and wider bandwidth.

II. ANALYSIS OF WIDEBAND BANDPASS FILTER

The wideband bandpass filter was constructed with a fractional bandwidth of approximately about 47.9% at the passband based on the configuration of an asymmetric SIR as suggested in Figure 1(a). The substrate with the dielectric constant of 3.48 and the thickness of 0.508mm was chosen in designing and simulating the wideband bandpass filter (BPF). The current flow visualization centered at 3.025GHz is demonstrated in Figure 1(b).



(a)



(b)

Figure 1: (a) Layout of proposed wideband BPF (b) Visualization of current flow of bandpass filter at 3GHz

Table 1 presents the results for a wideband bandpass filter with the bandwidth of 1.45GHz.

Table 1
Simulation Results for Wideband BPF

Bandpass Filter	
Frequency Band (GHz)	2.3 – 3.75
Fractional Bandwidth	47.9%
Insertion Loss, S_{21}	0.3dB
Return Loss, S_{11}	15dB
Group Delay	0.50 ns

Whereas, Figure 2 shows the outcomes of S parameters and group delay from the simulation. The group delay ranges between 0.23 to 0.83ns, within the passband response. At 3GHz, wideband bandpass filter demonstrates the least insertion loss of wideband bandpass filter structure at 0.3dB while the return loss was better than 15dB.

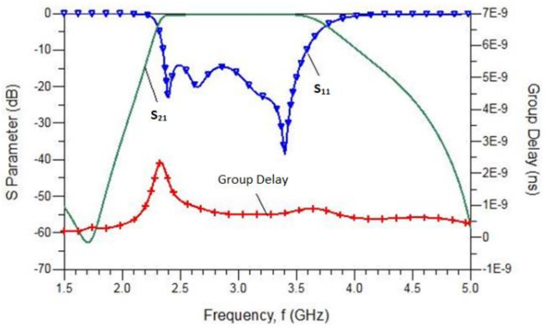


Figure 2: The results of S parameter and group delay for simulation

III. Notch Response with U-Shaped Microstrip Structure and its Equivalent Circuit Extraction

In an effort to develop the bandstop characteristic, the U shaped microstrip structure was made by defecting the microstrip structure that comprised of a horizontal slot and vertical slot in the middle of the conductor line as in Figure 3.

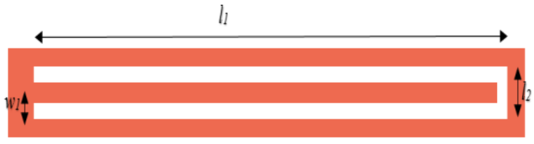


Figure 3: Dimension of U-Shape microstrip structure, l_1=15.04mm, l_2=1.9mm, w_1=0.55mm

Figure 4 illustrates the configuration of the parallel and series-parallel integrated circuit models for bandstop and bandpass. For the frequency below the series resonance, the bandpass defected microstrip structure configuration acted like a capacitor [11].

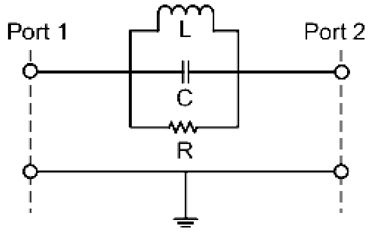


Figure 4: Equivalent circuit of microstrip structure

According to [12], capacitance C_p in pF, the inductance L_p in nH and the resistance R_p in ohm of the equivalent circuit of a bandstop microstrip structure as shown in Figure 3 could be attained as Equation (1):

$$C=\frac{f_c}{200\pi(f_0^2-f_c^2)} \quad (1)$$

Once the value of capacitance of the equivalent circuit was acquired, Equation (2) could be applied to determine the series equivalent inductance and resistance for the particular microstrip structure bandstop unit section:

$$L=\frac{1}{4\pi 2(f_0^2 C)} \quad (2)$$

$$Y=\frac{1}{z}=\frac{1}{R(\omega)+j(\omega C-\frac{1}{\omega L})} \quad (3)$$

$$z_{in}= z + z_0 \quad (4)$$

$$S_{11}=\frac{z_{in}-z_0}{z_{in}+z_0}=\frac{1}{1+2z_0 y} \quad (5)$$

where f_0 and f_c were the resonant frequency and the 3dB cutoff frequency, respectively. Yet, in resonance performance, the role of R_p was vital. However, on the frequency that was lower and higher than the resonance, the roles of the inductor and the capacitor are more important. Therefore, the frequency dependencies of R_p have been ignored and a constant value of R_p was obtained for $\omega=\omega_0$. Using Equation (6),

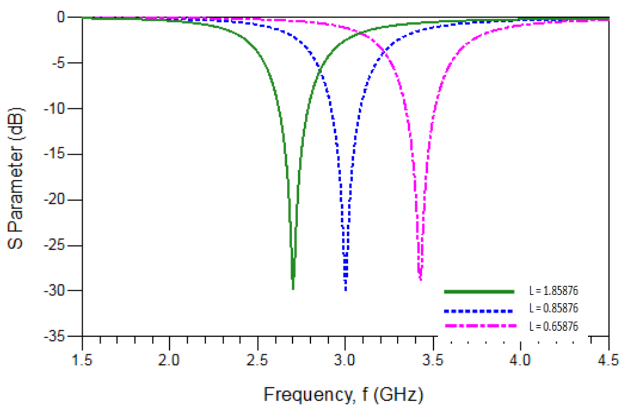
$$S_{21}=\frac{2z_0}{2z_0+z} \quad (6)$$

For $\omega = \omega_0$, z = Rp and the Rp was given as Equation (7),

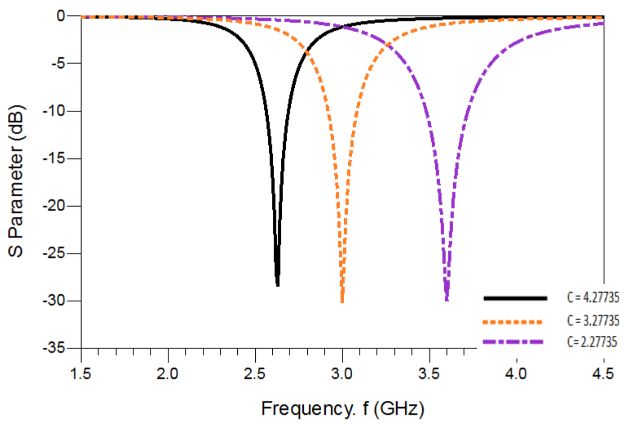
$$R_p = 2z_o\left(\frac{1-S_{21}(\omega_0)}{S_{21}(\omega_0)}\right) \quad (7)$$

This model had been simulated using Advanced Design System (ADS) Software to justify the circuit. The extracted R_p, L_p, and C_p values from the given equations were 3.0949kΩ, 0.8588nH and 3.2774pF, where f_c and f_0 were 2.68GHz and 3GHz respectively.

Figure 5(a) presents the parametric study of the proposed U-shaped of microstrip structure based on its equivalent circuit. This was to ascertain the resonant frequencies at 2.7GHz, 3GHz and 3.4GHz as the values of inductance, Lp was varied at 0.6588nH, 0.8588nH and 1.0588nH respectively. Figure 5(b) shows the effects of resonant frequency when C_p was adjusted while the L_p was kept constant. The C_p was varied at 2.2774pF, 3.2774pF and 4.2774pF respectively.



(a)



(b)

Figure 5: Simulated response of parametric analysis
(a) varying Lp = 0.6588nH, 0.8588nH and 1.0588nH,
(b) varying Cp = 2.2774pF, 3.2774pF and 4.2774 p

IV. Integration of SIR Configuration and U-Shaped Microstrip Structure

The dual-band bandpass filter was constructed for the requirement specified in Table 2. It demonstrated that the measured results matched well with the simulated results.

Table 2
Specification for Dual-Band BPF

Specification	Value
First Passband (GHz)	2.3-2.7
Second Passband (GHz)	3.1-3.75
Return Loss (dB)	<-15
Insertion Loss (dB)	<-1
Centered Notch (GHz)	2.97

The structure of the dual-band bandpass filter is detailed as in Figure 6. The current flow visualization of the integration bandpass filter with U-shaped DMS indicated that the concentration did take place at 2.97 GHz. Despite introducing the high attenuation of the band reject response, the microstrip structure of the U-shaped DMS was positioned on the connecting line. To gain a sharp rejection and to also ensure the second harmonic did not develop, the length of the U-shaped DMS has to be λ/4 at the preferred frequency.

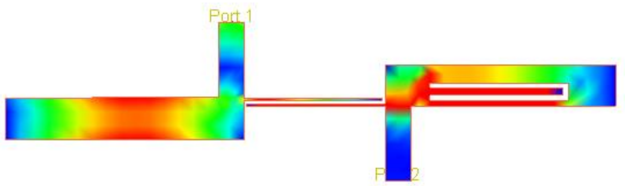


Figure 6: Current flow visualization of bandpass filter integrated with U-shaped of DMS at 3 GHz

As to prove the idea of the proposed filter, the dual band BPF centered at 2.97 GHz with 7% 3dB fractional bandwidth was simulated, optimized, fabricated and evaluated. The dimensions of the filter were acquired using the ADS software. Hence, the filter dimensions could be identified early as follows: L_1=25.1mm, W_1=4.9mm, L_2=14.6mm, W_2=0.6mm and gap, g=0.4mm.

The substrate utilized for fabrication had a relative dielectric constant of 3.48 and a thickness of 0.508mm. The fabricated proposed dual-band BPF is presented in Figure 7. The size of this filter was approximately about 71.40 x 22.20mm. Thus, the filter was rather small and compact in size.

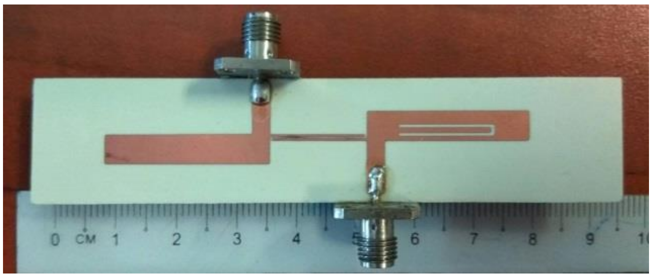


Figure 7: Fabrication of proposed design

V. Results and Discussions

Figure 8 denotes the simulated and measured results of the frequency response for the presented filter. The measurement results were carried out using the Vector Network Analyzer (VNA). The simulated passbands of the frequency response were centered at 2.5GHz and 3.5GHz with the fractional bandwidth of 16% and 18.3% respectively.

The simulated return and insertion loss of this dual band was above 15 dB and better than 1 dB respectively. It possessed two passbands centered at 2.55 GHz and 3.48GHz with 3dB bandwidths of 19.6% and 18.7%, respectively.

At the lower and upper passbands, the measured insertion losses including the loss from the two SMA connectors were 0.33dB and 0.36dB, respectively. The measured return losses for both passbands were greater than 10dB. Three transmission zeroes were realized at 1.57 GHz, 3 GHz and 4.75 GHz with the attenuation level of more than 50dB. The transmission zeroes at 1.57GHz and 4.75GHz were located near the passband edges which resulted in sharp roll-offs.

Transmission zeros produced in the stopband at 3 GHz had considerably enhanced the in between rejection. It demonstrated that the measured outcomes attained a reliable agreement with the simulated results. A minor variation was experienced which can be attributed to the fabrication tolerance in the implementation.

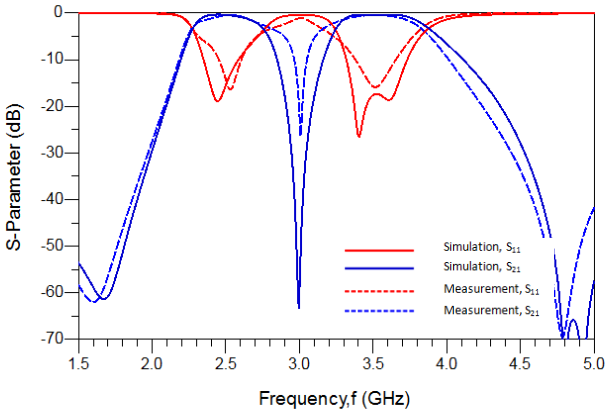


Figure 8: Simulated and measured results of proposed dual-band BPF

VI. CONCLUSION

In this paper, the study was set out to design a compact dual-band bandpass filter using a pair of coupled symmetric stepped impedance resonator (SIRs) and U-shaped microstrip structure.

The simulated and measured results of the fabricated filter has proven the overall performance of the proposed dual-band filter with the passbands centered at 2.5 GHz and 3.5 GHz. Apart from that, the presented filter was created with three transmissions zeroes and greater than 50 dB rejection between the two passbands. The measured results matched well with the simulated ones. The outcomes of this analysis signify that this dual-band BPF has many advantages for use in modern wireless communication and other applications.

ACKNOWLEDGMENT

The authors would like to thank UTeM for sponsoring this work under the grant PJP/2015/FTK (17B)/S01435.

REFERENCES

[1] S. F. R. Chang, W. L. Chen, S. C. Chang, C. K. Tu, C. L. Wei, C. H.Chien, C. H. Tsai, J. Chen, and A. Chen, "*A dual-band RF transceiver for Mult-standard WLAN applications*," IEEE Trans. Microw. Theory Tech., vol. 53, no. 3, pp. 1048–1055, Mar. 2005.

[2] H. M. Lee, and C.M. Tsai, *Dual Band Filter Design with Flexible Pass Band Frequency And Bandwidth Selections*. IEEE Transactions, vol. 55(5), pp. 1002-1009, 2007.

[3] D. C. Ma, Z. Y. Xiao, L. L. Xiang, X. H. Wu, C. Y. Huang, and X. Kou, "*Compact Dual-Band Bandpass Filter Using Folded SIR with Two Stubs for WLAN*," Progress in Electromagnetics Research, vol.117, pp. 357-364, 2011.

[4] J. T. Kuo and S. W. Lai, "*New Dual-Band Bandpass Filter with Wide Upper Rejection Band*," Progress in Electromagnetics Research, vol.123, pp. 371-384, 2012.

[5] Chu, Q.X. and F.C. Chen*, "A Compact Dual Band Bandpass Filter Using Meandering Stepped Impedance Resonators,"* Microwave and Wireless Components Letters, IEEE, vol. 18(5), pp. 320-322, 2008.

[6] Zhang, Y.P., and M. Sun, *"Dual-Band Microstrip Bandpass Filter Using Stepped-Impedance Resonators With New Coupling Schemes,"* Microwave Theory and Techniques, vol.54(10): pp.3779-3785, 2006.

[7] Zhang, S., J.K. Xiao, Z.H. Wang, and Y. Li, *"Novel Low-Pass Filters Using Defected Microstrip Structure,"* Microwave Journal, vol.49(9): pp. 118-128, 2006.

[8] Y.C. Chang, C.H Kao, M. H Weng, and R. Y Yang*, "Design of the Compact Wideband Bandpass Filter with Low Loss, High Selectivity and Wide Stopband,"* IEEE Microwave and Wireless Components Letters, vol.18(12) pp. 770-772, 2008.