Multilayer Dual-Mode Dual-Band Bandpass Filter

N. A. Wahab, Z. I. Khan, M. K. M. Salleh, , M. N. Bakhtiar, N. E. A. Rashid, K. A. Othman
Faculty of Electrical Engineering
Universiti Teknologi MARA (UiTM),
40150 Shah Alam, Selangor, Malaysia
fishahahu@yahoo.com.my

***Abstract*—This paper presents a single ring resonator using multilayer technique for dual-band bandpass filter. The resonator is composed of two resonators with each one having a quarter-wavelength coupled-line connected in series to a transmission line. The two resonators are arranged in parallel to form a single ring dual-band bandpass filter topology. The controlling impedance parameters of this ring are Z_r for the transmission line and even- and odd-mode characteristic impedances i.e. Z_{oe} and Z_{oo} for the coupled-lines. Observations on the controlling parameters are conducted to investigate the effect of each parameters in terms of bandwidth, matching level and the transmission zeros. For validation, the filter is realized using multilayer technique, designed at 2 GHz on FR-4 microstrip substrate. The results exhibited good isolation between the two passbands with centered transmission zero attenuated above 40 dB while the centered frequencies were found at 1.59 GHz in the first passband and 2.41 GHz in the second passband. The simulated and measured result is presented throughout this paper to validate the concept.**

Keywords—bandpass filters; couple-line; dual-band; microwave filters; multi layer technique; transmission line

I. INTRODUCTION

As the demand of wireless communication applications increases, it requires radio frequency (RF) components operating in multiband operations. Dual band filters; one of the components in the wireless system is well known for its performance in enabling pre-selection of more than one band in RF transceivers and isolating a specific band from interferers; seem as a suitable solution for a multifunctional system [1]. With recent technology advancement in wireless communication system, dual band bandpass filter topology with high selectivity, compact in size and easy to be duplicated is highly sought for. Amongst these, single layer microstrip bandpass filter is well-known for its simplicity, low cost and easy to be fabricated. However, when dealing with filter design that is constructed based on couple-line resonator which requires narrow line gap or separation between the lines; it is difficult to obtain high performance filter. Various multilayer techniques were explored to overcome this issue; while at the same time compact size filter can be achieved without hindering the performance of the bandpass filter [1-5].

In [2], a pair of identical dual-mode square patch resonators was coupled using resonant cavity technique. By using two different layers with different dielectric constant and height enabled the creation of the dual band filter response. While, the work proposed by [4] introduced multilayer technique for ring bandpass filter. This filter was constructed based on a number of square open loop resonators that are stacked on top of each other. The design allowed the middle stopband to be tuned to have either narrow or wide separation. Interesting research reported by [5] and [6], introduced the stepped-impedance resonator (SIR) configuration and embedded open-loop stepped impedance resonator (OLRs) into stepped impedance resonator (SIRs) respectively using multilayer technique. This technique had successfully miniaturized the filter sizes when compared to the conventional single layer filter. Meanwhile, in [7], square loop resonator was realized on two stacked microstrip substrates. By using superposition technique, two dual-mode resonators were separately designed to exhibit two separate passbands whose position and bandwidths can be individually tuned. While in [8], two identical cross-slotted patch resonators which were placed back-to-back were applied to achieve a dual-band bandpass filter response. The etched slits on the common ground produced two separated coupling path for the two different modes which allowed both center frequencies and coupling coefficients of the two passbands to be controlled independently. Another method made used of stub loaded stepped impedance (SL-SIR) and uniform impedance resonator (SL-UIR) proposed by [9]. The configuration consist of cross-shaped SL-SIR and SL-UIR, arranged on top and bottom layer respectively; which provide multipath propagation and compact size. The cross-coupling structure of the filter can effectively control the transmission zeros to improve the filter performance. A dual-band bandpass filter proposed by [10] comprised of 2 transmission lines with two coupled lines. By allowing the electrical length of the lines to be set at any wavelength, the bandwidth of the filter is controlled by setting all the lines to have equal electrical length. It was also reported that, the spurious peak at the rejection band was very high and therefore the design had to be improvised by adding coupling at both coupled lines. Therefore, based on all these reports, it is found that most of the proposed designs are quite complex and tedious to be realized because of the existence of too many controlling parameters in obtaining good filter response.

Thus, another concept of dual-band bandpass filter topology is proposed using multilayer technique in this paper. In this topology, all the lines are fixed at quarter wavelength electrical length. Based on this approach, the parameters can be easily controlled to obtain the desired filter performance with high rejection level. As shown in Fig. 1, this filter topology which comprises of a quarter-wavelength coupled-line that is directly connected to a transmission line to form a half wavelength resonator; and parallel connected with another similar arrangement. In this case, the controlling parameters are line impedance, Z_r and the even- and odd-mode impedances of the coupled lines, Z_{oe} and Z_{oo}.

II. Multilayer Dual-Band Bandpass Filter Design

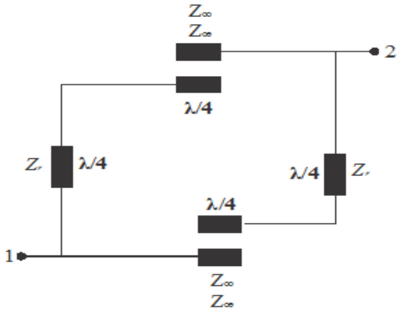


Fig. 1. Topology of the proposed dual-band bandpass filter

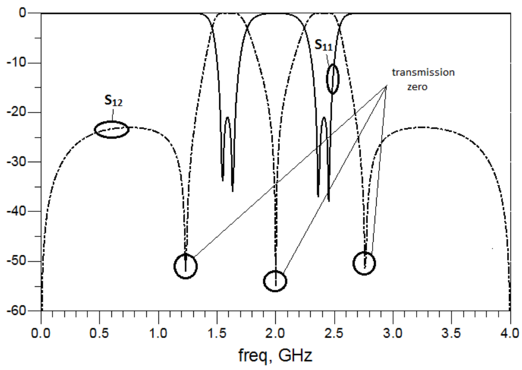


Fig. 2. Frequency response of the proposed dual-band bandpass filter

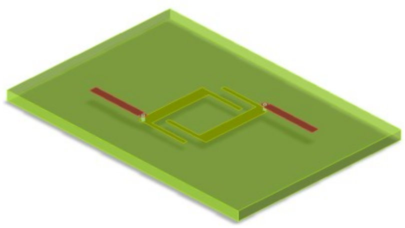


Fig. 3. 3D view of the multilayer dual-band bandpass filter

The topology of the dual-band bandpass filter is illustrated in Fig. 1. The ideal response of the filter shows that a transmission zero at frequency f_0 appears between two equally separated passband, resulting to a dual-band response as shown in Fig. 2; with two operating frequencies of $f1$ and $f2$ are found in the first and second passband respectively. Hence, the filter response gives three transmission zeros for better selectivity of frequency.

Using multilayer technique, the dual-band bandpass filter is designed on a three layers structure where the top and second layers are known as the conductors while the bottom layer served as solid ground as shown in Fig. 3. Both input and output feed-lines are located at the top layer while coupled lines and transmission lines are placed on second layer. The coupling between the two layers is achieved by placing via holes with a diameter of 1mm.

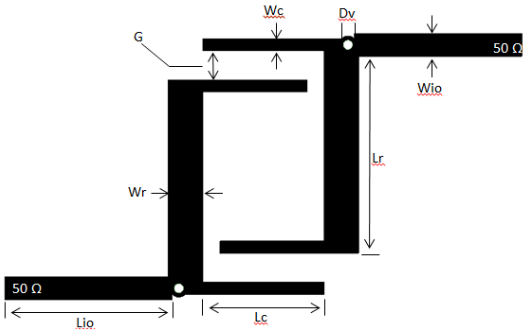
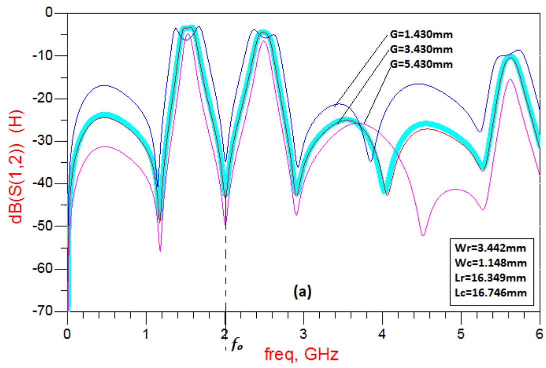
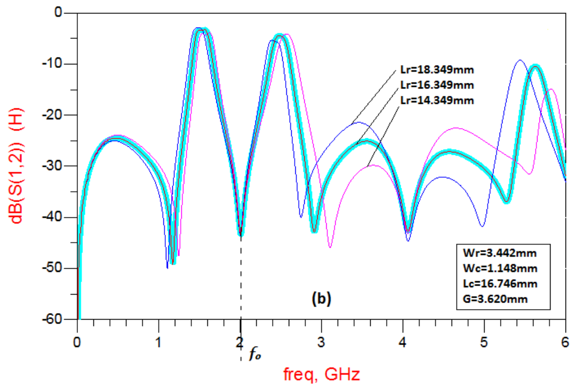


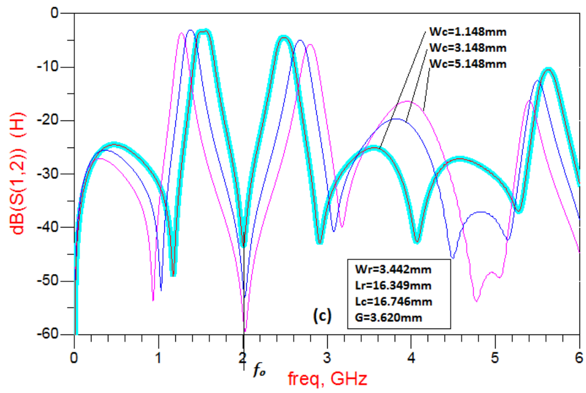
Fig. 4. Circuit layout of multilayer dual-band bandpass filter



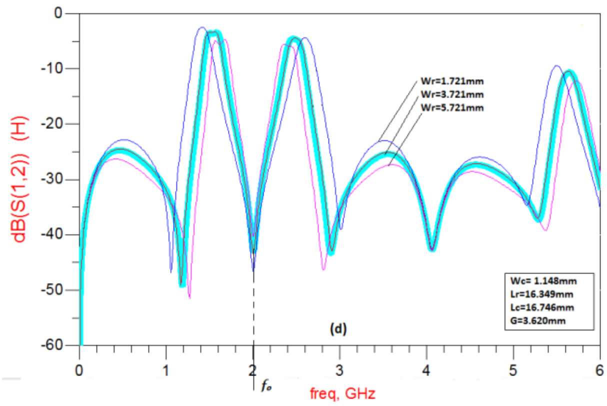
(a)



(b)



(c)



(d)

Fig. 5. Frequency response of the topology with variations of the optimizing parameter: (a) G (b) Lr (c)Wc and (d) Wr

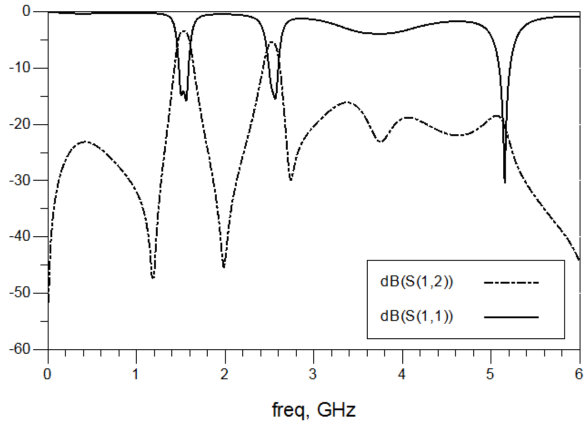
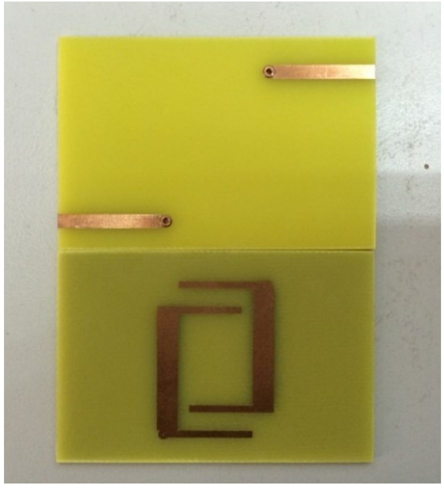


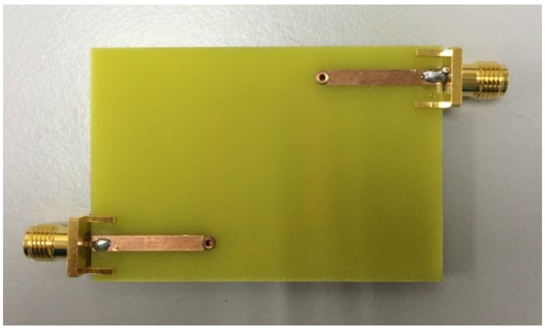
Fig. 6. Simulated results of the multilayer dual-band bandpass filter.

Finally, the filter is realized on a FR-4 substrate which have relative dielectric constant = 5.4, substrates thickness, *h*=1.6 mm with loss tangent, *tan δ* = 0.025. Each of the line impedances and even- and odd-mode impedances which are represented in terms of Z_r, Z_{oe} and Z_{oo}, are converted into microstrip having width (W), length (L) and gap (G). Fig. 4 shows the complete layout of the dual-band bandpass filter with the elements dimension.

The filter response such as bandwidth and the separation of the passbands can be varied by varying these parameters. Width of the line impedance, coupling line and feed-line are denote by Wr, Wc and Wio respectively while their length are represented by Lr, Lc and Lio. The value G denotes the gap of the coupling lines. Fig. 5 shows the filter response when each one of these parameters is varied while the other parameters are kept constant. As shown in Fig. 5(a), a higher value of gap, G resulting a better separation and rejection level while in Figure 5(b) by varying Lr give not much effect on the separation, but a higher value of Lr will cause a higher rejection level. In Fig. 5(c) it is found that by increasing the value of Wc, it gives a good separation but this will also increase the rejection level. While, in Fig. 5(d) it can be seen that by having a small value of Wr will give a better separation; but at the same time it will increase the rejection level.



(a)



(b)

Fig. 7. Fabricated multilayer dual-band bandpass filter: (a) the upper and bottom layer of the filter (b) completed multilayer dual band-bandpass filter design.

By optimization, the parameters in Fig. 4 can be determined and are given as follow Wr=3.9mm Lr=21.5mm Wc=1.3mm G=3.3mm Lc=11.7mm. Simulation is performed using electromagnetic fullwave simulator and the result is shown in Fig. 6. Referring to the filter response, the center frequency of the filter exists on 2 GHz and the passbands are center at 1.59 GHz and 2.41GHz with relative bandwidths of 13% and 8% respectively.

From the response, it can be seen that the isolation level between the two passbands is up to 45 dB and this has improved as compared to the previous design using single layer. However, due to the high tangential loss of the microstrip substrates FR-4, the insertion losses of the filter are quite high which is 3.35 dB in the first passband and 5.29 dB in the second passband.

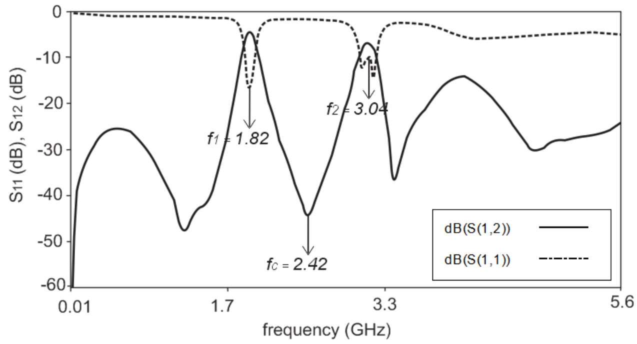


Fig. 8. Measured result of the dual-band bandpass filter.

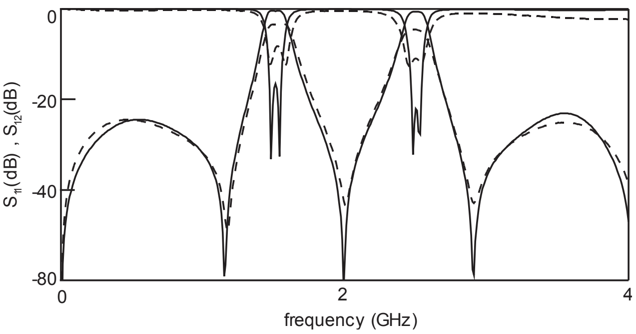


Fig 9. Comparison of simulated frequency responses between FR-4 and Tachonic.

III. RESULT AND DISCUSSION

To verify the filter response, the proposed dual-band bandpass filter was fabricated on FR-4 and the photo of the fabricated filter is as shown in Fig.7. The filter was measured and the response is illustrated in Fig. 8. In overall, the measurement is in good agreement with the simulation although there is a shift in frequency about 300 MHz as compared to the simulated response. The measured passbands are centered at 1.83 GHz and 3.04 GHz with relative bandwidths of 11% and 10% respectively. The insertion losses of 4.8 dB and 6.5 dB are high due to high loss tangent of the substrate. It can be seen from the result that the center transmission zero which provides the separation between the two passbands ensures isolation level between them up to 44 dB.

As observed, the out of band rejection level for the first passband is more than 20 dB while in the second passband, is more than 10 dB. Hence, the multilayer technique has improved the filter response as compared to the single layer dual-band bandpass filter. To improve insertion loss of the dual band filter, microstrip substrate with low tangential loss can be used. To demonstrate this, the dual-band filter was simulated using Tachonic (TRF45) with characteristics given; dielectric constant = 4.5, substrates thickness, h=1.63 mm with loss tangent, $\tan\delta = 0.003$ and the response is compared with FR-4 as illustrated in Fig. 9. It can be seen that using better dielectric with low tangential loss could improve the insertion loss in both passbands tremendously.

IV. CONCLUSION

A dual-mode dual-band bandpass filter with one-wavelength electrical length was proposed and fabricated using a multilayer approached. This topology introduced only three controlling parameters to control the desired characteristic of the filter response. The proposed filter topology was realized and tested using multilayer microstrip technology and results have shown good agreement between measurement and simulation. Even though the size of the filter was not much reduced when compared to the single layer design, but the proposed filter has improved in terms of performance such as high selectivity and the rejection level when compared to the same topology using a single layer technique. The performance of the filter such as insertion loss is expected to be improved by using low tangential loss microstrip substrate such as Tachonic or Rogers.

ACKNOWLEDGMENT

The author would like to thank Ministry of Education Malaysia and Research Management Institute(RMI), Universiti Teknologi MARA with grant number 600-RMI-NRGS 5/3(3/2013) for funding this project.

REFERENCES

[1] G. Matthaei, L. Young, E. M. T. Jones, Microwave Impedance-matching Networks, and Coupling Structures, Artech House, USA, 1985.

[2] Lugo, C. and J. Papapolymerou, “Multilayer Dual-band Filter Using a Reflector Cavity and Dual-Mode Resonators,” Microwave and Wireless Components Letters, IEEE, 2007. 17(9): pp. 637-639.

[3] Muhamad Kamil Khalid, Noriza Othman, Mohd Khairul Mohd Salleh, “Low temperature co-fired ceramic coupled-line bandpass filter design,” IEEE Symposium on Computer & Informatics, 2013, pg. 51-54.

[4] Hashemi, S.K., “Dual-band bandpass filters based on multilayer ring resonators,” in Mediterranean Microwave Symposium (MMS), 2011 11th. 2011.

[5] Djaiz, A. and T.A. Denidni, “Dual-Band Microstrip Filter Using a Multilayer Structure for Wireless Applications at 2.45 and 5.8 GHz. in Vehicular Technology,” Conference, 2006. VTC-2006 Fall. 2006 IEEE 64th. 2006.

[6] Djaiz, A., T.A. Denidni, and M. Nedil, “Dual-band filter using multilayer structures and embedded resonators,” Electronics Letters, 2007. 43(9): pp. 527-528.

[7] Radonic, V. and V. Crnojevic-Bengin, “Multilayer dual-mode dual-band filter using square loop resonators,” in Microwave Conference (EuMC), 2010 European. 2010.

[8] Chen, J.X., et al., “Multilayer independently controllable dual-band bandpass filter using dual-mode slotted-patch resonator,” Electronics Letters, 2013. 49(9): pp. 605-607.

[9] M Hung-Wei, W., C. Yu-Fu, and C. Yung-Wei, “Multi-Layered Dual-Band Bandpass Filter Using Stub-Loaded Stepped-Impedance and Uniform-Impedance Resonators,” Microwave and Wireless Components Letters, IEEE, 2012. 22(3): pp. 114-116.

[10] Ching-Wen Tang, Po-Hsien Wu, “Design of a planar dual-band bandpass filter,” IEEE Microwave and Wireless Components Letters, vol. 21, no. 7, pp. 362-364, Jul 2011.