Dual-Band Bandpass Filter using Defected Microstrip Structure (DMS) for WIMAX Applications

Mohamad Ariffin Mutalib, Zahriladha Zakaria, Noor Azwan Shairi, Sam Weng Yik, Yully Erwanti Maskurin and Mohd Khairy Zahari

Centre for Telecommunication Research & Innovation (CeTRI),
Faculty of Electronic & Computer Engineering, Universiti Teknikal Malaysia Melaka (UTeM),
Hang Tuah Jaya 76100, Durian Tunggal, Melaka, Malaysia.
ariffinmutalib@gmail.com

***Abstract*—This paper presents dual-band bandpass filter using defected microstrip structure (DMS). The two DMSs was integrated with short circuit stub bandpass filter to produce high attenuation and good selectivity between dual-bandpass. The DMS was designed at 3 GHz with a fractional bandwidth of about 20% and the attenuation is better than 70 dB. The group delay in the passband of dual-band was lower than 1.2 and 1.5 ns respectively. The design was simulated and fabricated on a Roger Duroid RO4350 with a thickness of 0.508 mm and dielectric constant, εr of 3.48. This type of filter is useful in any RF/microwave communication systems to enabling pre-selection of more than one band from interferers. While maintaining its excellent performance, the overall physical and cost reduction can also be achieved using this technique.**

***Index Terms*—Microwave Filter; Bandpass; Dual-Band; Defected Microstrip Structure (DMS); Q-Factor.**

I. Introduction

In recent years, bandpass filters play an important role in modern wireless mobile communication systems. The demand for new designs and approaches of this filter is increasing and intensively investigated. There are many applications used the filters in approximately all aspects and operate in a single-frequency band. The development of the filter technologies approach new method and demand a higher level of applications which can support dual band in a single device. For example, the GSM and CDMA mobile phones operate at 900 MHz and 1.8 Hz as well as WiMAX cover dual frequency band which are 2.5 GHz and 3.5 GHz [1]. Therefore, dual-band filter are significant elements at microwave frequency for wireless communication.

In [2]-[4], the various method and synthesis theory have been reported to design a wideband bandpass filter. The dual mode ring resonator in [2] was design using open-circuited stub. The filter design exhibited a poor performance in term of higher and lower frequency due to the nature of dual-band operation. But, this design can be produced a good insertion loss in the passband. The improvement can be made by using a series of rings to obtain wide lower and upper stopbands. In [3], the composite structure is favorable design for wideband filter. The combination of lowpass and highpass filter with high selectivity response of the bandpass filter to produce at the stopband insertion loss. However, this method has the drawback to control the ripple of composite structure lowpass and highpass response in order to produce a wideband frequency. A filter was developed in [4] which designed by using lossy composite substrate which attenuates a high frequency signal. However, this filter has a poor impedance matching at higher frequency and lacked sharpness at the lower frequency. The dual-band filter was designed by converting a single-band bandpass filter into a narrow band dual-band bandpass filter [5]. However, the response was shifted to the left by 100 MHz compare to the simulation results. This problem occurs during the manufacturing process and also inaccuracy of the substrate dielectric constant. In [6], the dual-band was designed by combining open- and short-circuit stubs and it was inspired by [7]. A transmission line shunted by two parallel open stubs and proposed as the dual-band inverter. However, the response has poor in term of insertion loss with 6 dB at 2.42 GHz. In [8], a dual-band filter was designed using a multilayer includes a reflector cavity and a dual-mode resonator. This type of filter consists of two different layers with different dielectric constant and height enable the creation of dual-band filter response. But, the harmonic suppression was introduced at the higher frequency that may interrupt with other frequency band.

The photonic band gap (PBG) structure [9], defected ground structure (DGS) [10], and defected microstrip structure (DMS) [11]-[12] have attracted the interest of many researchers. This method can produce the outstanding performance in term of sharp selectivity at the cutoff frequency. The characteristic of DMS is quite similar with DGS and both methods produce narrow sharp stopband frequency response. This structure also has an advantage in term of good sharpness response, low loss and simple circuit topology [13]. The comparison of the DGS and DMS structure is shown in [14]. The equivalent circuit lumped element has been reported in [15], to prove the concept of model transmission line of DMS. However, the equivalent circuit of modelling DMS provides only single band characteristics.

In this paper, a new topology of dual-band bandpass filter using integrated short circuit stubs and DMS is presented. A wideband bandpass filter was designed using quarter wavelength short circuit stubs with high selectivity and better return loss. While the band reject response was realized using the DMS with high attenuation and wider bandwidth. The dual-band bandpass filter was designed at the center frequency of 2.5 GHz and 3.6 GHz with FBW of about 16% and 16.7% respectively. The theoretical, simulated and measured results were obtained and demonstrated in this paper.

II. Wideband Bandpass Filter Design

The wideband bandpass filter was designed using quarter wavelength short circuit stubs with a fractional bandwidth of about 51.6% at the passband. The design of the filter was simulated using microstrip structure on the Roger Duroid RO4350 substrate with dielectric constant and the thickness of 3.48 and 0.508 mm respectively. Figure 1(a) shows the current flow visualization at center frequency of 3.1 GHz where the maximum value of current flow is 14.32 a/m. Figure 1(b) shows the simulated results of S-parameter with group delay. The group delay varies between 0.75 to 0.82 ns, within the passband response. The simulated group delay for the wideband bandpass filter is very flat in the passband. The minimum insertion loss of wideband bandpass filter structure is 0.3 dB at 3.1 GHz and the return loss is better than 18 dB.

Table 1 shows the results for wideband band-pass filter short circuit stub. The wideband bandpass filter structure has a bandwidth of around 1.6 GHz. The insertion loss S_{21} of the wideband bandpass filter is 0.2 dB.

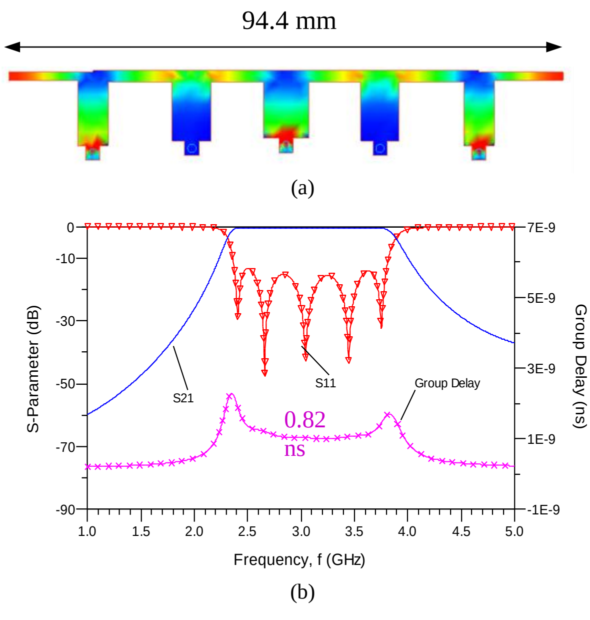


Figure 1: Simulation response (a) Current flow visualization of band-pass filter short circuit stub at 3.1 GHz and (b) Simulated response of band-pass filter short circuit stub with group delay.

Table 1
Results of Wideband Band-Pass Filter Short Circuit Stub.

Parameters	Values
Frequency Band (GHz)	2.3 – 3.9
Fractional Bandwidth (%)	51.61
Insertion Loss, S_{21} (dB)	0.3
Return Loss, S_{11} (dB)	20
Group Delay (ns)	0.82
Dimension (mm)	94.4 x 31

III. U-Shaped Of Defected Microstrip Structure (DMS)

The DMS was developed to reject the undesired signal that may interrupt the other signals. Figure 2 illustrates the geometry of U-shaped DMS which consists of a horizontal slot and a vertical slot in the middle of a microstrip transmission line. The DMS will defect the microstrip line to disturb the electromagnetic (EM) flow of the design in order to minimize the circuit. The DMS structure can be designed at any frequency by simply adjusting its length, *l*, and width, *h*, of the structure. The unloaded *Q*-factor, Q_u can be approximately determined using:

$$Q_u = 2\omega_0/\Delta\omega \quad (1)$$

where ω_0 is resonant frequency and $\Delta\omega$ is 3-dB bandwidth.

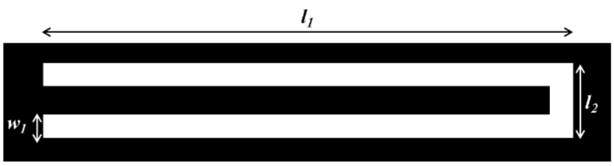


Figure 2: Dimension of DMS U-Shape, l_1=16.2 mm, l_2=1.1 mm, W_1=0.35 mm

As a result, the proposed inverse T-shape DMS has shown a good bandstop response with a narrow bandwidth and high selectivity that are necessary to integrate inside the bandpass structure. This is to remove the interference signal within the wideband applications. Figure 3 shows the equivalent circuit of DMS. The parallel capacitance and inductance value for the given DMS cell can be extracted equation, from the attenuation pole location. In the following f_0 and f_c is resonance frequency and the cutoff frequency respectively:

$$C = f_c/200\pi(f_0^2 - f_c^2) \quad (2)$$

$$L = 1/(4\pi^2 f_0^2 C) \quad (3)$$

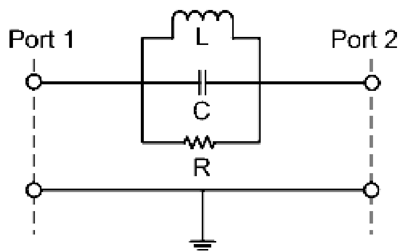
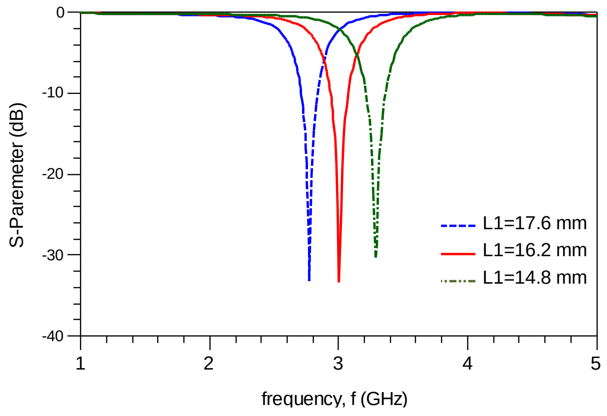
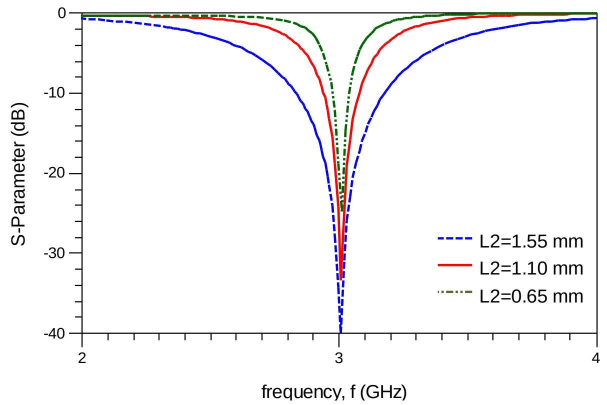


Figure 3: Equivalent circuit of DMS structure

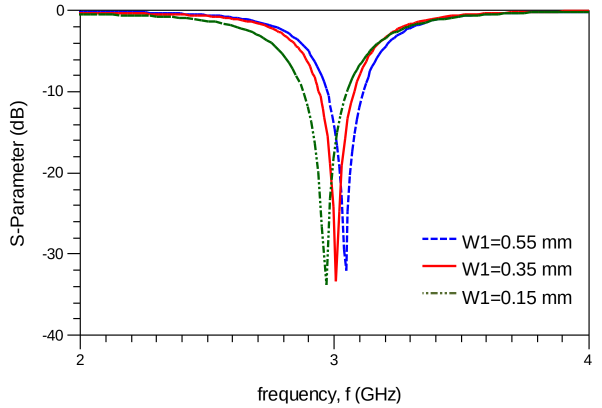
Figure 4(a) shows the parametric analysis of the proposed U-shaped of DMS. This is to determine the resonant frequencies at 2.8 GHz, 3.0 GHz and 3.25 GHz when the values of l_1 are 17.6 mm, 16.2 mm and 14.8 mm, respectively. Figure 4(b) shows the effects of resonant frequency, when l_2 is adjusted with l_1 and W_1 is kept constant. The length, *l* of the DMS also affects the performance of the DMS. The bandwidth will wider with different resonant frequency, if the width of the DMS has increased from 1.55 mm to 0.65 mm. Therefore, the width of 1.10 mm is chosen in this study. The analysis of the dimension W_1 with constant l_1 and l_2 shows the changing of the resonant when increase the dimension. The response was shifted to 2.95 GHz, 3.0 GHz and 3.05 GHz as shown in Figure 4 (c). The dimensions of U-shaped DMS are then further optimized using EM simulations to obtain a good response with a sharp notch and high attenuation.



(a)



(b)



(c)

Figure 4: Simulated response of parametric analysis (a) varying l_1=17.6 mm, 16.2 mm and 14.8 mm, (b) varying l_2 = 1.55 mm, 1.10 mm and 0.65 mm, and (c) varying W_1 = 0.55 mm, 0.35 mm and 0.15 mm.

IV. Integration Of Bandpass Filter With DMS

The layout of the dual-band bandpass filter is shown in Figure 5. The both U-shaped of DMS is placed on the connecting line to introduce high attenuation of the band reject response. The length of U-shape of DMS should be λ/4 at the desired frequency in order to produce sharp rejection and to ensure that the second resonant harmonic does not appear in the higher frequency. The current flow visualization of this integrated bandpass filter with U-shaped of DMS shows the concentration occur in DMS structure where focus at 3 GHz.

Figure 6 illustrates the fabricated of dual-band bandpass filter with U-shaped of DMS. The measurement results were taken using the Agilent Vector Network Analyzer (VNA).

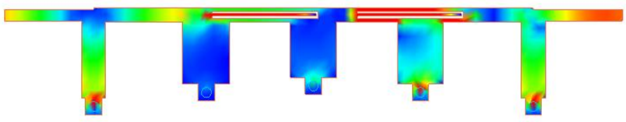


Figure 5: Current flow visualization of bandpass filter integrated with U-shaped of DMS at 3 GHz

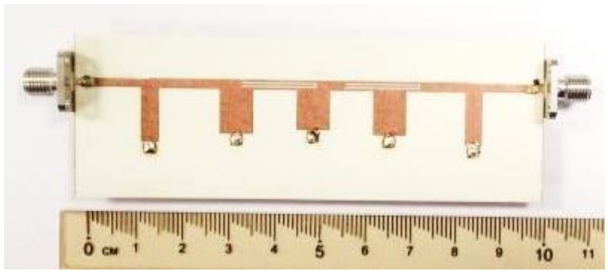
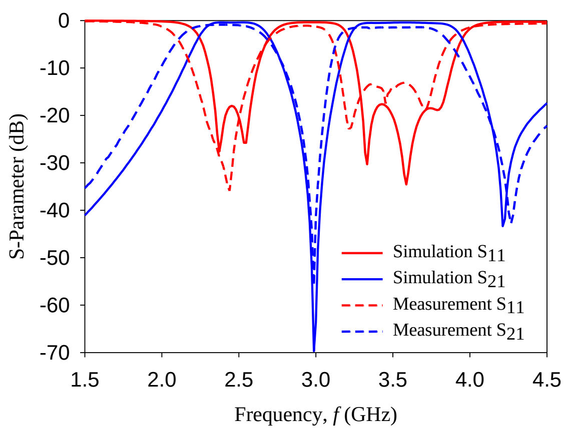
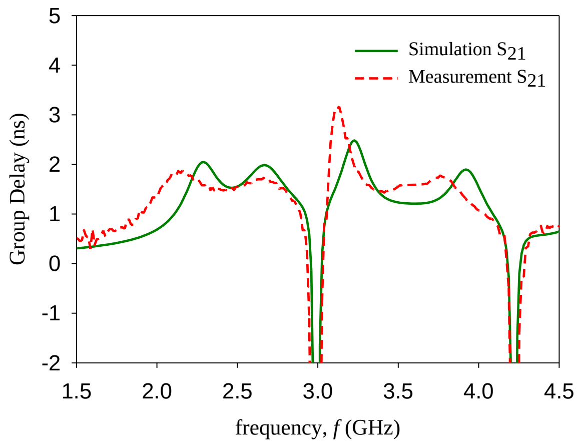


Figure 6: Fabricated of dual-band bandpass filter



(a)



(b)

Figure 7: Comparison measured and simulated result of dual-band bandpass filter (a) S-parameter and (b) Group delay

Figure 7(a) shows a comparison of measured and simulated frequency response. It can be found that the measured result is good agreement with the simulation. The measured passband of frequency response has been found to be at the centre frequency of 2.5 GHz and 3.6 GHz (FBW=16% and 16.7%). The return and insertion losses of this type of dual-band bandpass filter are found to be lower than 18 dB and better than 1 dB, respectively. The band reject response of DMS is 3.0 GHz with the fractional bandwidth of around 20%. The group delay of the wideband bandpass filter with DMS was measured and compared with the simulation as shown in Figure 7(b). The measured group delay was found very flat in the whole band except in the band reject response. The overall measured results are in good agreement with the simulations.

V. Conclusion

In this paper, a new class of dual-band bandpass filter with U-shaped of DMS has been presented and demonstrated in detail. The integration of two DMSs under a high-low transmission line introduces a high attenuation to separate the frequency band. A compact dual-band bandpass filter with the centre frequencies at 2.5 and 3.6 GHz has been designed, fabricated and measured. The experimental performance shows good return loss and low insertion loss with 18 dB and 0.2 dB respectively. Furthermore, the proposed design of integrated with two DMSs produced high selectivity of dual-band bandpass filter. This type of integrated bandpass filter with two DMSs is very useful in order to produce high selectivity and low insertion loss, especially in WiMAX, WLAN, etc.

Acknowledge

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