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Design of Microstrip Bandpass Filter with Defected Microstrip Structure (DMS)

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ABSTRACT

This paper presents a novel design of Chebyshev wideband bandpass filter (BPF) realized using microstrip with Defected Microstrip Structure (DMS) to produce bandpass and band reject characteristics simultaneously. This new class of filter is designed based upon λ_g0/4 short-circuited stubs structure of 7th degree. The filter exhibits wide bandwidth response from 3 to 6 GHz with a return loss, S11, better than -20 dB and insertion loss, S21, of around -0.1 dB respectively. While, the DMS exhibit a band reject response better than -20 dB at a frequency of 5.2 GHz with a narrow bandwidth. Therefore, the integrated BPF and DMS produce wideband bandpass and band reject response simultaneously in order to remove any undesired signals in the passband of the bandpass response. This design is simulated on a Roger Duroid RO4350 with a dielectric constant,ε_r of 3.48 and a thickness of 0.508 mm. The simulation results show a promising performance that could be further examined during fabrication and experimental works in a laboratory. This type of filter is useful in any RF/ microwave communication systems particularly to eliminate any undesired signals in wideband applications. The reduction of overall physical volume and weight as well as cost and maintaining its excellent performance can also be achieved using this technique.

INTRODUCTION

Recently, communication systems are one of the most important technologies that widely used in our daily life to communicate from one place to another place without moving to a particular place. One of the key issues in the wideband range is the interference with wireless local area networks (WLANs) at 5.2 GHz. A good performance with high selectivity of the bandpass response as well as the capabilities to avoid interference from existing radio signals are highly requiredfor wideband microwave filter.There has been increasing research on the wideband BPF to satisfy the two essential requirements (Zakaria, Z.,*et. al.*, 2013 and Zakaria, Z., *et. Al.*, 2008). In designing the microwave filter, researchers focus on how to produce the wideband frequency but there is some interference signals must be avoided under the wideband frequency. A number of synthesis theory and design methods of wideband BPFs have been reported (Ishida, H.,*et. al*., 2004; Hsu, C.L.*et.al*., 2005; Saito, A.,*et. al*., 2003; Wong W.T.,*et. al*., 2005). In Ishida, H.,*et. al*., 2004, the filter using a dual-mode ring resonator with open-circuited stub is designed. 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.

The method of combination lowpass and highpass filter is also capable of realizing a wideband bandpass filter. The composite method can produce a high selectivity of the transmission zeros (Hsu, C.L.,*et.al*., 2005). But, this method is hard to control the ripple of composite structure lowpass and highpass response in order to produce a wideband frequency. A filter was developed in (Saito, A.,*et. al*., 2003) 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. A microstrip bandpass filter with highly selective has been reported in (Wong, W.T.,*et. al*., 2005), which design using an optimum distributed highpass filter with an 11^{th} order to produce wideband. This design connects the lines between short-circuited stubs meandered to reduce the size but it suffers with poor insertion loss in the passband, i.e. changing from -1.16 dB at 3.1 GHz to -4.7dB at 10.6 GHz, which is apparently not good enough.

The photonic band gap (PBG) structure (Srivastava, R.,*et. al*., 2008), defected ground structure (DGS) (Zakaria, Z.,*et. al*., 2012), and defected microstrip structure (DMS) (Chaudhary, G.,*et. al*., 2011) have attracted

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the interest of many researchers. This method can produce the outstanding performance in term of sharp selectivity at the cutoff frequency.Slot on the strip that is DMS makes a defect on the circuit very useful in designing microwave devices such as antennas (Ahmad, B. H., *et. al.,* 2013), filters (Shairi, N. A., *et. al.,* 2013) , and amplifiers (Pongot, K., *et. al.,* 2013). The characteristic of DMS is quite similar with DGS and both methods produce narrow sharp stopband frequency response. This structure also have an advantage in term of good sharpness response, low loss and simple circuit topology (Xiao, J. & Zhu, W., 2011). The comparison of the DGS and DMS structure is shown in Tirado-Mendez, J. A., 2004. The equivalent circuit lumped element has been reported in Kazerooni, M., *et. al.,* 2010, 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 integration between BPF and DMS using the microstrip structure is presented. The BPF is providing wideband frequency from 3 GHz to 6 GHz with minimum stopband insertion loss of -15 dB. The DMS is designed at a frequency of 5.2 GHz with a band reject response better than -20 dB with a very narrow bandwidth characteristic. The improvement of the design is introduced using S-shape structure in order to provide small size and better performance in term of selectivity.

Bandpass Filter Structure:

The bandpass filters in

Fig. 1 isdesignedusing shunt short-circuited stubs which have $\lambda_{g0}/4$ long with connecting lines that are also $\lambda_{g0}/4$ long, where $\lambda_{g0}$is the guided wavelength in the medium propagation at the midband frequency f_0. The design equations for determining these characteristics admittancesare described in Hong, J. S., 2011and given by:

$$\theta = \frac{\pi}{2}\left(1 - \frac{FBW}{2}\right) \quad (1)$$

The bandpass filter is designed to have a fractional bandwidth (FBW) 0.5 at a midband frequency f_0 = 4.5 GHz. A 50 Ω impedance is chosen which give Y_0 = 1/50 mhos. The parameter design is summarized in

Table 1 (Hong, J. S., 2011). The filter circuit model is shown in

Fig. 2 (a). Based on formulas in Hong, J. S., 2011, the line impedance of each stub and connecting line in

Fig. 2 (a) can be calculated as follows: $Z_1 = Z_7 = 51.7$ Ω, $Z_2 = Z_6 = 14.74$ Ω, $Z_3 = Z_5 = 28.94$ Ω, Z_4=12.54 Ω, $Z_{1,2} = Z_{6,7} = 39.2$ Ω, $Z_{2,3} = Z_{5,6}$=40.57 Ω, $Z_{3,4} = Z_{4,5} = 41.13$ Ω. The simulated frequency response of the filter is shown in

Fig. 2(b). In general, the performance of the frequency response is seen to be good agreement with the modelling circuit of transmission line bandpass filter with a quarter wavelength short circuited.

Table 1shows the summarize design parameter for Y_i and $Y_{i,i+1}$ of 7^{th}order bandpass filter short circuit stub.

Table 1: Design parameter of a 7^{th} stub bandpass filter with $\boldsymbol{\lambda_{g0}/4}$ short-circuited stubs.

i	Y_i(mhos)	$Y_{i,i+1}$(mhos)
1	0.03681	0.02577
2	0.07271	0.02735
3	0.07257	0.02601
4	0.07334	0.02601
5	0.07257	0.02735
6	0.07271	0.02577
7	0.03681	-

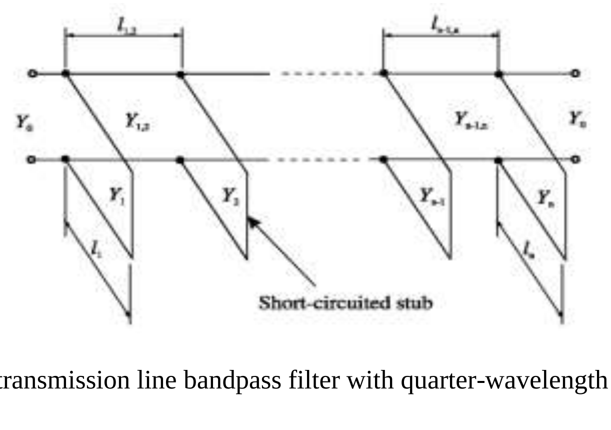
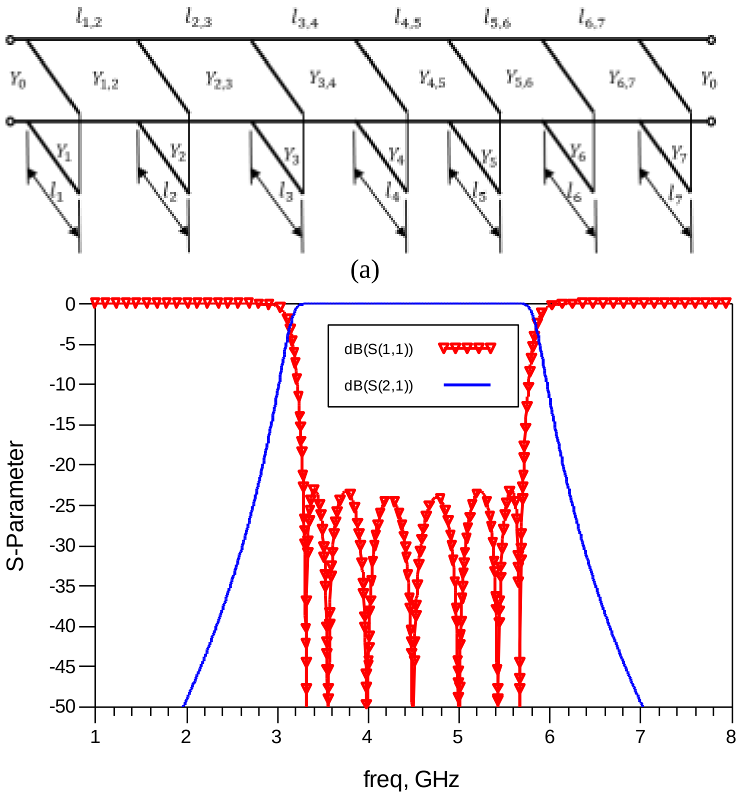


Fig. 1: Modeling circuit of transmission line bandpass filter with quarter-wavelength short-circuited.



(a)

(b)

Fig. 2: (a) Modelling circuit of the proposed wideband bandpass filter based on optimum highpass filter in figure 1 (a). (b) Simulated of ideal frequency response of the bandpass filter.

The width and length of the conductor microstrip with different dielectric will be representedusing (2) and (4) (Hong, J. S., 2011).

for $W/h \leq 2$

$$\frac{W}{h} = \frac{8e^{A}}{e^{2A} - 2} \quad (2)$$

With

$$A = \frac{Z_c}{60}\left\{\frac{\varepsilon_r + 1}{2}\right\}^{0.5} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left\{0.23 + \frac{0.11}{\varepsilon_r}\right\} \quad (3)$$

and for $W/h \geq 2$

$$\frac{W}{h} = \frac{2}{\pi}\left\{(B-1) - \ln(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left[\ln(2B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right]\right\} \quad (4)$$

With

$$B = \frac{60\pi^2}{Z_c\sqrt{\varepsilon_r}} \quad (5)$$

By using the microstrip design equation above, the width and guided quarter-wavelengths with the characteristic admittances in

Table 1 can be found and calculate using equation (6). The summarize design parameter for microstrip 7th stub bandpass filter is listed in

The design ofthe filter is implemented using microstrip on the Roger Duroid RO4350 substrate (ε_r=3.48, $tan\delta$=0.0019, and thickness = 0.508 mm) the circuit layout is shown in Fig. 3(a) and Fig. 4 (a). In order to further reduce the filter size, another microstrip wideband filter based on Fig. 3(a) is implemented with its layout in Fig. 4(a). Here the short-circuited stubs are arranged such that S-shape to reduce the length of the structure. The simulation response of this two structure shows the same performance in term of selectivity but the advantage of S-shape optimizes the size of physical structure (Zakaria, Z., *et. al.*, 2012). Fig. 5 shows the comparison simulation results of frequency response between conventional short circuit stub and S-shape wideband bandpass filter short circuit stub. The insertion loss, *S21is* nearly to -5 dB and produced good selectivity of wideband bandpass. The return loss, *S11* of S-shape is slightly higher -18 dB.

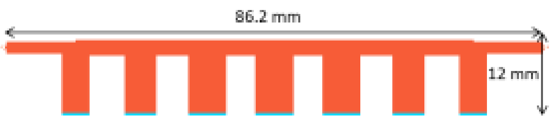
Table 2.

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{re}}} \tag{6}$$

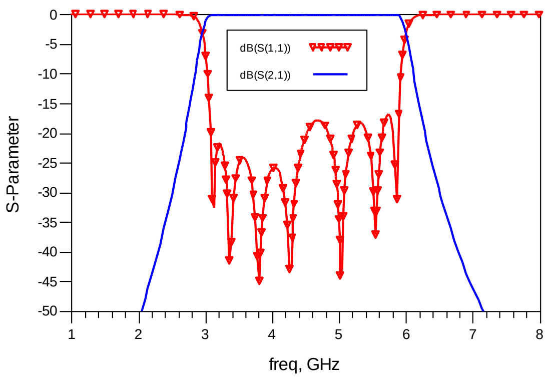
The design ofthe filter is implemented using microstrip on the Roger Duroid RO4350 substrate (ε_r=3.48, $tan\delta$=0.0019, and thickness = 0.508 mm) the circuit layout is shown in Fig. 3(a) and Fig. 4 (a). In order to further reduce the filter size, another microstrip wideband filter based on Fig. 3(a) is implemented with its layout in Fig. 4(a). Here the short-circuited stubs are arranged such that S-shape to reduce the length of the structure. The simulation response of this two structure shows the same performance in term of selectivity but the advantage of S-shape optimizes the size of physical structure (Zakaria, Z., *et. al.*, 2012). Fig. 5 shows the comparison simulation results of frequency response between conventional short circuit stub and S-shape wideband bandpass filter short circuit stub. The insertion loss, $S_{21}$is nearly to -5 dB and produced good selectivity of wideband bandpass. The return loss, S_{11} of S-shape is slightly higher -18 dB.

Table 2: Microstrip design parameter of a 7th stub bandpass filter with $\boldsymbol{\lambda_{g0}/4}$ short-circuited stubs.

i	W_i(mm)	$\lambda_{g0i}/4$(mm)	$W_{i,i+1}$(mm)	$\lambda_{g0i,i+1}/4$(mm)
1	3.03	9.70	7.35	9.88
2	6.72	9.41	7.98	9.85
3	6.70	9.38	7.45	9.75
4	6.78	9.42	7.45	9.75
5	6.70	9.38	7.98	9.85
6	6.72	9.41	7.35	9.88
7	3.03	9.70	-	-

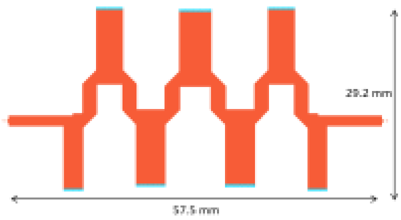


(a)

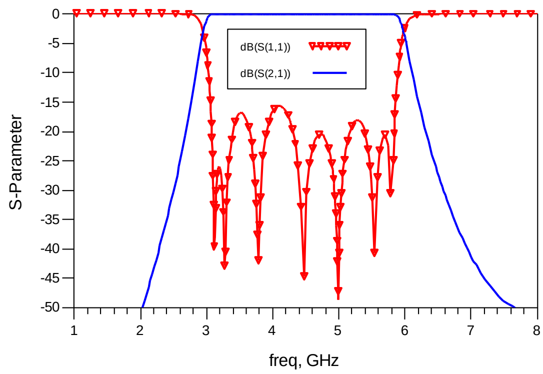


(b)

Fig. 3: (a) Layout of conventional wideband bandpass filter short circuit stub (b) Simulated frequency response of conventional wideband bandpass filter short circuit stub



(a)



(b)

Fig. 4: (a) S-shape wideband bandpass filter short circuit stub (b) Simulated frequency response of S-shape wideband bandpass filter short circuit stub

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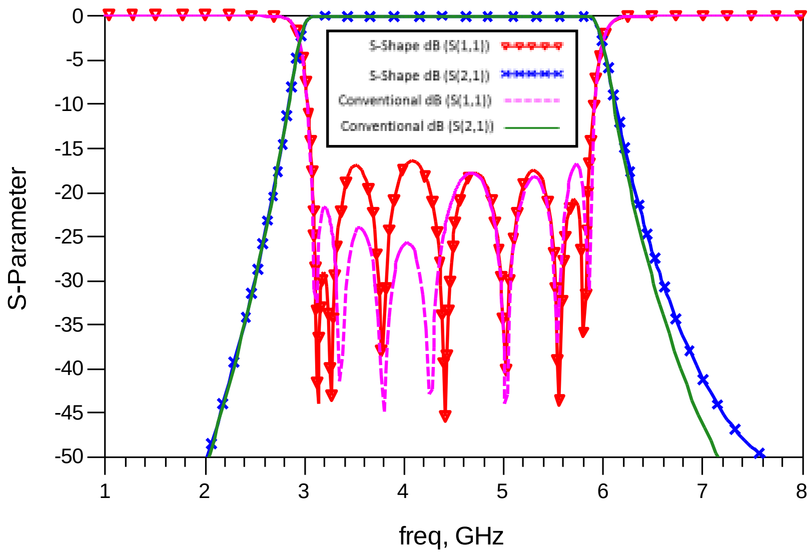


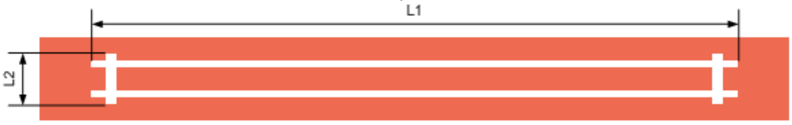
Fig. 5: Comparison simulation results of frequency response between conventional short circuit stub and S-shape wideband bandpass filter short circuit stub.

Bandpass Filter With DMS:

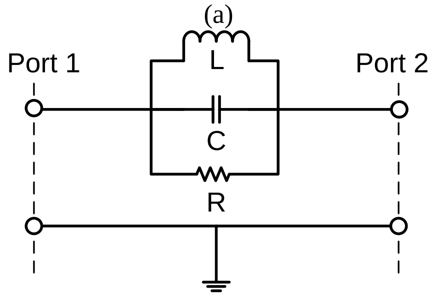
In order to demonstrate the band reject from DMS structure, a bandstop filter with a single band is designed with dielectric constant, ε_r = 3.48 and thickness of the substrate, t = 0.508 mm as shown in Fig. 6 (a) The structure of DMS consists of square shape slot which defect the microstrip line to disturb the electromagnetic (EM) flow of the design. The structure is produced a narrow bandwidth and sharp rejection at a specific frequency (according to its dimensions). The structure of DMS can also be represented by the single parallel RLC resonators as shown in Fig. 6 (b). Fig. 6 (c) and (d) show that if the length of the DMS structure increases its cut-off and pole frequency decrease. So, a DMS structure can be designed in any frequency by simply adjusting its length L_1 and L_2. The parallel capacitance and inductance value for the given DMS cell can be extracted from the attenuation pole location. In the following equation f_0 and f_c are resonance frequency and cut-off frequency respectively:

$$C = \frac{f_c}{200\pi(f_0^2 - f_c^2)} \quad (7)$$

$$L = \frac{1}{4\pi^2 f_0^2 C} \quad (8)$$



(a)



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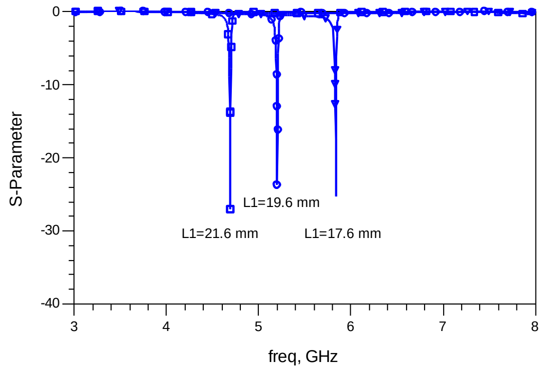
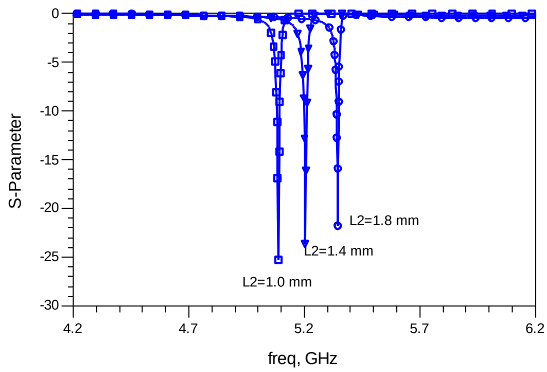


(c)



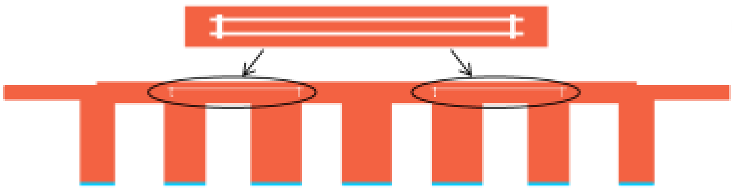
(d)

Fig. 6: (a) Structure of Defected Microstrip Structure (DMS), (b) Equivalent circuit of DMS, (c) Simulated S-parameter L_1= 21.6 mm, 19.6 mm, and 17.6 mm, and (d) Simulated S-parameter L_2= 1.0 mm, 1.4 mm and 1.8 mm.

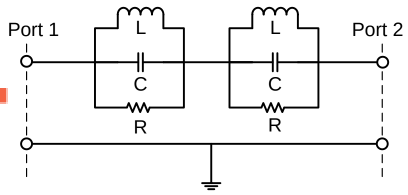
The DMS can be placed at any physical structure to produce band reject response.

Fig. **7** (a) shows the structure of 2-DMS consists of two square shape slot which defect the microstrip line integrated with conventional bandpass filter short circuit stub. The same substrate and dimension of DMS is used.The RLC equivalent circuit model of the 2-DMS structureis shown in

Fig. **7** (b). The simulation result of integrated bandpass filter short circuited stub and DMS shows the sharpness band reject at frequency 5.2 GHz and the bandpass response show the return loss is greater than -12 dB.



(a)



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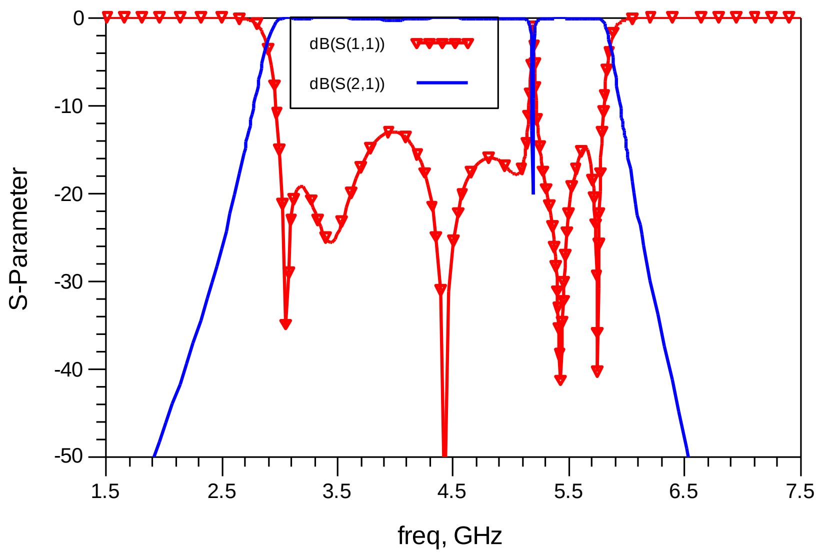

(c)

Fig. 7: (a) Physical structure of integrated with DMS, (b) Equivalent circuit of 2-DMS (c) Simulation result of integrated short circuit stub bandpass filter.

Conclusion:

A structure ofintegrated bandpass filter with DMS using microstrip technology has been designed and simulated. The resonant of double DMS are cascaded under a high-low transmission line tointroduce a narrow rejection band in the wideband frequency. The simulation results from EM simulation of the integrated bandpass filter and DMS show good agreement witha bandwidth of around 3 GHz. Areturn loss, S_{11}, better than -20 dB and insertion loss, S_{21}, around -0.1 dB have been obtained particularly in the passband.While the band-reject response better than -20 dB at a frequency of 5.2 GHz with a narrow bandwidth have been achieved. This type of integrated bandpass filter with DMS is very useful for removing any undesired signal within the passband especially for wideband applications such as radar, microwave imaging, etc. The design has the benefit with the reduction of overall physical size as well as the undesired radiation can be avoided.Therefore, the study can be further explored in future works by fabricating and validating the prototype in the laboratory.

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