Dual-Path Multilayer Substrate Integrated Waveguide Circular Cavity Filter

S. A. Nordin, Z. I. Khan, N. A. Wahab , N. Othman, Nur Dalila K. A, S. S. A. Wahid

***Abstract*— A dual-path multilayer substrate integrated waveguide circular cavity filter is introduces in this paper. The proposed dual-path multilayer circular cavity are designed between range 4.79 GHz to 4.85 GHz is thus suitable for wireless communication applications including DCS, WiMax, WLAN, WiBro, Bluetooth and C-band applications such as satellite communications, and weather radar systems. Two circular cavity based on SIW are connected via connect hole and probe which is attached at both side of the microstrip feed lines. Width and length of the feed lines probes have the ability to control the filter performances in terms of insertion and return loss. Measured response from fabricated filter shows resonant frequencies at 4.79 GHz and 5.05 GHz, and measured insertion loss found higher than simulation result around 4.47 dB. Consideration during fabrication and assembly process are required to avoid higher losses. The performances of the filter in terms of return loss, insertion loss and resonant frequency are analyzed in both simulations and measurement to validate the concept.**

***Index Terms*— surface integrated waveguide, cavity resonator, dual-band circular cavity, multilayer dual cavity.**

I. INTRODUCTION

Increasing demand on the wireless communication system with stringent requirements and high performance have attracts research which focus on dual-band and multi-band frequency resonator filter [1]-[2]. Recently, concurrent system have increased focus on combination circuit operating at multiband having single circuitry design. By applying the concept, the development of dual-band on multilayer technology has allowed miniaturization in microwave components and more advanced design [3]-[4]. Basically, dual band filters are designed based on parallel integration of two bandpass filter using dexplexing element or cascading a bandstop filter to produce multiple passbands [5]–[7]. However, it become popular using multilayer technology of SIW to create multiple passbands.

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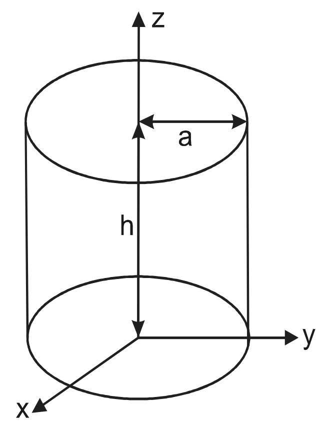


Fig 1: Geometry for circular cavity

Compact size, low cost, high Q-factor and ease of manufacture make the substrate integrated waveguide technology attractive for planar filter design. One such design of cavity resonator filter for dual-band application is presented in [8]–[10]. However, simple rectangular SIW cavity have larger size at lower frequency band. Several structure using circular SIW cavity have been reported in [11] and [12] which size, design flexibility and Q-factor were considered as important parameters.

Among various shapes of planar cavity filter, circular cavity substrate integrated waveguide became popular since it provide higher Q-factor, small size and unique structure which make it easy to be integrated with other planar technologies [13]–[15].

In this paper, a dual-path multilayer substrate integrated waveguide circular cavity filter is introduce. Two circular cavity based on SIW are connected via connect hole and probe which are attached to both side of the microstrip feed lines. Two circular cavity are directly connected to produce the coupling between the resonators. Triangle probe are attached at the both side of the microstrip feed lines which are connected to input and output port. Dual path modes are achieved at 4.79 GHz and 4.85 GHz with fractional bandwith 0.1 GHz.

II. DESIGN PROCEDURE

A circular cavity is formed by closing the two ends of the waveguide plates as shown in Fig. 1. The resonant frequency for circular cavity can be calculated using the following equation [16],

$$(f_r)_{mnp}^{TM^z} = \frac{1}{2\pi\sqrt{\mu_r\varepsilon_r}}\sqrt{\left(\frac{X'_{mn}}{a}\right)^2 + \left(\frac{p\pi}{\Delta h}\right)^2} \quad (1)$$

Where f_r is the resonant frequency, a is the radius of the cavity and Δh is the height of the cavity. While, *c* is refer to the speed of light, μ_r and ε_r are the permeability and permittivity of the material inside the cavity respectively, and for *m,n,p* are refering to the number of field variations in the standing wave pattern in the *x,y,z* directions. X'_{mn} is 3.8318 for the TM_{110}-mode.

Using (1), the initial dimensions of the cavity are determined for a desired frequency resonant for the TM_{110} mode and its resonant frequency is determined based on equation (2),

$$(f_r)^{TM^{110}} = \frac{C}{\sqrt{\varepsilon_r}}\cdot\left(\frac{3.8318}{2\pi a}\right) \quad (2)$$

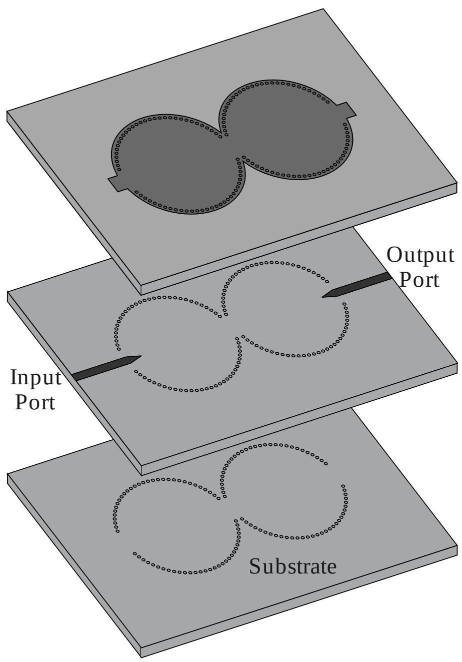


Fig 2: View of the layers.

Structure and view of each layers of the proposed dual-path resonator filter with triangle probe attached on the feed line is shown in Fig. 2 and Fig. 3. The dual-path resonator filter having radius *(a)* of 20mm, dielectric constant (ε_r) 3.48, loss tangent 0.0037 has been choosen to operate around 4.9 GHz using the well-established formulation (1) and (2). The substrate material used is Rogers RO4350B™ laminates with substrate thickness *h* =1.52 mm. The corresponding values of dimensions of radius, length, and length after optimization are obtained as referring to Table I.

TABLE I
CORESSPONDING PARAMETER AND DIMENSION

Parameters	Dimension
Length Total, L_T	121 mm
Width Total, W_T	80 mm
Radius of circle, a	20 mm
Radius of via, a_2	0.5 mm
Spacing, g	0.5 mm
Width of probe	4.7 mm
Length of probe	5 mm
Width of feedline	2.9 mm
Length of feedline	20 mm

In SIW structure, the spacing between metal via hole of side walls is limited to less than half guided wavelength at the high frequency so that the radiation losses become negligible. In this design, the via hole are arranged with an equivalent angle of 5 degree between two adjacent ones.The radius via holes is set up to be 0.5mm (D=1.0 mm), in order reduce the leakage between via walls and radiation loss.

Fig. 3 show the top view of the proposed design. Two width of W= 2.9mm microstrip lines act as feeding structure and rectangular slot serve as external coupling structure of SIW circular cavity. The triangle probe is designed in order to excite the field within the cavity waveguide and to maximize the energy transfer so that its field pattern matched with the configuration of the desired mode.

Simulations are carried out to investigate the effect of the triangle probe on the performance of the resonator filter where the simulation have been done using software circuit simulator.

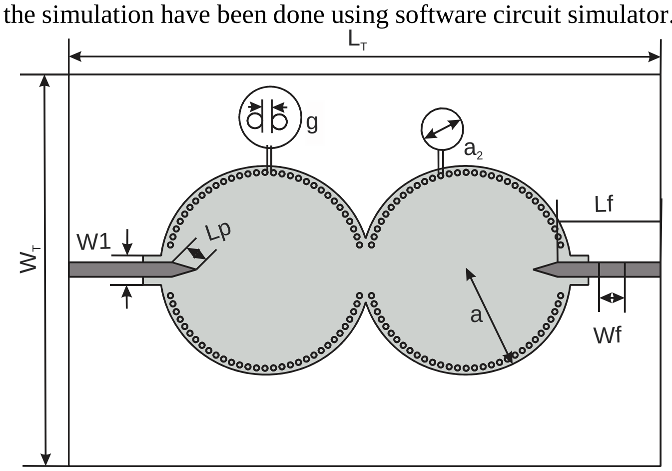


Fig 3: Geometry of the proposed filter, top view.

III. SIMULATION

In knowing the effect of each parameter, the optimum result of the proposed design is shown in Fig. 4. It shows two distinct resonance occurring around 4.79 GHz and 4.85 GHz. It is observed that the bandwidth is around 0.1 GHz. While, return loss is better than 20 dB with an insertion loss of 0.63 dB in the whole passband response. The position of via hole and length of the probe are found to be the key factors in term of insertion loss and return loss.

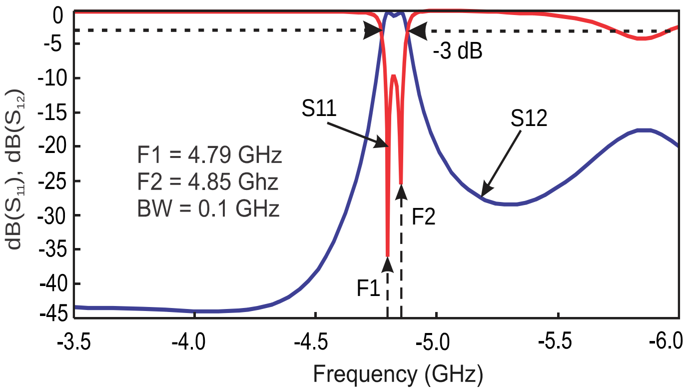


Fig 4: Simulation result of the proposed filter.

Fig. 5 shows the variation simulated result of the of S-parameters based on the adjustment equivalent angle, α (deg) with respect to the center frequency.

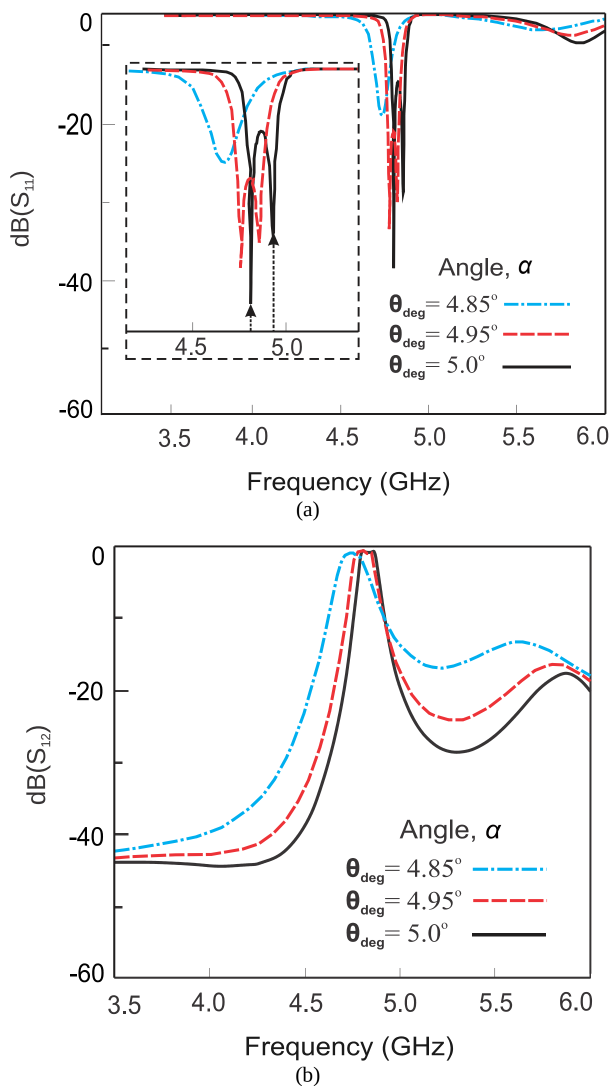


Fig 5: Effect of varying angle, α (deg), (a) S_{11} parameters and (b) S_{12} parameters.

By choosing the appropriate cavity dimensions, the dual-band can be achieve at the operating frequency at 4.79 GHz and 4.85 GHz. Based on simulation result in Fig. 5, as the equivalent angle, α, decrease the spacing between the vias become large thus reduced the number of poles at resonance frequency. Decreasing the spacing between via holes the center frequency is reduced by 0.1GHz. The optimal angle, α can be found around 5 degree in order reduce the leakage between via walls and radiation loss.

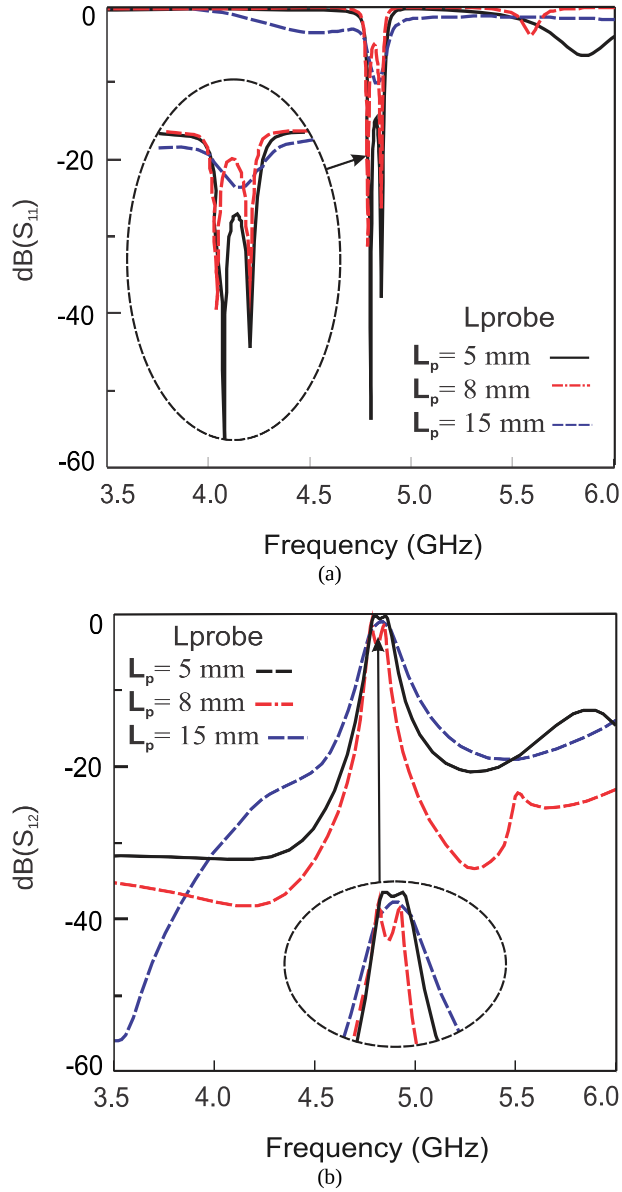


Fig 6: Effect of varying length of the probe, (a) S_{11} parameters and (b) S_{12} parameters.

The coupling effect between two dual-path circular cavity is achieved by magnetic coupling between the input and output coupling of the feedlines. Thus, in order to achieve greater performances, the dimension of probe are adjusted. Effect of varying length of the probe is shown in Fig. 6. The length of the probes has significant impact on the insertion loss and electric field in the circular cavity. Increasing the length of the probes will reduce the insertion loss. As can be seen, with the best chosen of the dimension, the spurious response at 5.5 GHz to 6 GHz can be reduced and the number of poles also clearly observed at the operating frequency.

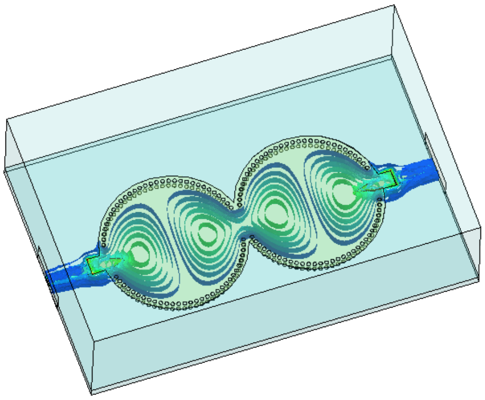


Fig 7: Simulated electric field distributions.

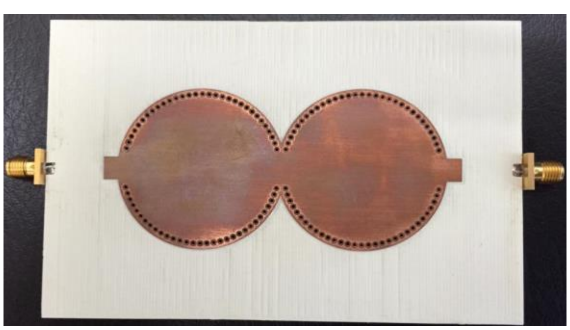
Besides, the effect of variation of the spacing between between via holes and length of the probe can be seen in Fig. 7, where it shows the electric field distributions in the dual-band filter at the operating frequency resonances. Based on the simulation, it can be seen that the proposed filter are properly excited by TM_{110} mode. Table II, tabulate the result based on the varying the length of the probe.

TABLE II
TABULATE THE RESULT BASED ON THE VARYING THE LENGTH PAPRAMETER.

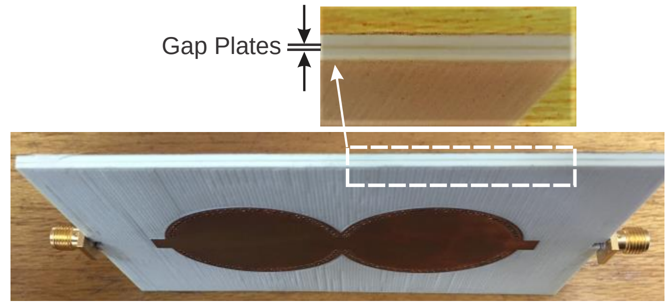
Length, L_p	Return Loss, S_{11}	Insertion Loss, S_{12}
5 mm	15 dB	0.63 dB
9 mm	6.1 dB	2.19 dB
15 mm	3.5 dB	1.57 dB

IV. FABRICATION

Dual path circular cavity was fabricated and tested using the proposed structure. The laminate was manufactured by Printed Circuit Board technology process. The thickness of the copper clad is 0.018mm and fabricated using Rogers RO4350B™ substrate with dielectric constant 3.48 and thickness 1.52 mm. The dual-band cavity filter is excited by microstrip line coupled through triangle probe at the middle side of the substrate. The photograph of the layout is described in Fig. 8.



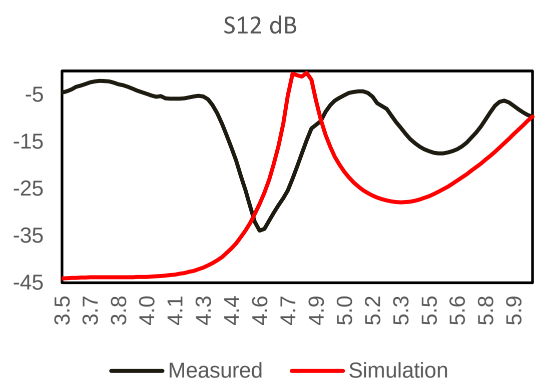
(a)



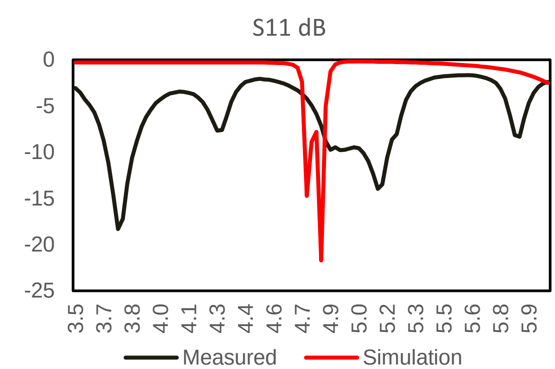
(b)
Fig 8: Pothograph of the layout of the proposed filter.

V. RESULTS AND DISCUSSION

The comparison between simulation and measured result of the proposed dual-band filter are shown in Fig. 9 and tabulated in Table III. A comparison between simulation and measurement result has been illustrates in Fig. 9(a) and 9(b). The measured response shows the resonant frequencies at 4.79 GHz and 5.05 GHz. The measurement values of return loss, S_{11} are 9.6 dB and 14.5 dB. at 5.05 GHz the measured insertion loss is 4.47 dB.



(a)



(b)
Fig 9: Comparison between measument ans simulation result of the proposed filter.

TABLE III
COMPARISON BETWEEN MEASURED AND SIMULATION RESULT.

Component	Measured	Simulation
Resonant Frequency	4.79 and 5.05 GHz	4.79 and 4.85 GHz
Insertion Loss, S12	4.47 dB	0.63 dB
Return Loss, S11	14.5 dB	15 dB

The higher insertion loss in the measurement result is mainly due to the imperfect bonding between each of substrate layers, such as mismatch in rectangular window size, and improper alignment during the assembly process. In the simulation, there is no spacing gap between each plate, but for realization each layers was embedded tight together to form the multilayer where it can be seen in Fig. 8(b).

VI. CONCLUSION

Design of dual-path multilayer substrate integrated waveguide circular cavity filter are connected via connect hole and probe has attached at both side of the microstrip feed lines is presented in this paper. The proposed filter has been designed and tested to give resonant frequency at 4.79 GHz and 5.05 GHz for the fundamental mode TM_{110}. Measured insertion loss found higher than simulation result around 4.47 dB. better bonding techniques are required in the assembly process in order to avoid losses in achiving the desired performance. All the design procedure is verified by the experimental result to ensure the validity of the concept.

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