Enhancement of Return Loss and Gain using 10mm air-cut technique for Integrated SIW Filtenna

Nurul Syafeeqa Binti Ishak
Faculty of Electrical Engineering
Universiti Teknologi MARA,
40450, Shah Alam, Selangor, Malaysia
Syfqaishak@gmail.com

***Abstract*—This paper presents a design of integrated substrate integrated waveguide (SIW) filter and microstrip antenna using multilayer approach at the nearest frequency of 2.38GHz. The design has been using Roger RT/Duroid 5880 with permittivity of Ɛr =2.2 and a thickness of 0.787mm as a substrate. The 10mm air-cut filtenna has improved by 15.51%. It is based on the circular cavity structure using TM_{010} mode for the filter and TM_{110} mode for the antenna. Both design techniques of SIW filter and microstrip antenna are coupled by rectangular iris at the common ground plane. However, losses are the main factor in SIW technology. The decreasing in dielectric loss will contribute to the reduction of total dissipated power and both filter and antenna response. Thus, to overcome the losses, lower dielectric loss is used by using air (conceptual) as the transmission medium in SIW. The simulation result show good antenna and radiation pattern that prove the capability to integrate SIW filter and microstrip antenna directly without requirement of external matching, thus it will reduce the size of the device. The design has been simulated using Computer Simulation Technology.**

***Index Terms*—Substrate integrated waveguide, microstrip antenna, iris aperture.**

I. INTRODUCTION

Nowadays, the wireless communications technology has been experiencing a rapid change of improvements such as the invention of many wireless products and services such as GSM, WLANs, satellite applications and the latest technology is LTE. All those applications use microwave devices such filters and antennas at the front end of the systems [1]. In modern wireless communications systems, filters and antennas are mainly needed both at the base station. However, the antennas and filters are usually connected to one or two filters to separate the transmitted and received signal [2].

Therefore, there will be great interest to make these wireless products to be smaller and more compact. Besides that, a wireless technology needs a good performance, low profile and small size of filter and antenna that can be implemented in the product. Several techniques have been introduced for integration of filter and antenna that offer a small size and cost reduction [3]. Thus, many researchers have found an interest in integration of filter and antenna by using substrate integrated waveguide (SIW) that can reduce the size and also the cost of implementation of both at the front-end subsystem [4].

Furthermore, due to SIW characteristics which offer low loss, higher quality factor and high in capability of power handling also made SIW as emerging approach for the implementation and integration of microwave and millimetre-wave components and wireless systems [5]. In fact, by using SIW technology, the need for external matching can be eliminated and also can reduce the overall size of the wireless devices [6].

Thus recently, an air-filled SIW has been proposed to improve the insertion loss and power handling capability with low cost structure. The purposed of introduced air-filled substrate are due to its concept of lower permittivity and lower loss tangent that can improved the performance of filter and antenna [7].

This paper demonstrates the integration of circular SIW filter and microstrip antenna based on multilayer structure. The circular SIW is placed below the circular patch antenna they share the same common ground plane. Next, an air-cut with difference size at the radius of the SIW filter. To couple between the filter and antenna, a rectangular iris aperture has been designed on the common ground plane. The "Filtenna" is designed at the nearest frequency of 2.38GHz center frequency. The propagation of the filtenna is under TM010 mode. Thus, all the simulation on these studies has been done using CST Microwave Studio.

II. METHODOLOGY

In this paper, the Roger RT/Duroid 5880 and air-filled Filtenna were optimized using Computer Simulation Technology (CST). Filter is used to reject or isolate specific frequency components. While, antenna is used to transmit Radio Frequency signal. The design of resonant frequency for TM010 circular SIW filter is fixed by diameter of 46.34 and is approximated by following formula;

$$\left(f_r^{\,filter}\right)\frac{TM^2}{010} = \frac{c}{2\pi\sqrt{\mu_r\varepsilon_r}}\left(\sqrt{\frac{2.4049}{a_{filter}}}\right)^2 \quad (1)$$

Where c is the speed of light in free space; μ_r is the relative permeability while ε_r is the dielectric permeability of the substrate respectively. The value of 2.4049 is the first zero in Bessel function and a_{filter} is the radius of the filter. There are rules in designing the SIW filter which via hole diameter, d need to be considered from the following equations;

$$d > 0.2\lambda_o\,,\ \frac{d}{p} \leq 0.5 \qquad (2)$$

The circular microstrip patch antenna is used in the integration with the circular SIW filter where the circular patch antenna is determined by following formula;

Circular radius a,

$$a = \frac{F\ (fringing\ effect)}{\left\{1+\frac{2h}{\pi\varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{\frac{1}{2}}} \qquad (3)$$

Where; $F = \frac{8.791x10^9}{f_r\sqrt{\varepsilon_r}}$ (4)

Effective radius, a_e

$$a_e = a\left\{1+\frac{2h}{\pi\varepsilon_r a}\left[\ln\left(\frac{\pi a}{2h}\right)+1.7726\right]\right\}^{\frac{1}{2}} \qquad (5)$$

Hence f_r for TM010 (given from Balanis) [8];

$$(f_r)_{110} = \frac{1.8412c}{2\pi a_e\sqrt{\varepsilon_r}} \qquad (6)$$

Where c is the speed of light in free space approximated to $3x10^8$; thus, the integration of circular SIW is where the circular antenna and are share same common ground plane. Both designs have been optimized to obtain the best performance. The integration between the SIW filter and the circular patch antenna is shown in figure 1.

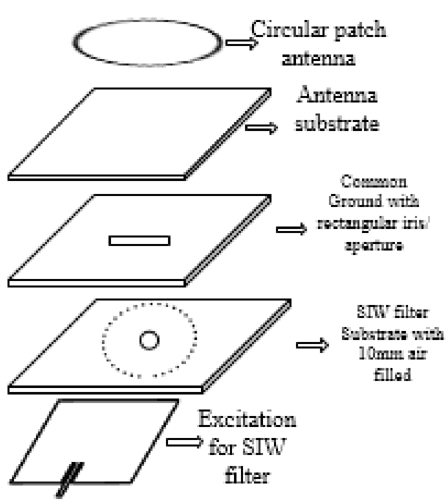


Fig. 1. Exploded view of integrated SIW filter and microstrip antenna.

Besides that, rectangular iris-coupled structure is used for the coupling between the SIW filter and the circular antenna. The coupling technique is used in order to couple the electric field between SIW filter and antenna from the EM simulations. According to [6], the two factors that determine the coupling between SIW filter and antenna are the position of iris and the size of the iris. Table 1 shows the optimized dimensions of figure 2.

Table 1. Optimized dimension of opening of 10mm air-cut Filtenna.

variable	**Dimension (mm)**
Length of the substrate, L	150
Width of the substrate, W	210
Length of patch, lp	120
Width of patch, wp	172.55
Radius of patch antenna, rp	40.50
Length Feed line, lf	15
Width of Feed line, wo	2.325
Length of inset, yo	17.34
Radius filter, RF	46.34
Thickness of substrates, ts	0.7807
Thickness of ground/ PEC	0.035
Radius of via, r	0.5
Cut out radius, rc	10
Radius of circular iris, rcg	7.1225
Length of iris, liris	0.95
Width of iris, wiris	5.4

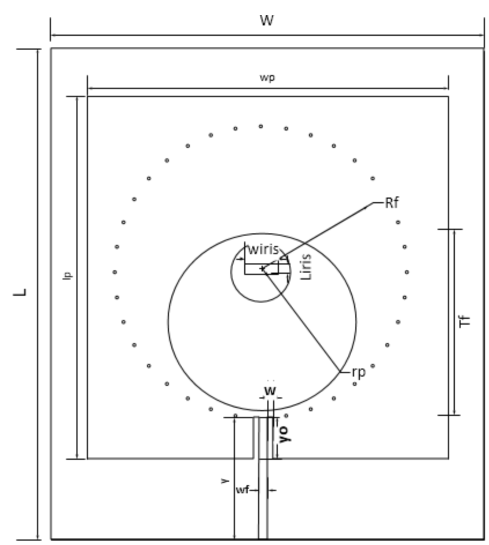


Fig. 2. Top view of SIW filter and Microstrip antenna (filtenna)

III. PARAMETRIC STUDY

Parametric study on the return loss and the antenna gain of the SIW filter and antenna was conducted using different size of cut out radius of circular SIW cavity, position of the patch antenna and position of the iris.

A. Cut out radius in SIW filter, rc

The parametric study of cut out radius, rc is simulated with opening of air filled from 5mm, 10mm, 15mm until it reached maximum opening of air filled of 45mm. The purposed of parametric study on different size of opening cut out radius in SIW filter is to show and to get the best response of filtenna. Cut out radius in SIW filter, rc is calculated as figure 3.

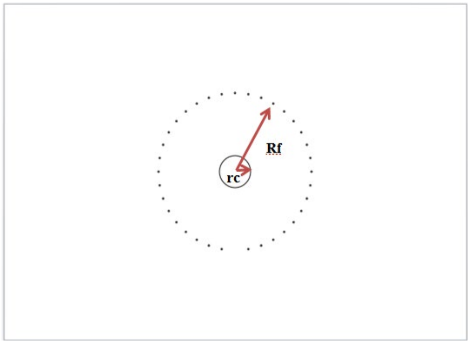


Fig. 3. Cut out radius in SIW filter, rc

Based on simulation, the best opening cut out radius, rc is 10mm which gives the best simulated response as shown in figure 4 and table 2 below are the simulated response of filtenna with Rogers and difference air-filled cut out radius, rc.

Fig. 4. Simulated response of filtenna with different cut out radius, rc

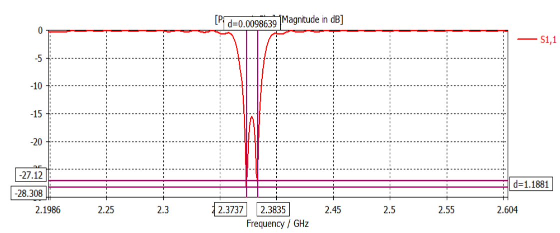
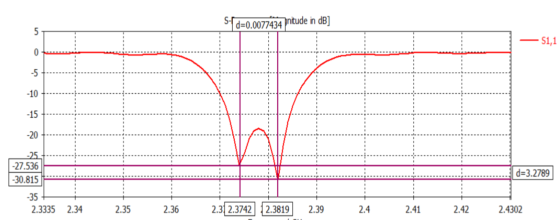
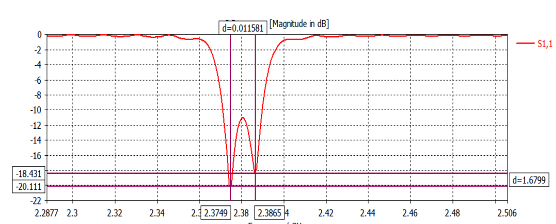
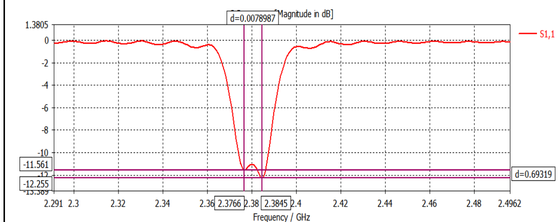
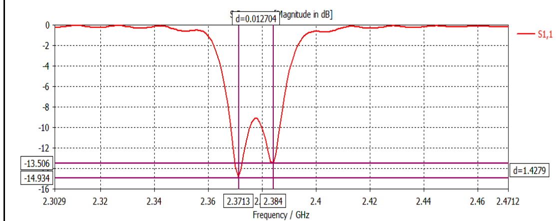
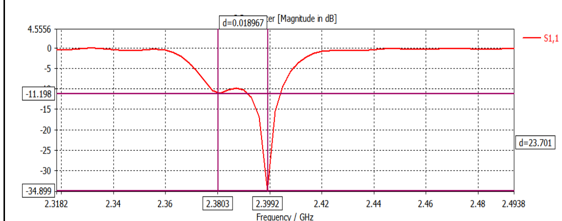
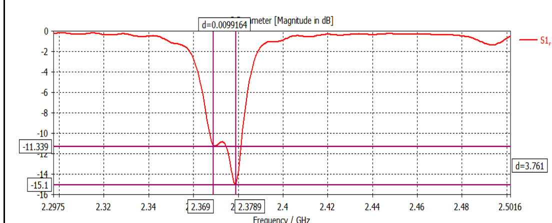
Cut out radius, rc	Simulated Response
rc 5mm	
rc10mm	
rc15mm	
rc20mm	
rc30mm	
rc40mm	
rc45mm	

Table 2. Coupling and response of filtenna with different cut out radius, rc

Cut out radius, rc (mm)	**Coupling response (dB)**	**Improvement percentage of coupling response (%)**	**Filtenna Response (dB)**
5	-15.62	2.37	-27.12 , -28.31
10	**-18.47**	**15.51**	**-27.31, -31.14**
15	-10.99	45.50	-18.43, -20.11
20	-11.09	44.18	-11.36, -12.26
30	-9.11	75.52	-13.51, -14.93
40	-9.96	60.54	-11.19, -34.89
45	-10.72	49.16	-11.34, -15.1

B. Position of CircularPatch Antenna

In order to get the best coupling between filter and antenna, the position of patch antenna need to be placed correctly on the iris aperture that coupled between filter and antenna. A good coupling occurs when position of both patch antenna and the iris aperture are on top of each other [9]. Figure 5 below show the performance of air-filed filtenna when the position of patch antenna been adjusted.

Fig. 5. Effect of filtenna response at different position of patch antenna.

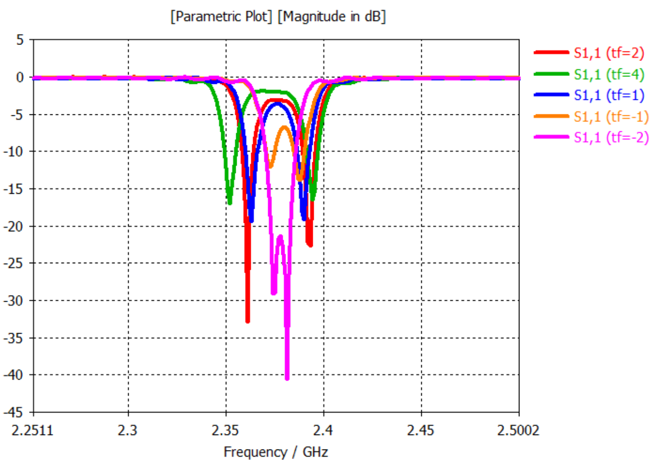


Table 3. Effect of Filtenna coupling response at different position of patch antenna

Position of Antenna (tf)	Coupling response (dB)
-2	-3.19
4	-2.08
1	-3.74
-1	-6.85
-2	**-21.58**

C. Position of iris aperture

Besides than the position of patch antenna, position of iris aperture also needs to be placed correctly. Thus, aperture position should be optimized around $\lambda_g/4$ in order to get maximize coupled power [10]. Thus, for fixed dimension of 10mm air-cut opening, at the position of 0.15, which is slightly at the center of the common ground, is having a good coupling between filter and antenna. As shown in figure 6 below is the filtenna response at the different position of iris aperture.

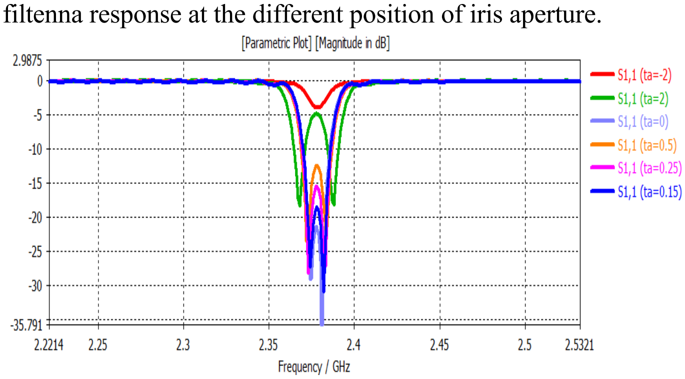


Fig. 6. Effect of Filtenna response at different position of iris aperture

Table 4. Effect of filtenna response at different position of iris aperture

Position of iris (Ta)	Coupling Response (dB)
Ta = 2	-4.85
Ta =0	-21.48
Ta = 0.5	-12.53
Ta =0.25	-15.53
Ta = 0.15	**-18.59**

D. Size of iris

All of the parametric study that has been carried is to get the best coupling response of filtenna. Thus, for fixed all the dimension of 10mm air-cut filtenna at the size of 7.1225 of iris is having a good coupling between filter and antenna of -21.47dB. Figure 7 and table 5 shows the effect of coupling response with the different size of iris.

Fig. 7. Effect of coupling response at different size of iris

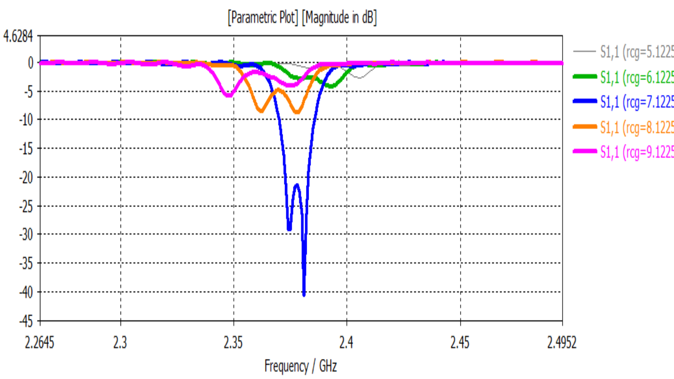


Table 5. Effect of coupling response at different size of iris

Size of iris, rcg	Coupling response (dB)
6.1225	-2.77
7.1225	**-21.58**
8.1225	-4.92
9.1225	-1.75

IV. RESULT AND DISCUSSION

For simulation and comparison purpose, both dielectric-filled and air filled SIW filter are designed and been optimized using CST Microwave Studio. Roger RT/Duroid 5880 having a relative permittivity of Ɛr =2.2 and a thickness of 0.787mm is used. While, the air-cut of the air filled are made by remove to a maximum cut diameter of rc through simulation design. Diameter d of the via hole 0.5mm for both filters.

A. Simulated Response of Roger RT/Duroid 5880 filter and air-filled filter

To prove that conceptually air is one of the elements that will enhanced the performance of filter, different size of the air-cut filter has been design from the minimum of 5mm until the maximum of 45mm and optimized to the best result.

Figure 8 shows the difference in performances of both filters. Simulation shows that air-filled filter that has maximum opening air-cut has better return loss and insertion loss performance compared to using Roger RT/Duroid 5880. Thus, Uses air as dielectric can improve the return loss, insertion loss and leads to better Q-factor for filter design [11]. Through these simulations result shows that the lower the permittivity of the material, the better the performance

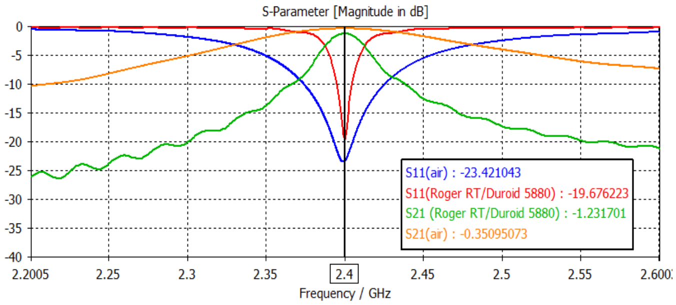


Fig. 8. Performances of filter using Roger RT/Duroid 5880 and air filled filter.

	S_{11}	S_{21}
Filter using Roger RT/Duroid 5880	-19.67	-1.23
Filter using air-filled	-23.42	-0.35

Table 6. Performances of filter using Roger RT/Duroid 5880 and air filled filter.

B. Simulated Response of Filtenna Roger RT/Duroid 5880 and air filled.

From the analysis in A, maximum air-filled filtenna has been designed and optimized to the resonance frequency of 2.4GHz and been compared to performance of Roger RT/Duroid 5880 Filtenna. Through simulation for filtenna shows that, the maximum opening air cut filtenna did not gives better performances in terms of coupling between filter and antenna which only coupled at -10.89dB while Filtenna roger coupled at better response than maximum air-cut opening which at -16.37dB as show in figure 9 below.

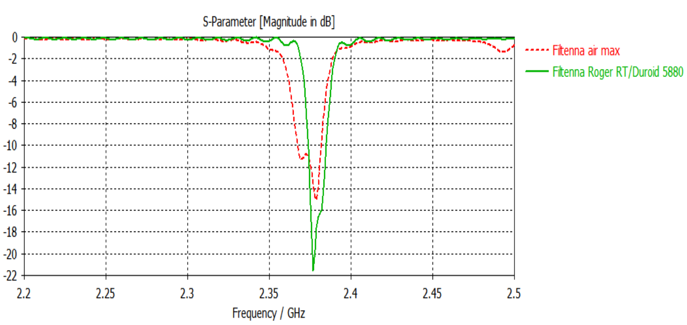


Fig. 9. Filtenna with max opening vs filtenna with Roger RT/Duroid 5880

Thus, several opening air cut has been optimized according to parametric study in section 3 and the simulation result on the opening air cut shows that air cut size 10mm gives the better response and a good coupling between the filter and antenna compared to the maximum opening 45mm air-cut. Figure 10 shows the filtenna with the opening air-cut of 10mm. Simulated response shows that at 10mm air-filtenna (blue) coupled at -18.46dB and give better simulated response between -21.88 and -23.39 dB.

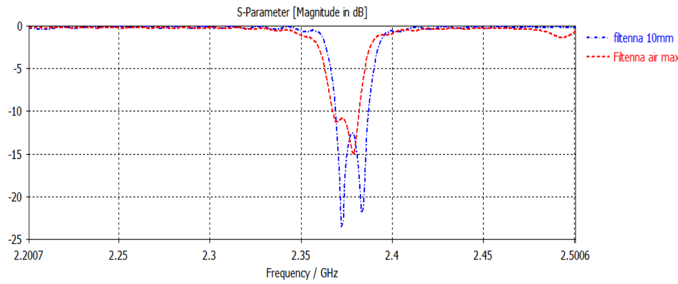
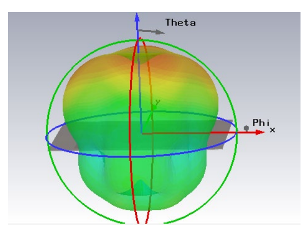
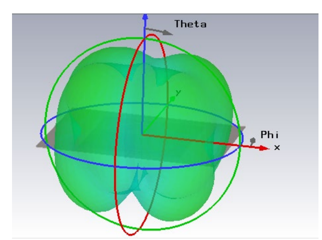


Fig. 10. Filtenna with opening air-cut 10mm

Filtenna with air-cut 10mm opening gives the better performance and the good coupling between filter and antenna due to the aperture length and width. Increase in aperture length will decreases in resonance frequency and will reduced coupling between filter and antenna, however, increase in width of aperture will provides the opposite effect of the coupling [12]. Further calculation on the effect of coupling due to aperture has been reported in details in [13].

Fig. 11. Comparison of 10mm air-cut filtenna gain with Rogers Duroid Filtenna.

10mm air-cut Filtenna	Rogers Filtenna
	
Gain: 4.62dB	Gain: 2 dB

As for the gain, 10mm air-cut filtenna also offer good filtenna gain of 4.62 dB compare to Rogers filtenna which only at 2dB. It is also shows that uses of air as dielectric has improved not only the filtenna response but also the filtenna gain. Figure 11 above show the comparison of 10mm air-cut filtenna gain with Rogers Duroid Filtenna.

V. CONCLUSION

A 10mm air cut of Filtenna has been presented in this paper for resonance frequency of 2.4GHz. The simulation result has shown that even though 10mm air cut still have the presence of dielectric material and the air-cut, but consider the coupling, position of the patch antenna and the size of the iris aperture will resulting the good performance on 10mm air-cut opening.

Furthermore, 10mm air-cut filtenna has improvement of 15.51% from the previous work of integrated filter. Thus, for the future work studies, 10mm air-cut filtenna can be optimized to other frequency according to its need. Lastly, air-filled is suitable to be implemented in communication wireless due it better performance

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