Design of SIW-Based Antenna-Filter for 6.2 GHz Applications

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Abstract—**In this paper a design of integration between antenna and filter was proposed. The design is based on Substrate Integrated Waveguide (SIW) on a Rogers 3003 substrate fabricated by printed circuit board technique. The dielectric constant of the substrate for both filter and antenna is $\varepsilon_r = 3$. The filter and antenna is designed and fabricated with 0.75 mm and 0.5 mm substrate height respectively. At first, the circular SIW filter on the TM_{010} was designed separately before integrating with a circular microstrip antenna operating on TM_{110}. At 6.2 GHz resonance frequency, a good simulation results are obtained with 6.6 dB gain and return loss less than -10 dB. Then, the simulated design is fabricated and measured. The result of the simulation is compared to the measurement taken from the fabricated hardware. The design is capable to reduce the size of receiving system and lowering the overall fabrication cost since it does not required a matching circuit.**

Keywords-Substrate Integrated Waveguide; circular microstrip antenna; bandpass filter; iris

I. Introduction

In communication system, it is good to have a small receiving system with the same performance to the bigger one. However, some of receiving system consists not only antenna but also another element such as filter or amplifier that manufactured separately. The uses of these separated wireless communication elements give rise to a bigger transceiver system that needs a larger number of materials for the fabrication. On the other hand, higher total production cost.

There is a growing interest in the integration of microwave filters and antennas in communication systems at the RF front end [1]–[6]. Each integrated solution brings its own unique advantages but all offer common size reduction. Design cycles are shorter with integrated solutions because they can efficiently handle the interactions between discrete components and have fewer RF components to put together. Furthermore, designing such subsystems in a multi-layer technology could further reduce the overall size [7], [8].

The substrate integrated waveguide is a type of planar waveguide structure which has the same characteristics as ordinary waveguide with a good prospect in microwave and millimetre-wave applications. The passive component such as resonators, filters, diplexers and antennas realized by SIW have the advantages of high Q value, high enduring power, low-cost and easy to integrate to system as well as other planar circuits. Moreover, the construction of SIW allows for planar integration of active and passive components on top of antennas, and it exhibits low loss and complete shielding, thus preventing interference and cross-talk phenomena [6]. On the other hand, the implementation of multilayer on the microstrip structure able to reduce the back lobe and side lobe of the antenna [9]. The application of the SIW also proved to increase the bandwidth of an antenna-filter [10], [11].

In general, the implementation of the substrate integrated waveguide was to reduce the drawbacks of the conventional waveguide which are outsized and expensive without losing its benefits.

This paper presents methods that integrating two elements of wireless communication by implementing a circular iris and substrate integrated waveguide operate at 6.2 GHz. The proposed design is shown in Fig. 1. The iris acts as a coupling medium between circular antenna and SIW filter. The radius of the iris and the position of the antenna were optimized for the best coupling without requiring a matching circuit. Other variation of variables that affecting return loss of the design also observed in this paper.

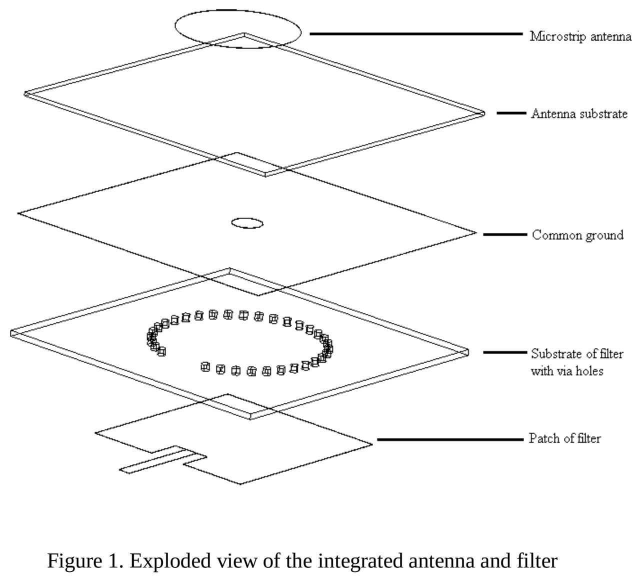


Figure 1. Exploded view of the integrated antenna and filter

II. METHODOLOGY

The design uses a computer aided design (CAD) called Computer Simulation Technology (CST) Microwave Studio for the simulation process. Besides, the software will also assists in optimizing the designed project to achieve desired result. For the hardware measurement, vector network analyzer (VNA) is used due to the suitability and availability of the equipment to the designer. The general work flow of the project is shown in Fig 2.

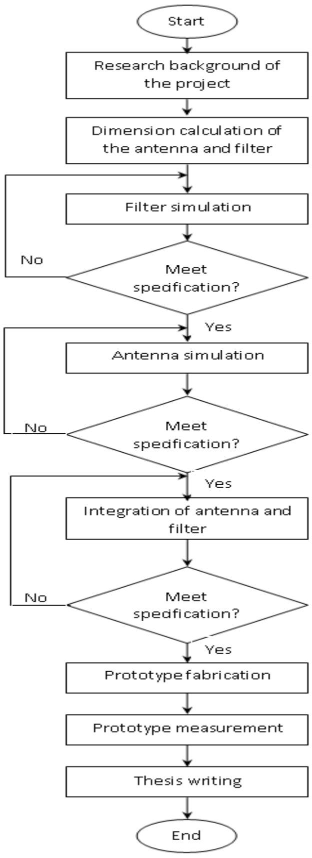


Figure 2. General flowchart of the project

The design process of the project start by collecting information related to the title of the project. The information needed including the theory and calculation of the prototype dimension. The dimension analysis separated into two parts, circular antenna and SIW filter. Then, simulation of the designs take place with help of the computer aided design software to achieve the finest performance for the filter following by the integration of the antenna and filter. At this stage, only the size of aperture and position of the antenna are manipulated for the coupling of electric field to correctly happen [4]. Lastly, the finalize design is fabricated by using printed circuit board technique.

A. Circular SIW Filter

The filter is estimated to operate using TM_{010} at radius given by:

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

where *c* is the speed of light in free-space and a_{filter} is the radius of the SIW filter.

The via hole for the filter dimension is based on study by [12]. The diameter, *d* and pitch, *p* between via is given by:

$$d < 0.2\lambda \ , \ \frac{d}{p} \leq 0.5 \quad (2)$$

B. Circular Microstrip Antenna

The mode used for the antenna is TM_{110} as the dominant mode and the resonance frequency of a circular antenna is given by [13]:

$$f_{antenna} = \frac{c}{2\pi\sqrt{\mu_r \varepsilon_r}} \sqrt{\left(\frac{1.8412}{a_{antenna}}\right)^2} \quad (3)$$

where *c* is the speed of light in free-space and $a_{antenna}$ is the radius of the antenna.

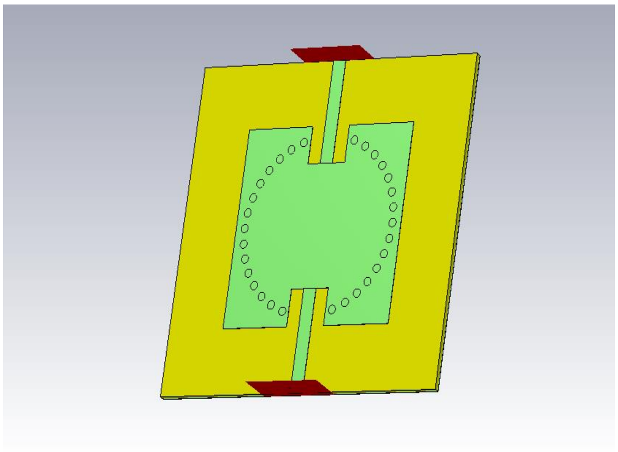
III. RESULT AND DISCUSSION

The antenna and SIW filter were simulated on a Rogers Duroid 3003 with dielectric constant $\varepsilon_r = 3$. Both antenna and filter has the same copper thickness, t = 0.035 mm including thickness of the common ground. However, the antenna and SIW filter were designed on different height of substrate. The antenna substrate height is 0.5 mm while the filter is 0.75 mm substrate.

A. SIW Filter Simulation

The dimension of the filter was obtained by using (1). Fig. 3 (a) shows the structure of the simulated bandpass filter optimized for best performance at 6.2 GHz of resonance frequency. Fig 3 (b) shows highest concentration of electric field at the centre. The shorted via holes between copper layer of the filter function as a wall of a waveguide to confine the electric field within the circular structure [14].

The E-field distribution also show the best position for the iris location which is at the centre of the filter. This iris is used as a path for the E-field to excite the antenna on the other layer of substrate.



(a)

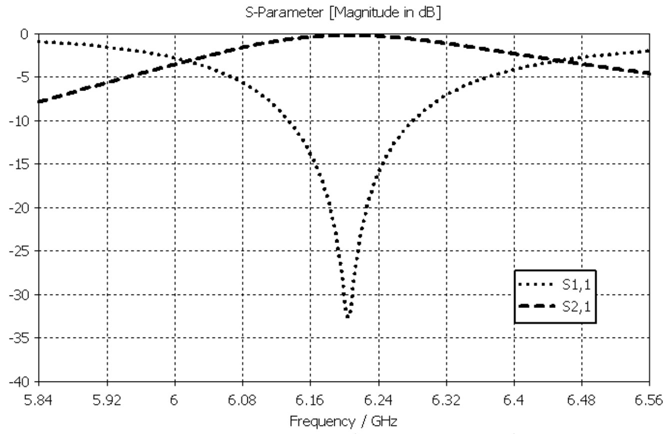
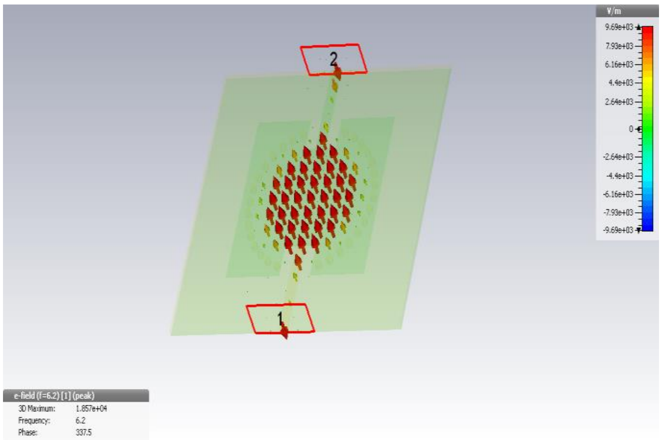


Figure 4. Return loss and insertion loss of the circular SIW filter simulated at 6.2 GHz



(b)

Figure 3. (a) Simulated design prototype of the circular SIW filter (b) Distribution of the E-field at 6.2 GHz resonance frequency

The feeding methods used for the filter are the microstrip line and inset with line impedance at 50 Ω. The inset approach is used to ensure there is no reflection at the input port and the filter has maximum power transfer.

Based on the design, the return loss and insertion loss of the filter was generated as shown in Fig. 4. At 6.2 GHz, the filter shows a good return loss as low as -32 dB and insertion loss about -2 dB. This proved that the simulated design has no mismatch issue.

B. Integration Between SIW Filter and Circular Microstrip Antenna

The integration of antenna and filter was done by stacking both designs that have the same substrate dimension together. Then, a circular iris was created by etching the common ground of the integrated design. Fig. 5 shows the integrated design of the antenna and filter.

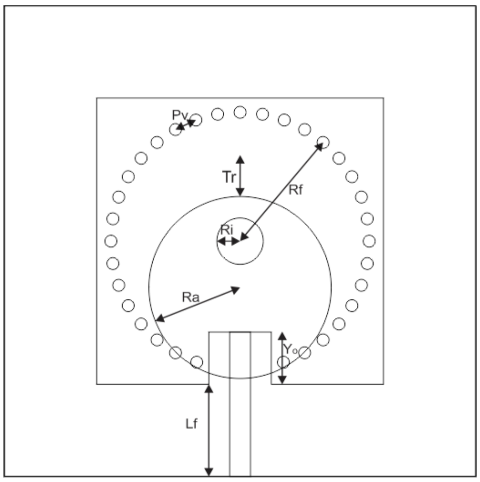


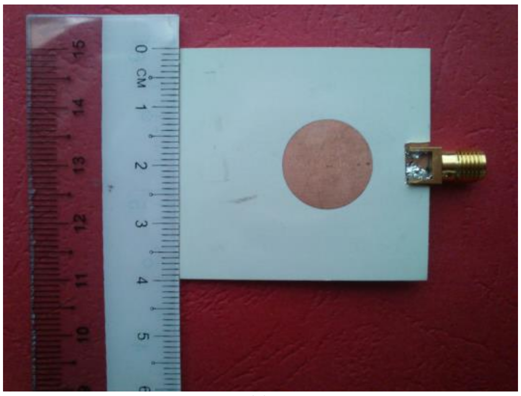
Figure 3. Final prototype of the integrated antenna filter viewed from top

The position and the radius of the circular antenna were optimized for the best coupling at 6.2 GHz resonance frequency. The dimension of the integrated antenna filter is summarized in Table I.

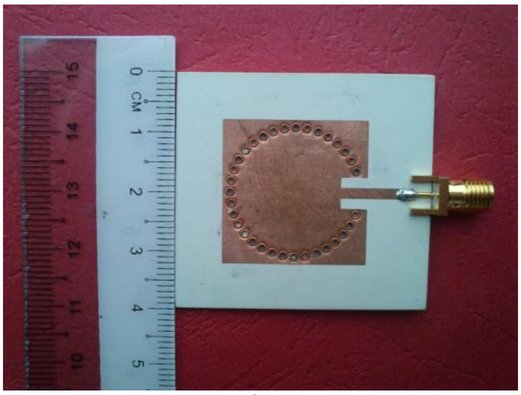
Fig. 6 (a) and (b) show the fabricated of the integrated circular SIW filter and circular microstrip antenna. The overall size of the design is 39.62 mm x 39.62 mm.

TABLE I. SUMMARY OF THE ANTENNA FILTER DIMENSION

Variables	**Dimension, mm**
Length of feedline, L_f	7.76
Radius of antenna, R_a	7.66
Radius of filter, R_f	10.85
Antenna position, T_r	3.9
Width of feedline, W_f	1.75
Inset, Y_o	4.4
Diameter of via, D_v	1
Pitch between vias, P_v	1.86
Radius of iris, R_i	1.95



(a)



(b)

Figure 4. (a) Front view (b) Back view of the integrated circular SIW filter and circular microstrip antenna

Fig. 7 shows simulated radiation pattern of the integrated antenna filter. At 0 degree direction, the design radiate with 6.6 dB gain. However, the return loss of the simulated and experimental results shows a slight different pattern as shown in Fig. 8 with the bandwidth of the simulation is 148 MHz and the measured bandwidth is 498 MHz. There is a frequency shift about 400 MHz to the right of the simulated return loss. Besides, the dips of the return loss also show a small deviation from -16 dB at 6.2 GHz to -30 dB at 6.7 GHz which due to the over coupling of the prototype. This is caused by the manufacturing tolerance during fabrication and the existence of parasitic effect due to the excessive soldering of connector even though the parasitic effect has been reduced due to the uses of aperture coupling for the design [15], [16].The coupling between antenna and filter is very sensitive to the change of antenna position [17]. The antenna and filter was manually combined by hand without the help of tool to correctly align both prototypes is one of the factors contribute to the problem.

A parametric study is done to show the different of the return loss when there is a slight offset to the simulated antenna position. Fig. 12 shows the outcome of the study.

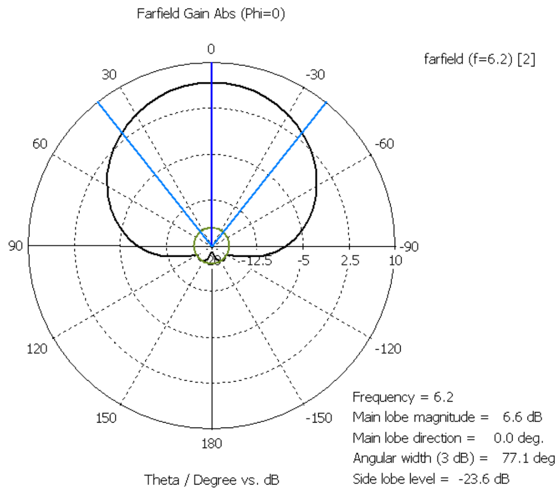


Figure 5. Simulated radiation pattern of the integrated antenna filter

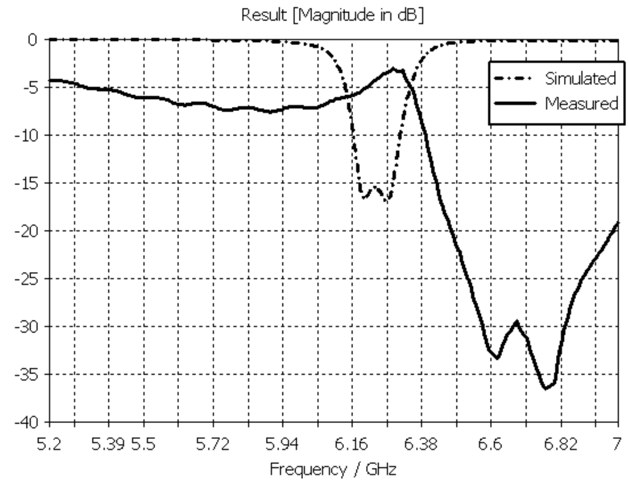


Figure 6. Simulated and measured return loss of the integrated

In Fig. 9 and Fig. 10, a co and cross polarization measurement at E and H plane of the design is shown. The radiation pattern for the H plane co-polarization is better compared to cross polarization since co-polarization is the intended polarization for the antenna-filter designed.

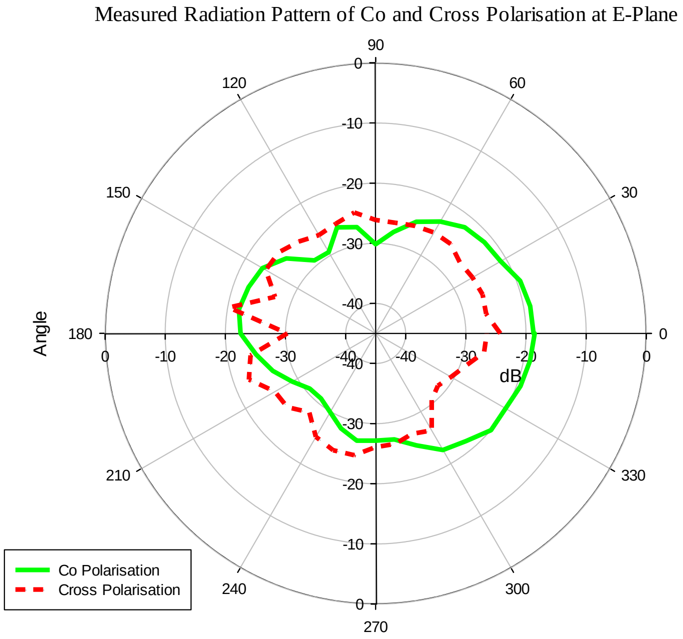


Figure 7. The measured E-plane co and cross polarization

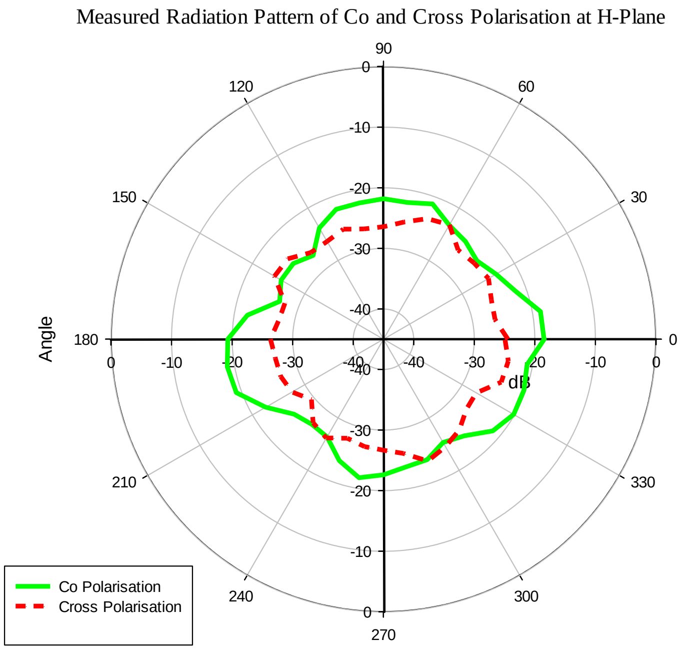


Figure 8. The measured H-plane co and cross polarization

IV. Parametric Study

The performance of the filter and the integrated prototype are observed and studied based on the several changes made to the variables of the design.

A. *Radius of the Aperture Opening*

Fig. 11 shows the return loss obtained when there is variation of iris radius. At 1.95 mm radius, the return loss read at -16 dB on 6.2 GHz. While radius at 2.95 mm there is no good coupling take place. The same goes to 0.95 mm radius since there is no coupling occurs between antenna and filter. The iris is used to control the magnitude of electric field passes through the common ground to excite the antenna. The design with large iris does not produce a good coupling and vice versa since larger iris opening result in an over coupling while small iris result in under coupling. Thus, the optimum size of the iris has to be realized by manually and gradually increase its size.

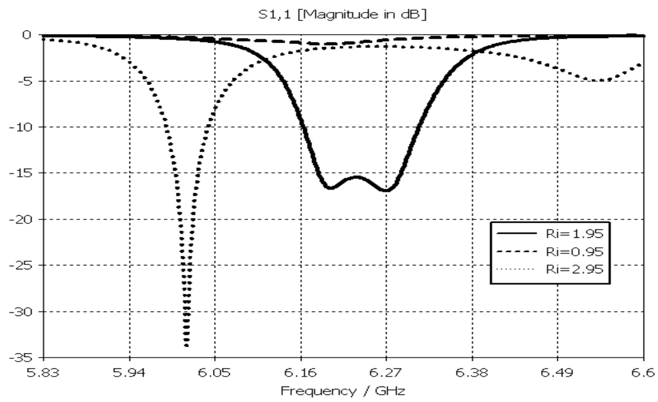


Figure 9. Variation of the aperture radius to return loss of the integrated antenna filter

B. *Position of the Antenna*

The antenna position is one of the variables used to obtain good coupling between the integrated antenna and filter design. A good coupling occurs when there are two closely positioned dips that represent an antenna and filter resonance frequency[11], [18]. The variation of the variable causes changes to return loss and make the dips to become unbalance. In other word, it has undesired coupling and unbalance return loss as shown in Fig. 12 for the antenna position T_r = 3.8 mm and T_r = 4 mm with return loss obtained are -13 dB and -12 dB respectively.

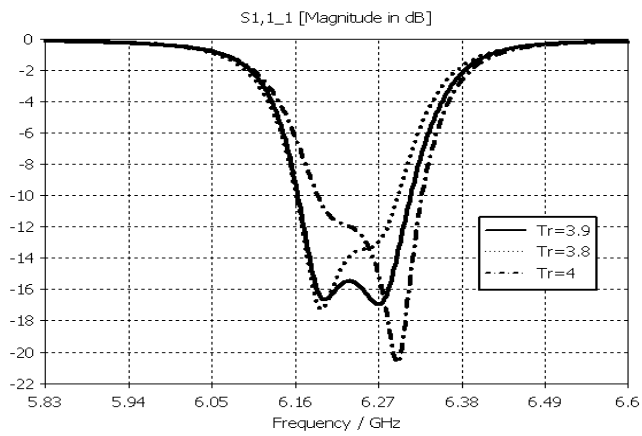


Figure 10. Return loss of the antenna filter at different antenna position

C. *LENGTH OF THE INSET*

The inset is introduced in the design to reduce the reflection at the input port. The study show the deeper the inset implemented to the design prototype, the return loss will be significantly reduced. Fig. 13 shows the results of the study were read at -15 dB and -25 dB for 2.4 mm and 3.4 mm respectively.

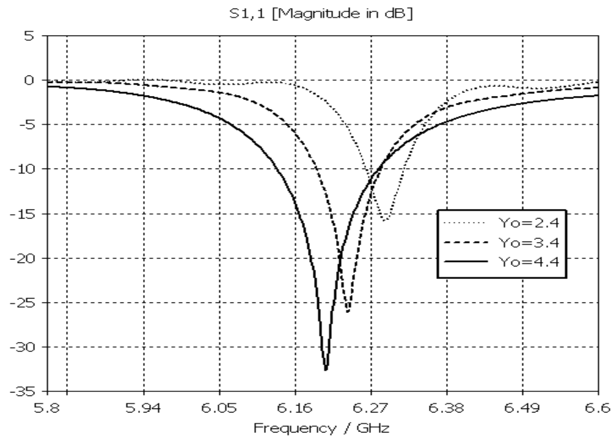


Figure 11. Return loss of the filter at different inset length

V. CONCLUSION

In this paper, the realizations of integrated circular SIW filter and antenna have been successfully presented. The study has been further explored by presenting parametric study to the proposed design. The simulation performance of the multilayered integration shows good results that could be further validated during the experimental works. This new class of integrated filter and antenna to produce filtering and radiating element in a single device would be useful in microwave RF front systems where the reduction of overall physical size and cost are very important compared to the conventional waveguide operated at the same frequency. The design can be further improve in term of physical dimension by integrating other wireless communications element into current design.

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