Development of Substrate-Integrated Waveguide Horn Antenna for Material Characterization

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ABSTRACT

In this paper, a new design of Substrate Integrated waveguide (SIW) horn antenna for material characterization, which works at X band is analyzed and investigated. To enhance its performance, this paper presents the interconnect SIW horn antenna for the material characterization application. Analysis of pitch and distance on the performances of the SIW interconnect horn antenna was considered and simulated to get the best result for material characterization. The proposed antenna is in the dimension of 415 mm x 60 mm x 1.6 mm. For the simulation, antennas are numerically investigated using High Frequency Structure Simulator (HFSS) software. Performance of the modified horn is presented and compared with those of the conventional horn. Results illustrate that proposed structures of distance. From the results, proposed antenna shows good agreement with good result of pitch and distance between two horn antennas. The findings may contribute to the development of the compact design of material characterization having a comparable performance with the conventional waveguide.

Keywords: antenna, substrate integrated waveguide (SIW), H-plane horn antenna

1. Introduction

Recently, the introduction of substrate integrated waveguide (SIW) technology is a good alternative for high-frequency applications due to its low-profile, compact and low-cost structure [1]. This planar waveguide is generally implemented by using two rows of conducting cylinders, so-called via, acting as sidewalls in a dielectric substrate that connects two parallel metal plates. Hence, it provides a good match to the printed circuitry, and planar active and passive microwave and millimetre devices and antennas [2]. One of the most used antenna applications using SIW technology is the H-plane horn [3–6]. Although a conventional 3D horn antenna is known as a high-performance end-fire radiator, the performance is remarkably reduced when the antenna is fabricated as a planar SIW antenna on printed circuit board (PCB). In fact, the low performance and gain is mostly due to the dielectric loss and small PCB thickness which makes poor matching between the antenna and air [7]. Several campaign have been done to improve this SIW antenna shortcoming. In [8], a dielectric loaded antenna configuration is proposed which it improves the gain. Two different printed transition designs are also proposed in [9] and [10] to increase the matching between SIW horn antennas and the air.

The novel SIW horn antenna such as circularly polarized SIW horn antenna, dual polarization SIW horn antenna is researched and designed in recent years.

So far, ordinary SIW horn antenna works at high frequency part of microwave band or millimeter wave band, and its radiation performances are deeply explored and wide applications of SIW horn antenna are realized. On the other hand, the researchers of SIW horn antenna for material characterization are few.

In this context, SIW technology allows to build horns of acceptable weight and as robust as the pyramidal horn antenna and our goal is to fabricate one pair of SIW horns antenna interconnect for material characterization applications. Moreover, the analysis on the different pitch of the vias and distance between interconnect horn antenna are used to see the effect of the performance. The antenna performances were achieved and analyzed. In section II, the structure of the SIW horn antenna is presented. Section III provides the simulation results and its analysis of the designed the SIW horn antenna. The conclusion is provided in Section IV.

2. SIW Structure

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SIW technology was proposed in the last decades [1][2] as a new concept for millimeter-wave integrated circuits and systems for the next generation. The purpose of this technology is to facilitate the integration of rectangular waveguide with planar circuits. Indeed, several studies of transitions between microstrip line and rectangular waveguide have been carried out [3]–[6]. These studies show that typical integration techniques from rectangular waveguide with planar structures are bulky and require a very precise manufacturing process, difficult to achieve at millimeter-wave frequencies. Hence, SIW is intended to replace traditional hybrid systems which are a combination of both waveguides and microstrip line. Due to its planar structure, low profile, simple manufacturing and easy integration with other planar circuits using a standard printed circuit board or other planar processing techniques, SIW has received much attention [7]–[10]. In its simplest form, it is composed of two periodic rows of vias drilled through a dielectric substrate that connect two parallel metal plates. To ease the via-hole metallization, the substrate thickness should be about 2.5 mm or lower [11]. SIW can then be viewed as a dielectric filled waveguide (DFW) where the vias replace the narrow walls of traditional rectangular waveguides to avoid leakage.

SIW structures also preserve the advantages of conventional metallic waveguides such as high-power handling capability, low losses, and high-quality factor [12][13]. It is then a good candidate for feeding the surface wave or leaky wave antennas [14–16].

3. Research Method

3.1 Designing single SIW horn antenna

SIW H-plane horn antenna can be implemented on a PCB by adding a set of vias. The geometry of SIW antenna is shown in figure 1. Both sides of the board are metalized using copper as shown in figure 2 to realize a waveguide, for the feed, and the horn antenna. To eliminate the higher order modes in the waveguide and leakage through the SIW walls, the thickness of the substrate, and the vias geometry and spacing needed to be optimized. There values are computed by using the design rules of SIW [11–13].

$$t < 2W \quad (1)$$

$$W < \lambda/5 \quad (2)$$

where t, W and λ are respectively the PCB thickness, the spacing between two adjacent vias and the wavelength. Taking into consideration the physical dimensions of the antenna in Table I, the SIW horn antenna is designed on a RT/Duroid substrate with the permittivity (εr) of 2.33, height (h) of 0.8 mm and loss tangent of 0.0012. Moreover, based on this design rule of SIW, the radius of the via, R, is chosen to be 0.25 mm. The design of the SIW horn antenna in HFSS for side view and top view are shown in figure 2 and figure 3 respectively.

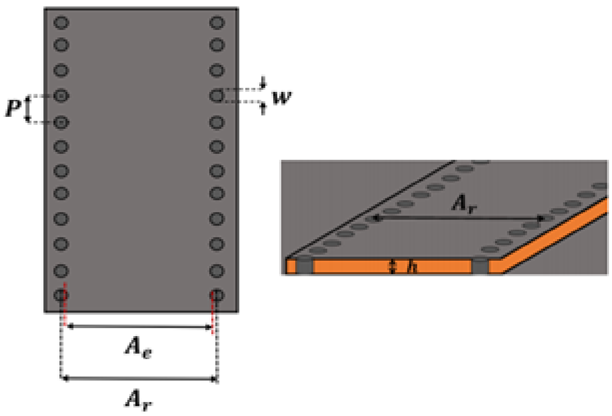

Figure. 1. Substrate intergrated waveguide

The key parameters for the SIW design are presented in figure 1:

P: via holes spacing (also called pitch)
w: via diameter
A_r: central distance between via arrays
A_e: equivalent SIW width
ε_r: permittivity of the substrate
h: substrate thickness

Table 1. Model design parameters

Description	Value (mm)
P	2
W	0.5
Ar	10
h	0.8

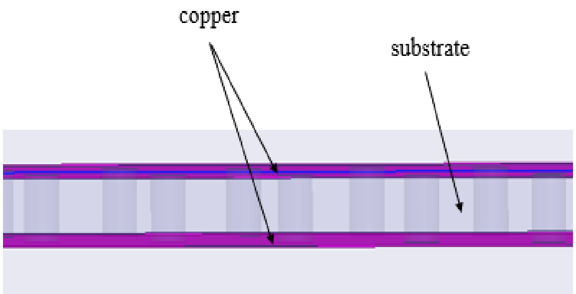

Figure. 2. The placement of the copper and substrate

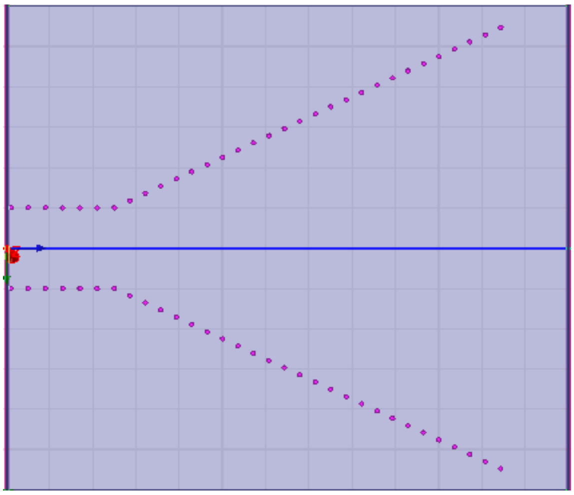

Figure. 3. Single SIW horn antenna designed in HFSS

3.2 Designing Interconnect SIW Horn Antenna

A study on the effect of the different length on S-parameters has been achieved at X-band based on Rogers RT/Duroid 5870 substrate for several lengths: 30, 60, 90, 240, 260 and 300 mm. In designing the interconnect SIW horn antenna measurement, two identical SIW horn antennas are placed face-to-face with a distance R, as shown in figure 4. One antenna is used as a transmitting antenna and the other as a receiving antenna.

The distance of separation between the antennas is equal or greater than the far-field distance. The far field distance is defined as follow.

$$\text{Far field region} > 2D/\lambda \qquad (3)$$

where D and λ is the largest aperture dimension of the SIW and the free-space wavelength at the measurement frequency, respectively.

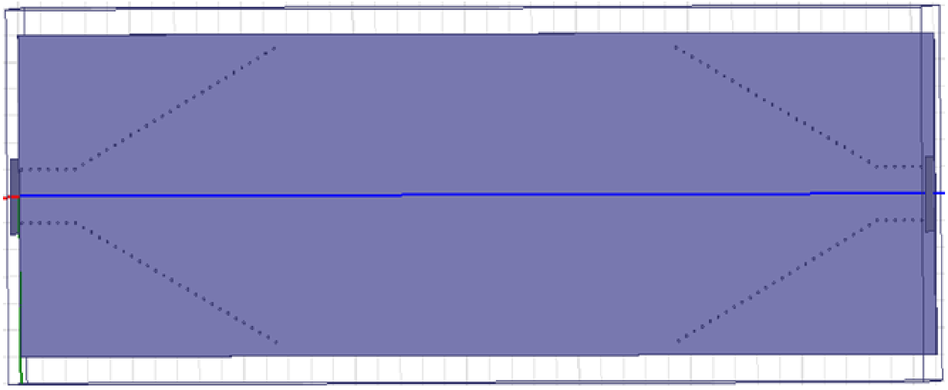

Figure. 4. SIW interconnect horn antenna designed in HFSS

4. Result and Discussion

In this project, the antenna was designed with a few analysis, which is in the HFSS software. The result of return loss S11 and S21 has been calculated for the final design.

4.1 SIW Single Horn Antenna

The simulated reflection coefficient of SIW single horn is shown in figure 5 versus frequency. The antenna demonstrates best matching condition at 10.75 GHz with S_{11} = -33dB.

Generally, single SIW horn is designed to operate around 10 GHz. The magnitude of the simulated S11 of this horn is plotted in figure 5 versus frequency. This antenna provides few separates resonate frequency, in which impedance bandwidth is narrow at these frequencies.

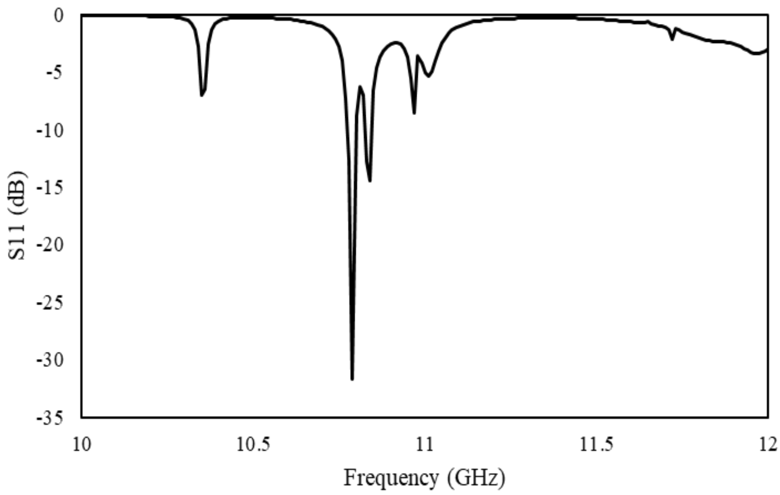

Figure. 5. Simulation results of S_{11} for SIW single horn versus frequency

4.2 SIW Pins Distance

Using the equivalence between conventional guide and SIW guide (Eq.1) and for a pin diameter of 2 mm, the width in the SIW guide is 62 mm. The value of thickness is 0.8 mm corresponding Rt/Duroid plates covered with two copper sheets.

The design of the SIW guide is now done with several spacing value which is 1, 2 and 3 mm for the SIW single horn antenna. The behavior of the system for different values of spacing is considered and simulated. The result of the S-parameter is shown in figure 6.

Observing the various curves of *S*11 for different values of spacing in figure 6, it is concluded that for 1mm and 3mm the guiding is poor. For the 2mm spacing, the curves of *S*11 < -10 dB at 10.75 GHz.

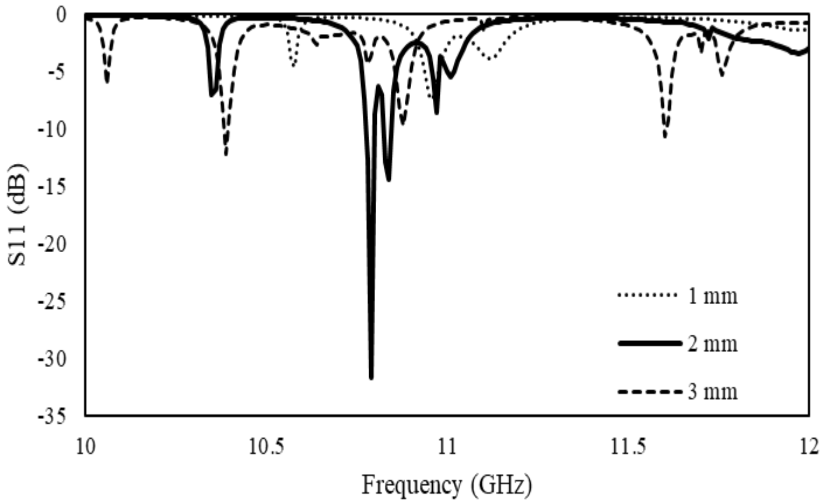

Figure. 6. Simulation results of S_{11} for difference pins distance versus frequency

4.3 SIW interconnect horn antenna

A study on the effect of the different length on S-parameters has been achieved at X-band based on Rogers RT/Duroid 5870 substrate. Figure 7 show the |S21| in X band. It can be seen from figure 7 that a better matching is obtained for longer transitions. Moreover, the shorter the transition is, the lower the transmission losses are. This leads to a trade-off between the entire length of the transition and the return loss.

Due to the far-field restriction which means the distance R must be longer than 240mm, 260mm is used in our measurement and the measured frequency is 10 GHz. The measured insertion loss is 35.362 dB. Under the premise that there is no other effect considered, the difference between insertion loss and path loss is which is the sum of the gains of transmitting and receiving antennas. The measured S21 in the frequency range of 8-10 GHz are shown in figure 7.

To verify our antenna, gain measurement, we change the separation distance of the two antennas to see if the measured results are in consistence. Figure 7 shows the S21 of these two interconnect horn antennas versus the distance, which is varied from λ to 10λ. According to (3), to satisfy the far field distance requirement, the distance between the two antennas must be longer than 240 mm. Therefore, the shortest distance is selected at λ. At 10λ, due to the path loss, the S21(D=300mm) is already too small and are affected seriously by noise, leading to erroneous result.

The transmission coefficient S21 results are shown in figure 7. As can be seen in Table 2, when the distance increases, then S21 also decreases significantly. Starting at 9λ transition length the S21 values increase as presented in figure 7. This is because the transition length is more stable when the length increase.

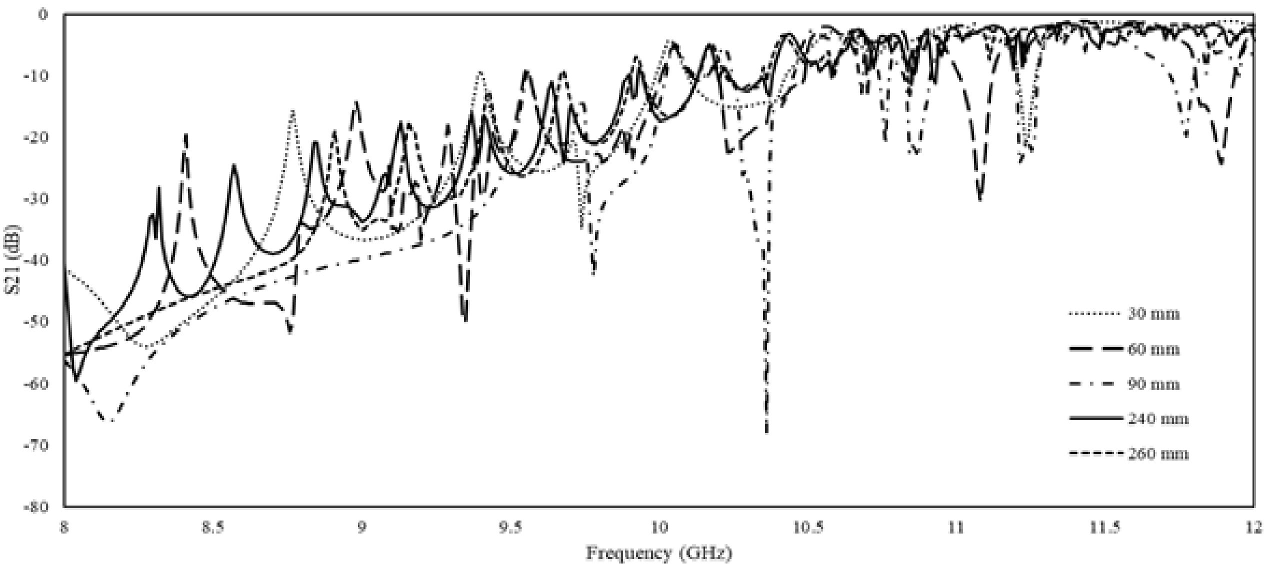

Figure. 7. Simulation of S21 for difference length of interconnect SIW horn antenna versus frequency

Table 2. Summary of all patterns for figure 7

S-parameter	Distance (mm)	Measure S_{21} (dB)
λ	30	-8.2565
2λ	60	-10.900
3λ	90	-14.449
8λ (D)	240	-17.387
9λ	260	-15.745
10λ	300	-12.642

5. Conclusion

Simulated experiment is carried out using designed substrate integrated waveguide to analyse electromagnetic wave propagation over structure. Results of s-parameter was calculated and analysed. The design acts as with usable frequency band from 8.2 GHz to 12.4 GHz. The length of were proposed to be the best length of interconnect SIW horn antenna. The proposed design can be used in material characterization applications.

For this purpose, the losses along the transition have been characterized by using full-wave analysis. The results of the full-wave analyses have shown important characteristics of the losses in the transition that are beneficial in the design of SIW. The linear transition, which is the simplest design, is quite effective for the length of 8λ onwards for X-bands. The results from the full-wave analysis have conclusively shown that the distance of antenna can be used to control the transition losses. The contribution of the findings is to develop a compact design of the substrate integrated waveguide horn antenna with better performance compared to the conventional waveguide.

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