Design and Fabrication of W-Band SIW Horn Antenna using PCB process

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Abstract— **A W-band SIW horn antenna is designed and fabricated using PCB process. Measured S_{11} reaches -15 dB at 84 GHz with bandwidth of 1 GHz and the maximum simulated gain is 9 dBi. The antenna is loaded with dielectric to increase gain and the effect of different loading lengths on gain is studied. The antenna is fed using a WR10 standard waveguide through a coupling slot in the SIW. The effect of changing the slot width on the return loss is studied. Good agreement is achieved between measured and simulated results. The proposed antenna is suitable for medical imaging and air traffic radar.**

Keywords-Substrate Integrated Waveguide (SIW); Printed Circuit Board (PCB)

I. INTRODUCTION

Extensive research has been devoted to millimeter wave technology due to several reasons. First, the increased available bandwidth at millimeter wave frequency, up to 10 GHz, allows for multi-gigabit data speeds even with the simplest modulation schemes, such as ASK or QPSK, making it suitable for applications such as real time high definition quality video and telemedicine [1]. Moreover, secure communication and frequency reuse in cellular wireless networks make use of atmospheric absorption losses at millimeter wave band [2]. In addition, the short wavelength associated with millimeter wave technology makes it useful for imaging and body penetrating applications such as air traffic radar, medical applications, cloud profiling radar, and military applications [3], [4].

Substrate integrated waveguide has been recently studied [5–12] for its important advantages such as low cost, low loss, and highly integrated structure. It consists of upper and lower conductors on a substrate with shorting vias at both edges, acting as a rectangular waveguide. It has many millimeter wave applications for realizing both active and passive components.

Recently, integrated SIW horn antennas have been extensively studied for their high gain and their ease of integration with transceiver front-ends [13-22]. A 94 GHz SIW horn antenna on LTCC substrate has been proposed, [15], with gain 3 dBi and bandwidth of 400 MHz. A dielectric loaded SIW horn operating at 27 GHz designed using PCB process, [14], achieved a gain of 9.7 dBi and a bandwidth of 700 MHz. A 60 GHz integrated horn antenna fabricated using micromachining technology, [23], showed a gain of 14.6 dBi and bandwidth of 3 GHz. To achieve high performance, substrates with very low losses such as LTCC have been used for integrated horn antennas [24], [25]. However, although from a system integration point of view LTCC has the advantage of integrating active, passive, 3D, and planar structures on the same substrate due to its multilayer structure and possibility of cavity processing within the substrate, its high cost and complexity make it undesirable for many commercial applications [26], [27]. PCB process overcomes these limitations. For an antenna to achieve high gain and bandwidth, it is desirable to use a thick substrate with low permittivity. However, to eliminate the higher order modes in the waveguide, the thickness of the substrate is restricted. Moreover, a substrate of high permittivity is used to decrease the size of the antenna. To increase the gain an antenna array could be designed. However, this has a limitation due to the increased losses from the feeding network. Another method is to load the integrated horn antenna with a dielectric which acts as a dielectric guiding excited by the horn aperture resulting in a narrower beamwidth.

In this paper a dielectric loaded H-plane sectoral SIW horn antenna operating at W-band which is fed with a WR10 standard waveguide through a coupling slot [28] is proposed.

II. SUBSTRATE INTEGRATED WAVEGUIDE

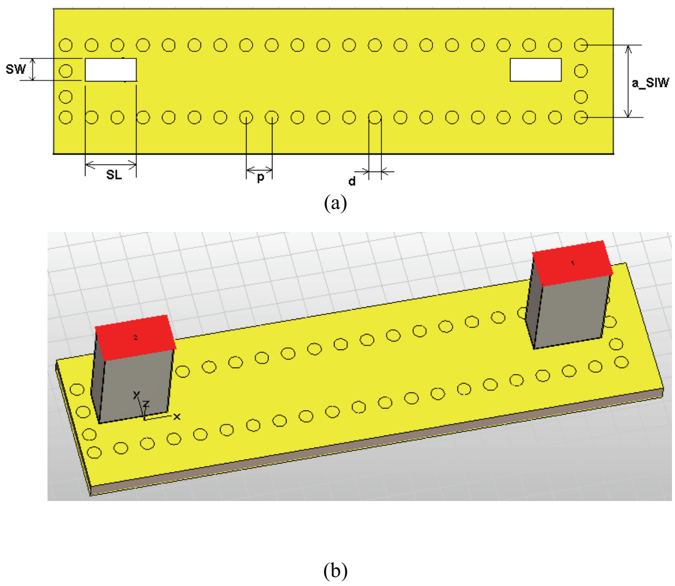


Figure 1. (a) SIW structure, (b) WR10 standard waveguides mounted on SIW

Fig. 1a shows the SIW structure simulated using CST MWS, which is based on the Finite Integration Technique.

Transient solver has been used with hexahedral mesh generation. The width of the SIW, a_{SIW}, is 2.8mm and is found from the empirical equation [29]:

$$a_{RWG} = a_{SIW} - \frac{d^2}{0.95p} + \frac{0.1d^2}{a_{SIW}} \qquad (1)$$

Where d, the via diameter is 0.5mm, p, via separation, is 1mm, and a_{RWG} is the width of the equivalent rectangular waveguide. When p/d is smaller than three and d/a_{SIW} is smaller than 1/5, the empirical equation is very accurate.

Two coupling slots with length SL of 2mm and width SW of 0.5mm are used as transitions to WR10 standard waveguides as illustrated in Fig. 1b which shows the waveguides with ports connected to them. The offsets of the slots from the centerline are 0.45mm, and from the short are 5λ/4 to act as an open circuit.

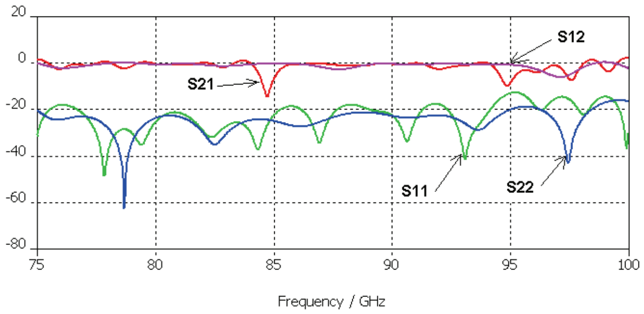


Figure 2. S-parameters for SIW

The simulated S-parameters for the SIW structure are shown in Fig. 2. It is noticed that the wave is propagating properly between the two ports at the band of operation.

III. SIW HORN DESIGN

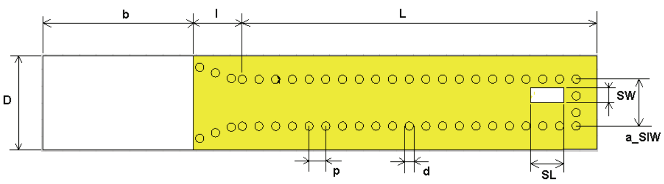
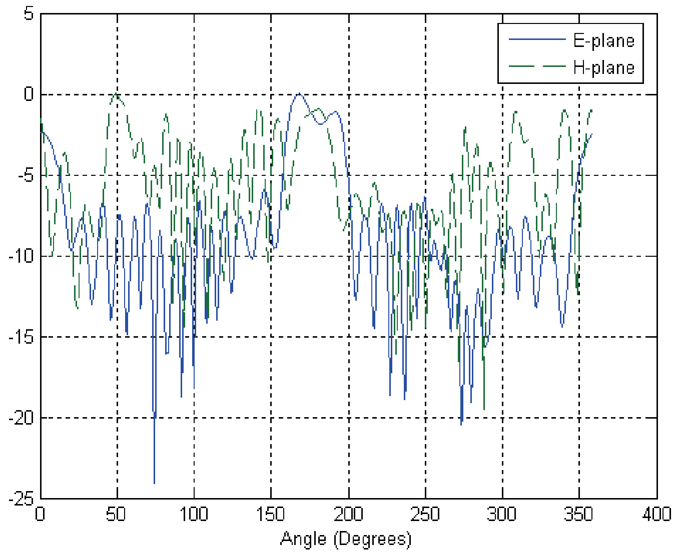


Figure 3. Geometry of SIW horn antenna

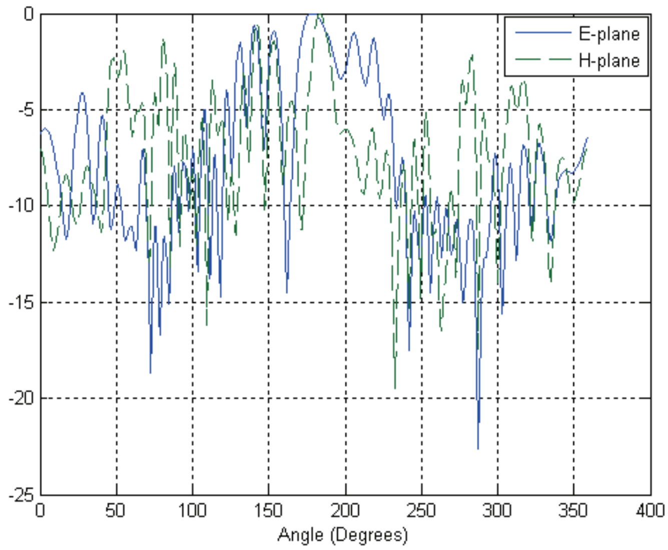
Fig. 3 shows the optimized SIW horn antenna using CST MWS. The parameters p, d, a_{SIW}, SL, and SW are as before. The length L of the SIW is 21.7mm, and l is 2.54mm. The length of the horn aperture, D, is 4.8mm and a dielectric slab with length b of 9mm is placed in front of the horn aperture which acts as a dielectric guiding structure to increase gain. The effect of different dielectric loading lengths on gain is shown in Table I.

TABLE I. EFFECT OF DIFFERENT LOADING LENGTHS ON GAIN, ε_r=10.2

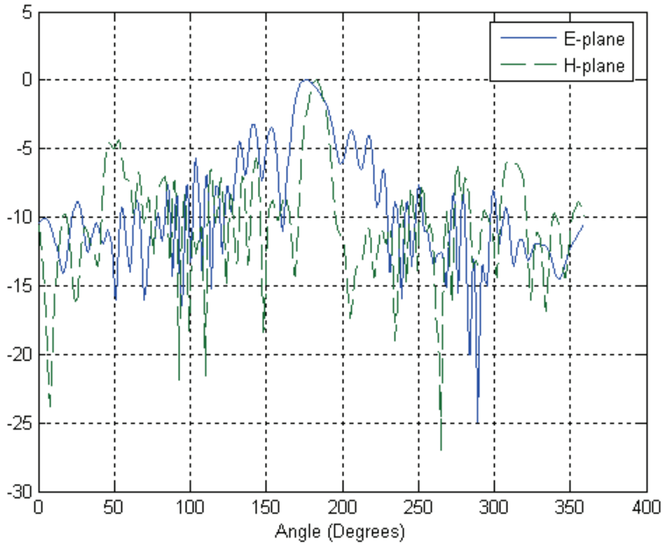
LOADING	GAIN dBi
Without loading	5.35
3mm	5.97
5mm	5.83
7mm	9
9mm	9



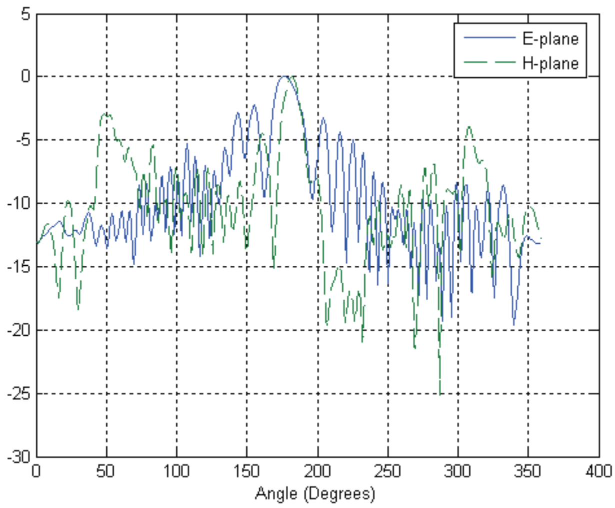
(a)



(b)



(c)



(d)

Figure 4. Radiation pattern of proposed design (a) 3mm loading, (b) 5mm loading, (c) 7mm loading, and (d) 9mm loading

Fig. 4 depicts the normalized radiation pattern in E-plane and H-plane for the proposed antenna in the cases of 3mm, 5mm, 7mm, and 9mm loading. It is seen that for the cases of 3mm and 5mm loading, the radiation pattern is distorted due to quadratic phase error. For the case of 9mm loading, the simulated gain for lossless substrate is 9 dBi. The slot width SW affects the coupling between the SIW and the waveguide feed. Fig. 5 shows the return loss for the proposed design for three different slot widths. It should be noted that the relatively small bandwidth could be due to the high dielectric constant.

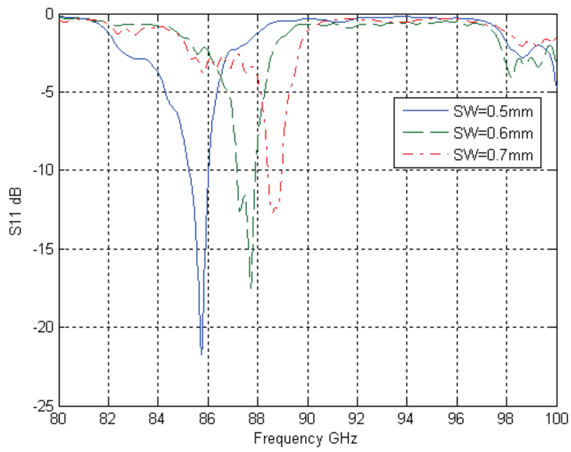


Figure 5. S_{11} for three different slot widths

IV. Fabrication and Measurement

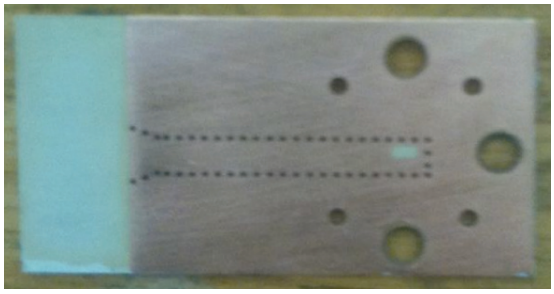


Figure 6. Photo of fabricated antenna

A photo of the fabricated antenna is depicted in Fig. 6. The substrate used is RT/duroid 6010 substrate with dielectric constant ε_r of 10.2, loss tangent tanδ of 0.0023 and height h of 0.635mm. The holes in the structure are used to fix the standard flange of WR10 waveguide by using screws and pins. The measured versus simulated S_{11} for the proposed design is presented in Fig. 7. The discrepancy between measured and simulated results could be due to the tolerance in the measurement setup, which could not do an exact replica of the simulation. Moreover, the PCB fabrication tolerance causes further discrepancy in the results.

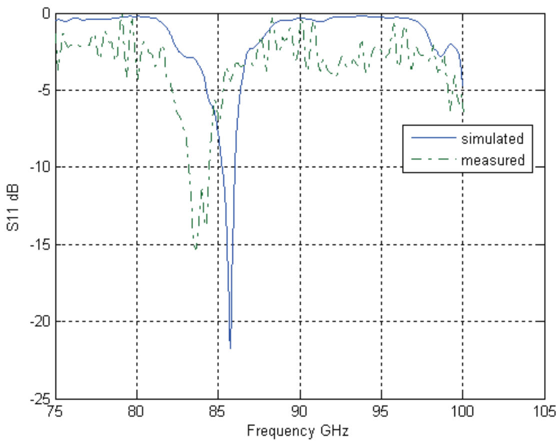


Figure 7. Measured and simulated S_{11} for the proposed design

V. Conclusion

A WR10 standard waveguide is used to feed a SIW horn antenna through a coupling slot. PCB process is used to fabricate the antenna, which has the advantages of ease of fabrication and low cost, however, it has relatively high tolerance in fabrication at millimeter wave frequencies. The measured bandwidth is 1 GHz and maximum simulated gain is 9 dBi.

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