Radiation Characteristic Improvement of Ku-Band SIW Horn Antenna using Probe-Feeding Technique

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***Abstract*—In this paper, a coaxial to substrate integrated waveguide (SIW) transition is integrated with Ku-band SIW H-plane horn antenna to improve the radiation characteristic over the desired operating band. The probe-fed SIW horn is realized on a $\lambda_0/13$ (λ_0, being calculated at the center frequency) thin substrate and loaded with a multi-layer multi-dielectric impedance transformer (MLMDIT) at its aperture. The MLMDIT is basically a three-layer multi-dielectric structure which reduces the aperture mismatch over a wide operating band. The materials of high dielectric values are used to realize the top and bottom layers of the MLMDIT, while the substrate extended from horn aperture acts as its middle layer. The use of high dielectric constant material to realize the top and bottom layers of the MLMDIT facilitates the wideband operation while maintaining the overall thickness to 0.2λ_0 at 15 GHz. The fabricated prototype is relatively simple, compact and thin. The experimental result show -10 dB reflection coefficient bandwidth of 34.73 % (12.9- 18 GHz). The observed end-fire radiation pattern is fairly stable and undistorted throughout the operating band with maximum gain of 7.5 dBi.**

***Index Terms*—end-fire, Ku-band, probe-fed, SIW Horn**

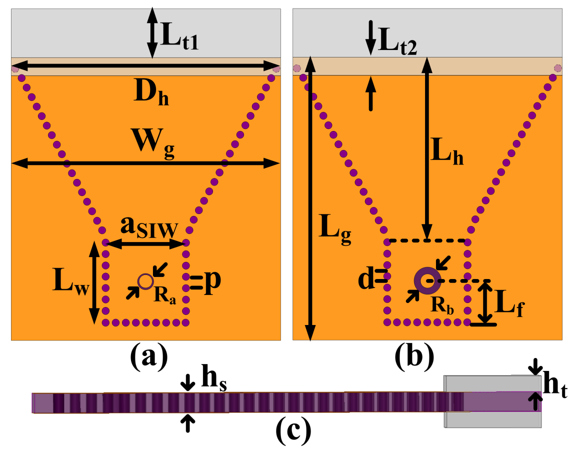

Fig. 1. Geometry of the proposed antenna. (a) Top view, (b) Bottom view, (c) Side view. (D_h = 29, L_h = 22.6, W_g = 31, L_g = 34.6, L_w = 10, a_{SIW} = 10, L_{t1} = 5.5, L_{t2} = 2.0, h_s = 1.57, h_t = 1.27, p = 1.3, d = 0.8, L_f = 4.5, R_a = 0.85, R_b = 2.0). All dimensions are in millimetres.

I. Introduction

The substrate integrated waveguide technology facilitates the development and integration of H-plane horn antenna on a single layer of substrate by using simple PCB fabrication process. In the millimetre wave region, high gain wideband SIW horn antennas with low back radiation have been demonstrated successfully [1]. However, the design of SIW horn antennas in the lower frequency region such as Ku-band encounters several challenges. In lower frequency band, commercially available substrates are electrically thin which lead to poor matching (between dielectric slab and air) at SIW horn aperture, resulting into narrow impedance bandwidth and high back radiation. If a customized thick substrate is used in the low frequency region for SIW horn antenna design then efficient feed line realization will be a challenge. In order to achieve, wide bandwidth at the lower frequency band (such as Ku-band and K-band) several methods have been reported. For example in [2], perforated substrate loaded SIW horn antenna has been presented having the impedance bandwidth of 40% (16-24 GHz). In order to achieve this, $\lambda_0/3$ thick substrate has been utilized. However, this thickness limits the efficient excitation in the planar environment. Thus in [2], the authors have adopted a bulky WR-42 waveguide for the feeding purpose which make the overall structure non-planar. The waveguide feeding has been replaced by a planar elevated coplanar waveguide (ECPW) feeding in [3], however the impedance bandwidth in this case get reduced to 31.88%. In [4], probe-fed meta-material loaded Ku-band SIW horn antenna on $\lambda_0/20$ thin substrate has been proposed having the impedance bandwidth of 10.6%. However, one major disadvantage is that, the maximum radiation has been obtained in the backward direction (back end-fire radiation). The dielectric-metal composite lens loaded SIW horn antenna has been reported in [5], which exhibits an impedance bandwidth of 18.5% (15.2-18.3 GHz) with 2 dB gain enhancement over the operating band. However, in order to realize the antenna, 5 mm (0.3λ_0) thick substrate has been utilized which limits the efficient planar feed realization. Recently, in [6], Ku-band SIW horn antenna having microstrip feed has been presented which exhibits impedance bandwidth of 31.91%. However, parasitic radiation from the feed line lead to poor FTBR and distorted end-fire radiation pattern.

Based on the above discussion, this paper presents a probe-fed Ku-band SIW horn antenna loaded with multi-layer multi-dielectric impedance transformer (MLMDIT) for wideband operation with undistorted end-fire radiation pattern. To the best knowledge of the authors this kind of low profile wide-

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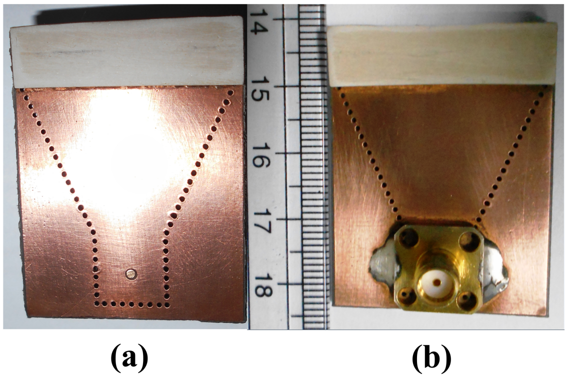

Fig. 2. Fabricated prototype of the proposed antenna, (a) Top view, (b) Bottom view.

band SIW horn antenna with undistorted end-fire radiation pattern in Ku-band is not reported earlier in the literature. The proposed antenna is relatively simple and compact and achieves moderate gain with high FTBR. Full wave simulations are carried out using CST microwave studio and a prototype of the proposed antenna is built and verified experimentally.

II. Antenna design

The geometry of the proposed antenna is shown in Fig.1a-c. Initially, a SIW horn antenna is designed using the standard procedure given in [7]. Rogers RT-Duroid 5880 (ϵ_{r1} = 2.2) substrate of thickness h_s =1.57 mm ($\lambda_0/13$ at 15 GHz) is utilized to design the antenna. The use of thin substrate, lead to poor matching at SIW horn aperture resulting into narrow impedance bandwidth. To overcome this, the SIW horn antenna substrate is extended by length L_{t1} beyond the aperture. Moreover, two extra Rogers RT-Duroid 6010 dielectric layers of high dielectric constant (ϵ_{r1} = 10.2) and height h_t = 1.27 mm is placed above and below the extended aperture as shown in Fig.1c. Thus the use of high dielectric constant layers reduces the overall thickness of MLMDIT to $0.2\lambda_0$ (calculated at 15 GHz). The placement of these layers are optimized through simulation and it is found that for L_{t1} = 5.5 mm and L_{t2} = 2 mm maximum impedance bandwidth is achieved. Probe feeding technique along with SIW cavity is used to excite the horn antenna [8]. The width of the SIW cavity (a_{SIW}) is selected to support the propagation of TE_{10} mode over the entire Ku-band. Diameter (d) and pitch (p) of the via are chosen using the design principles proposed in [9].

III. Results and Discussion

A. Fabricated prototypes

The proposed antenna prototype is fabricated by using multi-layer PCB fabrication process. The top and bottom view of the fabricated prototype are shown in Fig.2. The optimum dimensions of the proposed antenna is given in the caption of Fig.1. The overall size of the proposed antenna prototype is $40.1 \times 31 \times 4.11\ mm^3$ ($2.0\lambda_0 \times 1.55\lambda_0 \times 0.2\lambda_0$), λ_0, being calculated at center frequency.

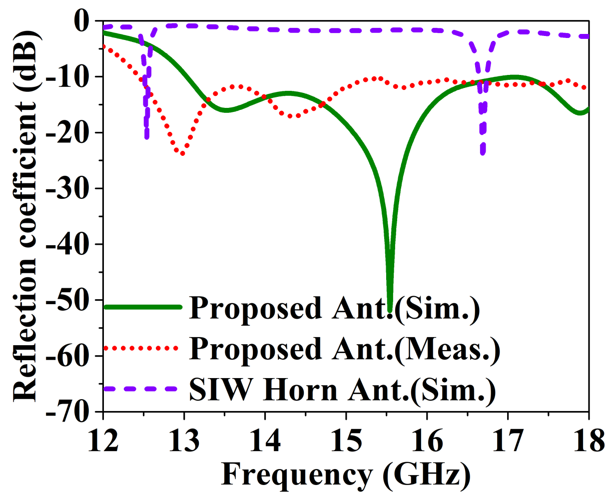

Fig. 3. Measured and simulated reflection coefficient of the proposed antenna and simulated reflection coefficient of the SIW horn antenna.

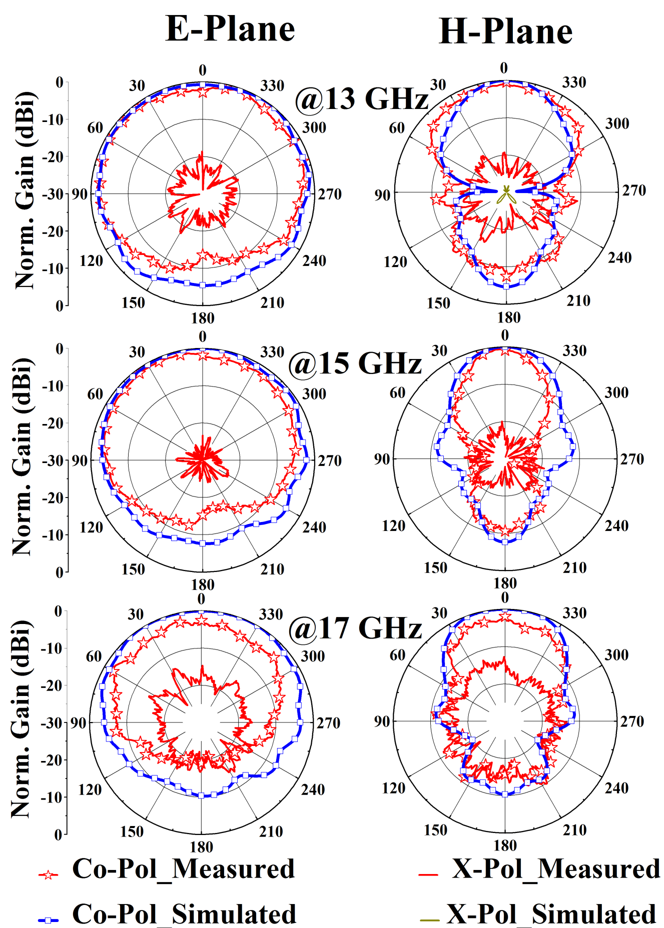

Fig. 4. Measured and simulated normalized radiation patterns of the proposed antenna in E-plane and H-plane at different frequencies.

B. Simulated and measured results

The comparison between the simulated and measured reflection coefficient is depicted in Fig.3. From Fig.3, it is observed

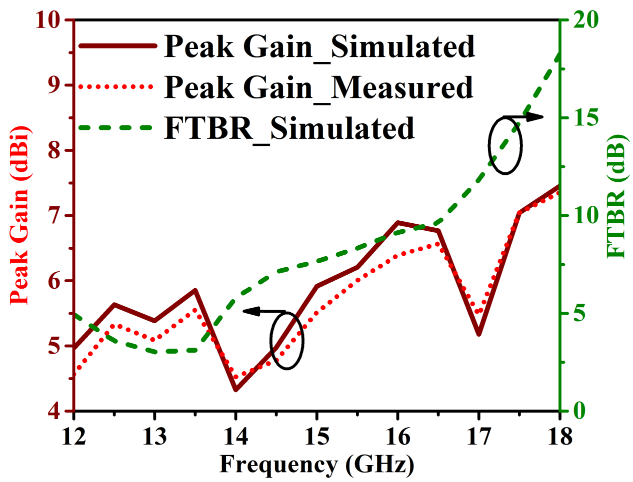

Fig. 5. Measured and simulated peak gain and simulated FTBR of the proposed antenna.

that the standard SIW horn antenna designed on the thin substrate do not have better matching characteristics over wide frequency band. This is mainly due to the high difference between the impedance at horn aperture and standard free space impedance (377Ω). On the contrary, the proposed antenna design shows the wider impedance bandwidth. The measured and simulated impedance bandwidth are 34.73% (12.79-18 GHz) and 33.33 % (13-18 GHz) respectively. The slight discrepancy between the simulated and measured results is owing to the fabrication tolerances and the alignment of different layers. Though a very small amount of adhesive is used to glue the layers but it might affect the measurement as well. The air gap between the layers is minimized by mechanically pressing the layers together. Fig.4, shows the normalized radiation pattern of the proposed antenna at different frequencies of Ku-band, where a good agreement between measured and simulated data can be observed. The end-fire radiation pattern is fairly undistorted and stable throughout the operating bandwidth and the difference between the measured co-polarized and cross-polarized fields is below 15 dB in both the planes. Fig.5, shows the peak gain and FTBR variation of the proposed antenna over Ku-band. The measured peak gain attains the maximum value of 7.5 dBi at 18 GHz while FTBR varies from 3 to 19 dB over the entire Ku-band.

C. Probe-feeding vs microstrip-feeding

From Fig. 6 (a) it is observed that, microstrip-fed MLMDIT loaded SIW horn antenna exhibits distorted end-fire radiation pattern (maximum radiation is along $\theta = 38°$ at 15 GHz in E-plane) due to the parasitic radiation from the feed line. The simulated 3D-gain pattern of the probe-fed proposed antenna is shown in Fig. 6 (b). Here coaxial to SIW transition provides undistorted end-fire radiation pattern (maximum radiation is along $\theta = 0°$ at 15 GHz in E-plane) by suppressing the parasitic radiations.

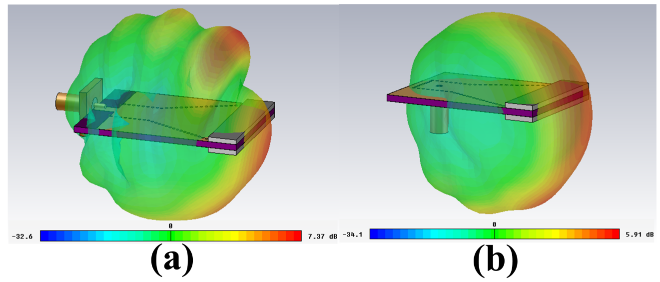

Fig. 6. Simulated 3D-gain pattern of the MLMDIT loaded SIW horn antenna at 15 GHz with (a) Microstrip-feeding, (b) Probe-feeding.

IV. Conclusion

In this paper, a probe-fed multi-layer multi-dielectric impedance transformer loaded $\lambda_0/13$ thin SIW horn antenna has been proposed possessing wide measured impedance bandwidth of 34.73% covering 12.79-18 GHz. The proposed antenna shows fairly undistorted and stable end-fire radiation pattern over the working band with measured cross-polarization level better than -15 dB in both planes. FTBR variations of 3-19 dB have been observed over the Ku-band while measured peak gain attains a maximum value of 7.5 dBi. The proposed antenna has been fabricated using simple PCB fabrication process and suitable for Ku-band applications.

References

[1] J. Wang et al., "Wideband dipole array loaded substrate integrated H-Plane horn antenna for millimeter waves," in *IEEE Trans. Antennas Propag.*, vol. 65, no. 10, pp. 5211-5219, Oct. 2017.

[2] Y. Cai, Z. Qian, Y. Zhang, J. Jin and W. Cao, "Bandwidth Enhancement of SIW Horn Antenna Loaded With Air-Via Perforated Dielectric Slab," in *IEEE Antennas Wireless Propag. Lett.*, vol. 13, pp. 571-574, 2014.

[3] Y. Cai et al., "compact wideband SIW horn antenna fed by elevated-CPW structure," in *IEEE Trans. Antennas Propag.*, vol. 63, no. 10, pp. 4551-4557, Oct. 2015.

[4] Y. Cai, Y. Zhang, L. Yang, Y. Cao and Z. Qian, "Design of Low-Profile Metamaterial-Loaded Substrate Integrated Waveguide Horn Antenna and Its Array Applications," in *IEEE Trans. Antennas Propag.*, vol. 65, no. 7, pp. 3732-3737, July 2017.

[5] H. Zong, X. Liu, X. Ma, Z. Zhao and S. Lin, "Printed H-plane horn antenna with loaded dielectric-metal composite lens," in *IET Microw. Antennas Propag.*, vol. 11, no. 5, pp. 642-648, 15 4 2017.

[6] S. K. Sahoo, K. K. Katare, A. Biswas and M. J. Akhtar, "Matching improvement of thin substrate SIW horn antenna using dielectric transitions," 2017 IEEE Applied Electromagnetics Conference (AEMC), Aurangabad, 2017, pp. 1-2.

[7] C.A. Balanis, "Antenna theory: analysis and design, third edition," Wiley-India.2005.

[8] C. S. Prasad, S. Mukherjee and A. Biswas, "Efficient probe excitation of dielectric image line using substrate integrated waveguide based matching network," 2015 9th European Conference on Antennas and Propagation (EuCAP), Lisbon, 2015, pp. 1-4.

[9] Feng Xu and Ke Wu, "Guided-wave and leakage characteristics of substrate integrated waveguide," in *IEEE Trans. Microw. Theory and Tech.*, vol. 53, no. 1, pp. 66-73, Jan. 2005.