Journal of Physical Sciences, Vol. 18, 2014, pp.46-53
ISSN: 0972-8791, www.vidyasagar.ac.in/journal
Published on 27th March 2014

Design of Compact Slot Antenna Array using Half-Mode Substrate Integrated Waveguide Technology

B.Rana and S. K. Parui

Department of Electronics and Telecommunication Engineering
Indian Institute of Engineering Science and Technology, Shibpur
Howrah-711103, West Bengal, India
Email: biswaruprana@gmail.com

Received on 28th February 2014; accepted on 25th March 2014.

ABSTRACT

In this work, a novel half-mode substrate integrated waveguide (HMSIW) fed compact slot antenna array has been presented. The HMSIW structure contributes to reduce the size of antenna by nearly half compared to the substrate integrated waveguide (SIW) structure. A new type of compact slot has been introduced in the HMSIW structure which reduces the antenna size further without degrading the characteristics like gain, co-polarized radiation over the principal planes and input impedance compared to those with the conventional SIW structure. At 16.8 GHz, the conventional slots (vertical slot) can not be etched within the width of the HMSIW structure as the length of slots are long enough compared to the width of HMSIW structure. Hence, two types of miniaturization techniques have been used in this design. One type of miniaturization technique has been achieved by using HMSIW and another type of miniaturization technique has been achieved by using a new type compact slot. The slot length and width have been optimized for better performance of the HMSIW.

***Keywords**:* Substrate Integrated Waveguide (SIW), Half-Mode Substrate Integrated Waveguide (HMSIW), Folded Substrate Integrated Waveguide (FSIW), Antenna array, Antenna gain.

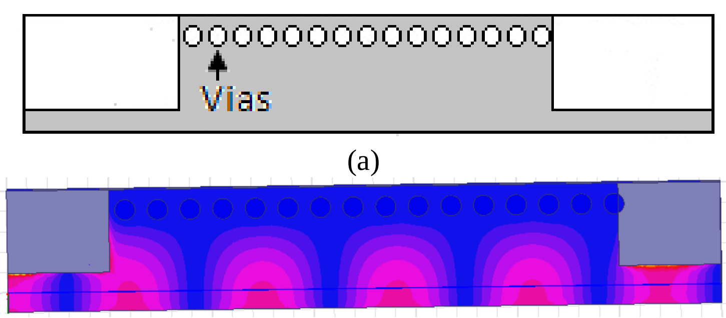
1. Introduction

SIW technology has been proposed as an emerging and promising candidate for microwave and millimeter wave circuits and systems achieving low cost, planar, compact, and high-density integration etc. SIW structures preserve the advantages of conventional metallic waveguides, namely low radiation loss, high quality-factor and high power-handling capability [1-3]. Waveguide slot antennas are very popular in microwave and millimeter wave region with numerous applications such as radar and communication systems, which require narrow-beam or shaped-beam radiation patterns. The distances between the slots are taken as the one-half of the guided wavelength at deign frequency so that the peaks of the standing wave and slots position coincide. All the slot antennas have to have same phase and same amplitude distributions to achieve the given gain and side-lobe levels. Slot antennas are fed by conventional metallic waveguide feeding techniques which process high quality factor, high power-handling capability. However, conventional metallic waveguides, voluminous and expensive to manufacture, are not compatible with planar microwave and millimeter wave integrated circuits. Recently, a new technology known as SIW also known as post wall waveguide has been explored. SIW technology has been applied to different microwave components like antenna [4,5], filter [6,7], directional coupler [8,9], circulator [10], oscillator [11,12], power amplifier [13] etc. This technology can be used as a feed for different kind of slots antennas and leaky antennas, having advantage like low weight, low cost, easy to fabricate, compatibility with planar microwave and millimeter integrated circuits, even it is compatible with non-planar integrated circuits. At lower frequency regimes, the width of the SIW becomes large. As a result, the size reduction of SIW is a challenging task for the researchers. By using FSIW technique, the size can be reduced considerably [14]. The disadvantage of this technique is that it employs multi-layer structure which increases the costs and complexity during fabrication. Some works on HMSIW based on slot antenna are available in the recent literature [15].

In our investigation, the introduction of HMSIW reduces the size of the width compared to that of slot antennas fed by FMSIW. The antenna has been further miniaturized by introducing a new type of compact slot without affecting the full mode characteristics of SIW.

2. Concept of Half-Mode Substrate Integrated Waveguide

Configuration of a HMSIW is shown in the Figure 1 (a). The dimension of HMSIW is half of the FMSIW having linear array metallic vias in one side as illustrated in the Figure 1 (a). On the opposite side, it is open circuited, whereas in the case of a FMSIW there are metallic vias on the both sides. As the opposite side of the HMSIW is open-circuited, it acts as a magnetic wall. Consequently, in the HMSIW only quasi $TE_{(m-0.5,\ 0)}$ (where m=1, 2, 3…) modes propagate. For m=1, the mode is quasi $TE_{(0.5,0)}$ which is the dominant mode of HMSIW. The electric field distribution of the SIW is almost similar to the electric field distribution of the rectangular waveguide filled with same dielectric material. For the HMSIW, the electric field distribution as shown in Figure 1 (b) is just half of the electric field distribution of the FMSIW.



(a)

(b)

Figure 1: (a) Configuration of a HMSIW (b) Electric field distribution of the HMSIW in the H-plane.

3. SIW Characteristics Study

In this work, initially SIW transmission characteristics have been studied on the Arlon substrate of dielectric constant (ε_r) =3.2, height (h) =0.79 mm, and loss tangent (tanδ)=0.002. After that, FMSIW slot antenna has been studied on the same substrate. A new type of compact slot is proposed here. Finally, the proposed HMSIW slot antenna array has been designed using the new type of compact slot. The design of the antenna has been performed using Ansys High-Frequency Structure Simulator (HFSS) based on the three-dimensional finite element method (FEM).

The schematic diagram of the SIW as shown in Figure 2, consists of a 50 Ω feed line, ground plane and metallic vias on the both sides. A 50 Ω line is implemented by a microstrip line of width of 1.9 mm. The distance between two adjacent vias and the radii of the vias are the critical factors in the design of any kind of SIW structure.

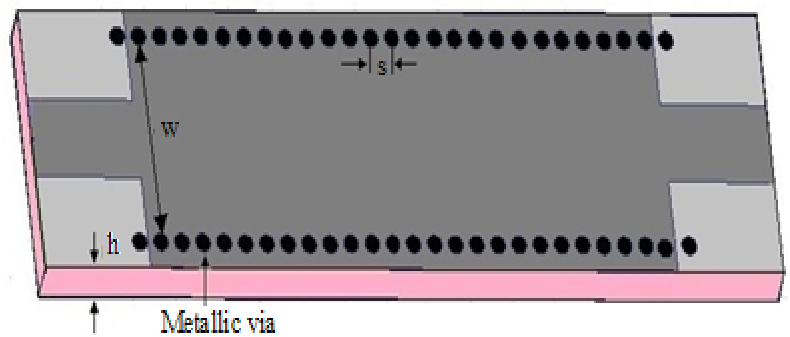


Figure 2: Schematic diagram of SIW

Dispersion characteristics of the SIW are identical with the characteristics of equivalent rectangular waveguide filled with same kind of dielectric material. The equivalent width of the rectangular waveguide is given in the equation (1)

$$w_{equi} = w - 1.08\,\frac{d^2}{s} + 0.1\,\frac{d^2}{w} \quad \ldots\ldots\ldots\ldots\ldots(1)$$

This empirical equation is very accurate when s/d is smaller than three and d/w is smaller than 1/5[16]. In our design, the center to center distance(s) between two vias is 1.6 mm and radius of the vias is 0.5 mm each.

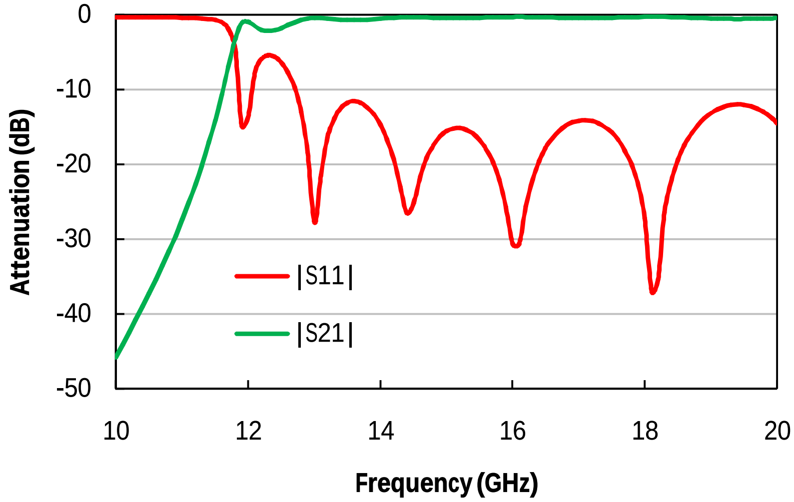
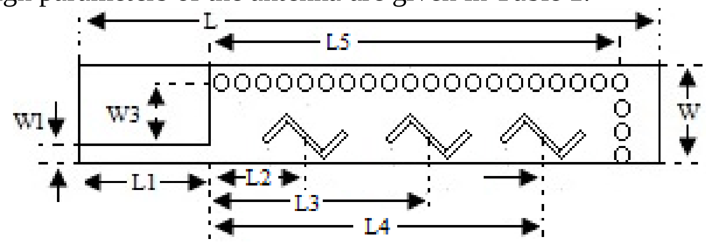


Figure 3: Transmission characteristics of the SIW

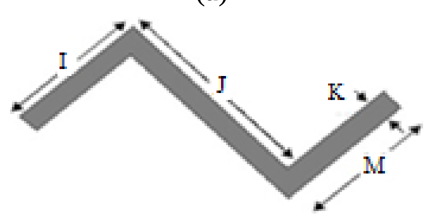
Figure 3 shows the transmission characteristics of the SIW. The insertion loss of the SIW is about -3.3 dB at 11.8 GHz and the refection is lower than -10 dB over a wide range of frequency.

4. HMSIW Antenna Array Design

HMSIW compact antenna has been designed from the concept of FMSIW antenna. The schematic diagram of HMSIW antenna is shown in the Figure 4(a) and larger view of slot is shown in the Figure 4(b). The antenna has been fabricated upon Arlon substrate of dielectric constant (ε_r) =3.2, height (h) =0.79 mm, and loss tangent (tanδ)=0.002. The optimized design parameters of the antenna are given in Table 1.



(a)



(b)

Figure 4: (a) Schematic diagram of the HMSIW antenna (b) larger view of slot

TABLE I. DESIGN PARAMETERS OF HMSIW ANTENNA (UNITS: MM)

Parameters	**Dimension in mm**	**Parameters**	**Dimension in mm**
W	5.95	W3	3.05
L	35	I	2
W1	1.9	J	2.6
L1	5.0	K	0.4
L2	5.6	M	2.2
L3	11.0	L4	16.5

The simulated resonant frequency of the proposed antenna array is 16.8 GHz with 3.1% impedance bandwidth. The return loss characteristic of the proposed HMSIW compact slot antenna array is studied in Figure 5. The lengths of "I" and "M" have been varied over a range as shown in Fig.6 and the optimum return loss for the I=M=2.2 mm has been observed. The simulated E-plane radiation pattern is shown Figure 7. A simulated gain of 10.6 dBi is observed for the E-plane radiation pattern of the proposed HMSIW antenna. For the H-plane radiation pattern as shown in Figure 8, simulated gain was also 10.6 dBi. The cross-polarization level for both the E-plane and H-plane are well below compared to the co-polarization level as shown in Fig. 7 and Fig. 8.

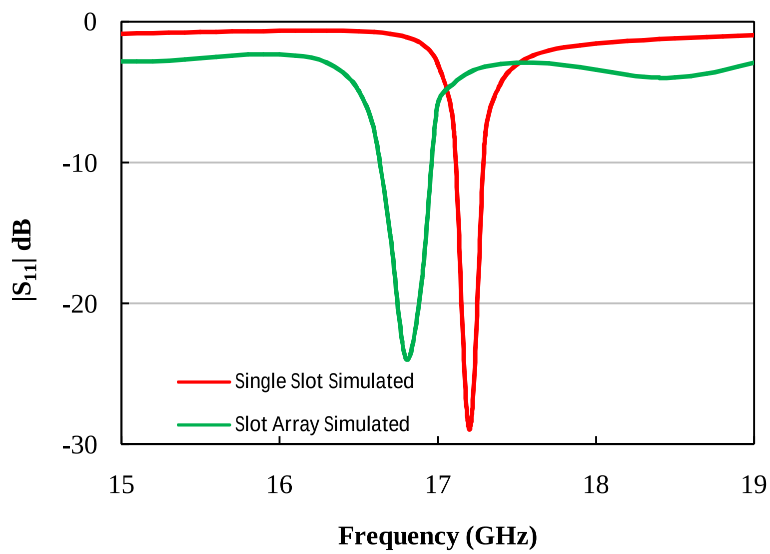


Figure 5: Simulated return loss of HMSIW antenna

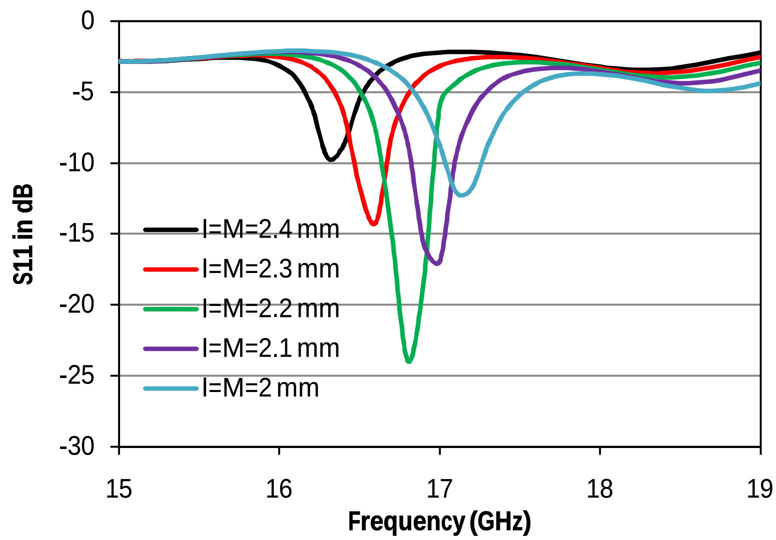


Figure 6: Simulated return loss of HMSIW antenna for different value of “M” and “I”

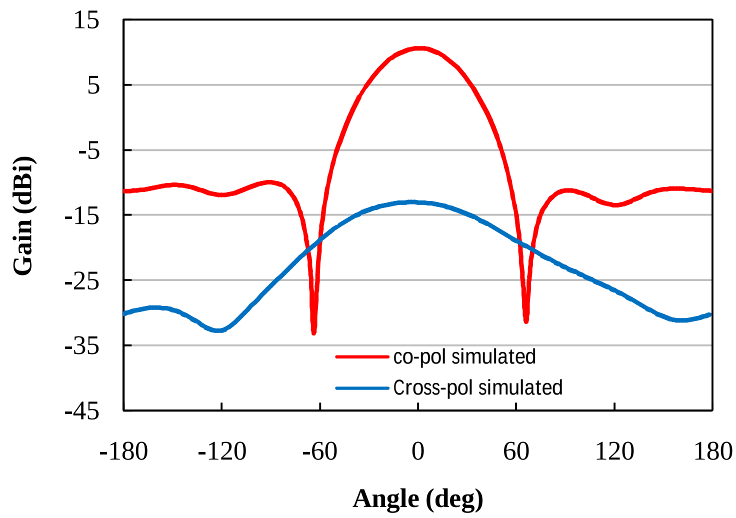


Figure 7: Simulated E-plane radiation pattern of HMSIW antenna

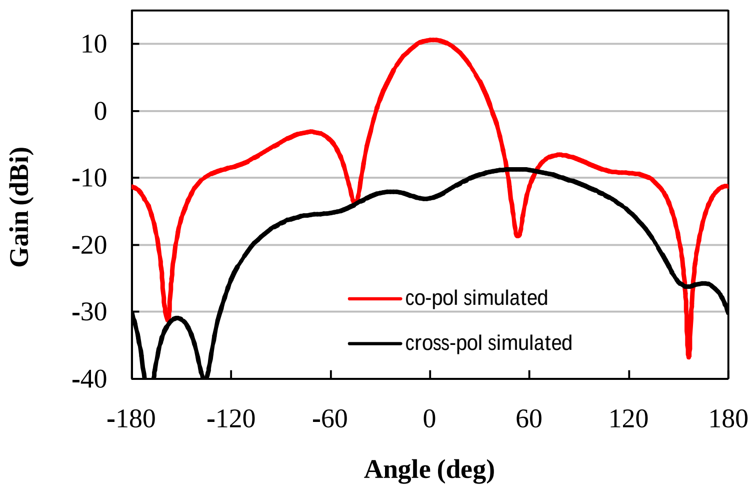


Figure 8: Simulated H-plane radiation pattern of HMSIW antenna

5. Conclusion

In this paper, a HMSIW fed compact slot antenna array has been designed to operate at the Ku frequency band. It has been found to resonate at a center frequency of 16.8 GHz and enjoys a fractional -10 dB impedance bandwidth of 3.1%. Two methodologies of miniaturization have been used here. By using the HMSIW structure, the antenna has been miniaturized 50% as compared to that of FMSIW. The antenna has been further miniaturized by utilizing a new type of compact slot antenna. The maximum gain of 10.6 dBi obtained in the HMSIW fed slot array antenna along the both E-plane and H-plane radiation patterns at the operating frequency. Further, the said gains of the HMSIW compact slot can be enhanced significantly by introducing more numbers of slots in this proposed design.

Acknowledgement: We like to thank Dr. Chandan Kuamr Ghosh of Dr. B.C. Roy Engineering College, Durgapur for some useful academic discussions during the execution of this work.

REFERENCES

1. H. Uchimura, T. Takenoshita and M. Fujii, Development of a laminated waveguide, IEEE Trans. Microw. Theory Techn., 46 (12) (1998) 2438-2443.
2. J. Hirokawa and M. Ando, Single-layer feed waveguide consisting of posts for plane TEM wave excitation in parallel plates, IEEE Trans. Antennas Propag., 46 (5)(1998) 625–630.
3. M. Bozzi, A. Georgiadis, and K. Wu, Review of substrate-integrated waveguide circuits and antennas, IET Microw. Antennas Propag., 5 (8) (2011) 909-920,.
4. L. Yan, W. Hong, G. Hua, J. Chen, K. Wu and T. J. Cui, Simulation and Experiment on SIW Slot Array Antenna, IEEE Microw. Wirel. Compon. Lett., 14(9)(2004) 446-448.

5. J. Liu, D. R. Jackson and Y. Long,Substrate Integrated Waveguide (SIW) Leaky-Wave Antenna With Transverse Slots, IEEE Trans. Antennas Propag., 60(1)(2012) 20–29.
6. D. Deslandes and K. Wu, Single-substrate integration technique of planar circuits and waveguide filters, IEEE Trans. Microw. Theory Tech., 51(2) (2003)593–596.
7. H. Tang, J. W. Hong, Z.C. Hao, J.X. Chen and K. Wu, Optimal design of compact millimetre-wave SIW circular cavity filters, Electronics Letter, 41(19)(2005).
8. J. X. Chen, W. Hong, Z. C. Hao, H. Li and K. Wu, Development of a Low Cost Microwave Mixer Using a Broad-band Substrate Integrated Waveguide (SIW) Coupler, IEEE Microw. Wirel. Compon. Lett., Vol.16(2) (2006) 84-86.
9. Z. C. Hao, W. Hong, J. X. Chen, H. X. Zhou and K. Wu, Single-layer substrate integrated waveguide directional couplers, IEE Proc.-Microw. Antennas Propag., 153(5) (2006) 426-431.
10. W. D'Orazio and K. Wu., Substrate-Integrated-Waveguide Circulators Suitable for Millimeter-Wave Integration, IEEE Trans. Microw. Theory Techn., 54(10) (1998) 3675-3680.
11. Y. Cassivi and K. Wu, Low cost Microwave Oscillator Using Substrate Integrated Waveguide Cavity, IEEE Microw. Wirel. Compon. Lett., 13(2)(2003) 48-50.
12. C. Zhong, J. Xu, Z. Yu and Y. Zhu, Ka-Band Substrate Integrate Waveguide Gunn Oscilator, IEEE Microw. Wirel. Compon. Lett., 18(7) (2008) 461-463,.
13. M. Abdolhamidi and M. Shahabadi, X- Band Substrate Integrated Waveguide Amplifier, IEEE Microw. Wirel. Compon. Lett., 18(12)(2008) 815-817.
14. B. S. Izquierdo, P. R. Young, N. Grigoropoulos, J.C. Batchelor and R. J. Langley, Substrate-Integrated Folded Waveguide Slot Antenna, Proc. IEEE Small Antennas Novel Metamaterials, pp. 307-309, Sep. 2005.
15. Q. H. Lai, W. Hong, Z. Q. Kuai, Y.S. Zhang and K. Wu, Half-Mode Substrate Integrated Waveguide Transverse Slot Array Antennas, IEEE Trans. Antennas Propag., 57(4)(2009) 1064–1072.
16. Xu. Feng, and Ke Wu,Guided-Wave and Leakage Characteristics of Substrate Integrated Waveguide, IEEE Trans. On Microwave Theory and Techniques, 53(1)(2005) 66-73.