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Substrate Integrated Waveguide Slot Array antenna for Broadband Applications

Rekha S, S Ramani

Abstract : This paper presents a design of substrate integrated waveguide slot array antenna for X and Ku band applications. This is a low weight and simple profile antenna covering a vast range of frequencies. A substrate integrated waveguide is formed by two rows of metallized cylinders connecting upper and bottom layer of substrate. On the metallic plate, slot arrays are etched in a periodic fashion to achieve broad bandwidth. The SIW is excited by the microstrip feeding through a tapered transition to achieve smooth flow of current. The simulated result shows that -10 dB return loss of the proposed antenna is -35 dB, -29 dB and -22 dB at 11.1 GHz, 12.7GHz and 17.6 GHz respectively. The simulated bandwidth of the design is 7.6 GHz from 10.4-18 GHz which covers X band partially and Ku band. The gain of the antenna is about 6 dB. The proposed design is simulated using 3D full wave simulator named Ansys HFSS.

Keywords : Substrate integrated waveguide, slot arrays, broad bandwidth, X band and Ku band applications.

I. INTRODUCTION

Substrate integrated waveguide (SIW) is an emerging technology for the design of microwave circuits, antennas and cost-effective components. Traditional transmission lines like microstrip and coaxial lines suffer conductor and radiation losses at high frequencies. The metallic waveguide has good performance at high frequency but it is bulky and costly. In order to balance the cost and performance, SIW was developed. This SIW has three layers namely top metallic layer, bottom metallic layer and intermediate dielectric substrate. Metallic cylinders are inserted between top and bottom metallic conductors. This SIW has the merits of high power handling capacity, low radiation losses and less fabrication cost. The structure of SIW is similar to dielectric filled rectangular waveguide [1]. The slot is etched on the top surface of the SIW to radiate the electromagnetic waves. Different shapes of slot [2-3] are etched to increase the bandwidth since conventional rectangular slot is a narrow band [4]. The slot arrays are introduced to create resonance at different frequencies and the bandwidth is extended for different microwave applications [5-7]. Such slot arrays on SIW is also employed to design passive devices like couplers [8], filters [9], etc. In this paper, slot arrays are etched on the top metallic layer of SIW and they finds its application in X and Ku bands. The SIW is fed through microstrip feeding on both the ends via tapered transition.

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* Correspondence Author
Rekha S*, Dept. of ECE, Sreenidhi Institute of Science and Technology, Hyderabad, Telangana.
S Ramani, Dept. of ECE, Sreenidhi Institute of Science and Technology, Hyderabad, Telangana.

II. DESIGN EQUATIONS OF SIW

The proposed design is built on the substrate namely Rogers RT/Duroid 5880 having ε_r as 2.2, μ_r as 1 and having dielectric loss tangent of 0.0009. The top and bottom geometry is shown in figure 1 and 2. The dimension of the proposed design is mentioned in Table 1. The overall dimension of the design is 40 x 14.6 x 0.762 mm^3. The resonant frequency of the SIW slot array antenna is given in equation (1).

$$f_{r(TE\,m,n,q)} = \frac{c}{2\sqrt{\varepsilon_r}}\sqrt{\left(\frac{m}{a}\right)^2+\left(\frac{n}{b}\right)^2+\left(\frac{q}{c}\right)^2} \quad (1)$$

where,
c - velocity of light in free space,
ε_r - relative permittivity of the substrate,
a,b,c - width, height and length of SIW,
m,n,p - positive integers.

To minimize leakage between the consecutive metallized cylinders, equation (2) and (3) are maintained.

$$d/s \geq 0.1 \quad (2)$$
$$d/\lambda o \leq 0.1 \quad (3)$$

where, d is diameter of the metallized cylinder, s is center to center distance between the successive cylinders and λ_0 is free space wavelength. The slots of a particular shape are etched in the definite intervals on the top conductor.

These slots are placed on the dense current distributed region having a distance of $\lambda/4$ from the tapered edge. The distance of $\lambda/4$ is maintained in order to create constructive interference of radiated waves.

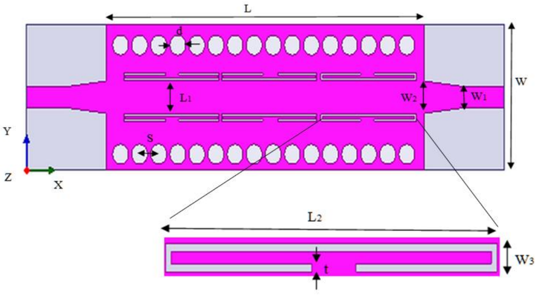


Fig. 1. Top view of the proposed SIW slot array antenna

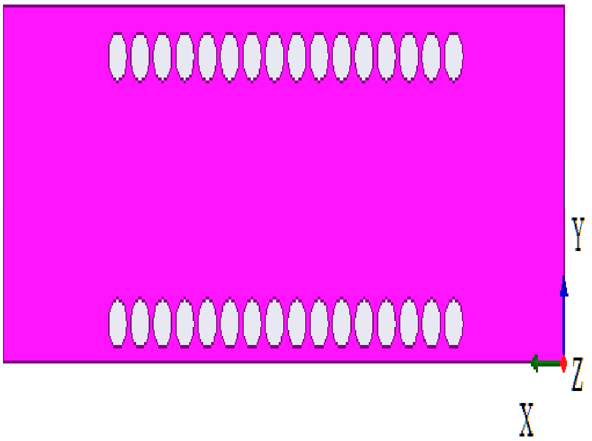


Fig. 2. Rear view of the proposed SIW slot array antenna

Table- II: Dimensions of the proposed design

S. No	Parameters	Dimensions (in mm)
1.	L x W x H	40 x14.6 x 0.762
2.	S	1.3
3.	d	2
4.	L_1	3.5
5.	W_1	2
6.	W_2	3
7.	L_2	11.8
8.	W_3	0.6
9.	t	0.2

III. Results and Discussions

The simulated proposed design has strong resonances at 11.1 GHz, 12.7 GHz and 17.6 GHz and their return losses are -35 dB, -29 dB and -21 dB respectively. It shows a broad bandwidth from 10.4 to 18 GHz that occupies the X band (upper half) and Ku frequency band. The simulated return loss and insertion loss is shown in figure 3 in which the insertion loss is around -2 dB (acceptable). Figure 4 shows that the voltage standing wave ratio (VSWR) is less than 2 for the operating bandwidth.

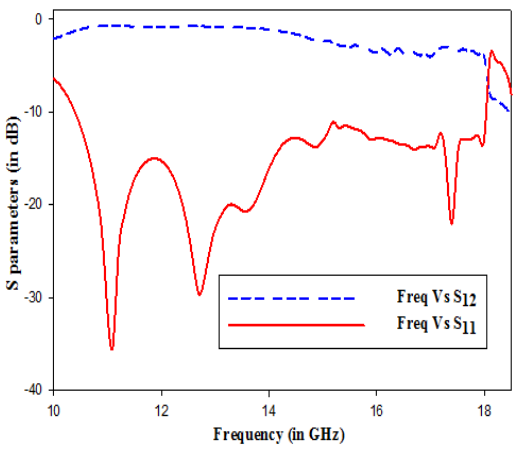


Fig. 3. Simulated return loss and insertion loss of proposed SIW slot array

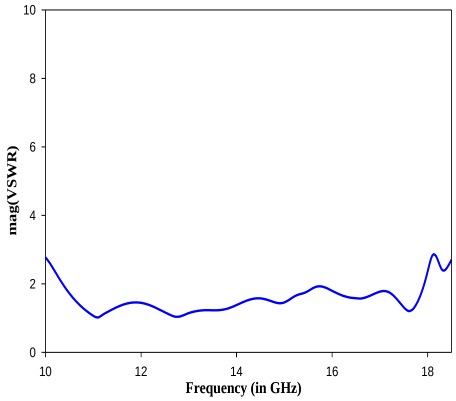
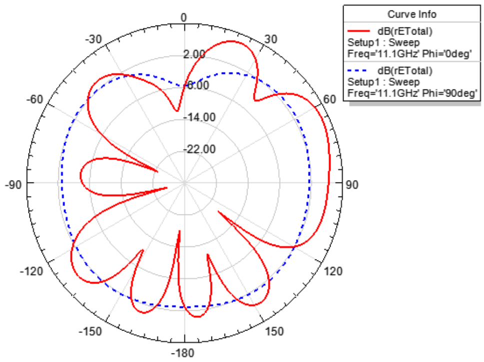
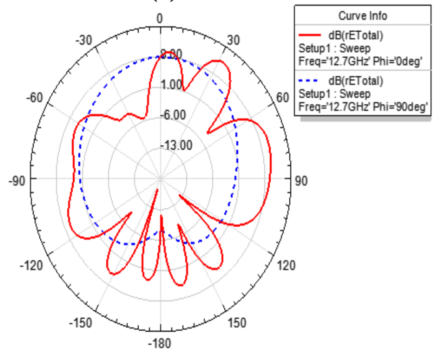


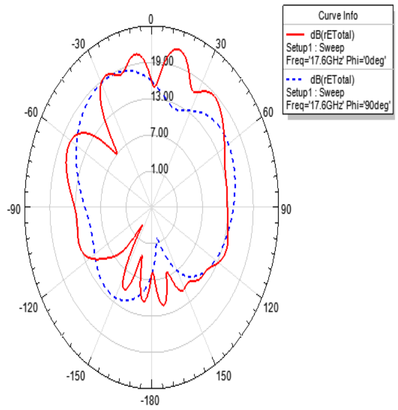
Fig. 4. Simulated VSWR of proposed SIW slot array



(a)



(b)



(c)

Fig. 5. Simulated radiation pattern of proposed SIW slot array

At resonance frequencies (a) 11.1 GHz (b) 12.7 GHz c) 17.6 GHz and The radiation pattern for resonant frequencies is presented in figure 5. It is plotted for the resonant frequencies of 11.1 GHz, 12.7 GHz and 17.6 GHz. The figure shows plotting of electric field and magnetic field pattern. The antenna is radiating sufficiently at their resonant frequencies. The radiation pattern shows that it is an quasi omi-directional antenna. Figure 6 shows simulated E field distribution at peak resonant frequency of 11.1 GHz. The figure shows that the radiation is maximum around the slots which is indicated by intensity of the colours. The peak gain of the proposed antenna is around 6 dB. The radiation efficiency of the design is about 75%.

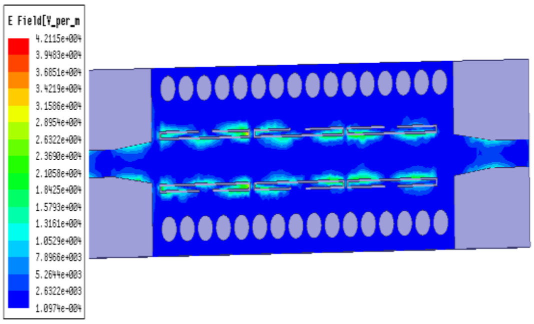


Fig. 6. Simulated E field distribution of SIW slot array at peak resonant frequency of 11.1 GHz

IV. CONCLUSION

The substrate integrated waveguide slot array antenna is presented in this work. The antenna is designed for X band and Ku band applications. The profile of the antenna is maintained simple with use of substrate integrated waveguide technology. The antenna is fed by a microstrip feeding using a tapered section on both its sides in order to achieve smooth flow of current distribution. The slot array etched on the top conducting layer of the antenna. The etching of slots has introduced multiple resonances at different frequencies. The length of the slot is about half of the wavelength and the distance of the slot from the edge of excitation is about quarter of the wavelength. The length and distance are maintained in terms of wavelength to create constructive interference of the waves. Then, the multiple resonances are adjusted by varying the electrical lengths of the slot to create a broad bandwidth. These resonances are extended by introducing small resonances between peak resonances and broad bandwidth is achieved. The antenna exhibits wideband characteristics from 10.4 GHz to 18 GHz which covers both X band and Ku band frequencies. It gives a nominal gain of about 6dB at resonances. The radiation efficiency of the antenna is 75%.

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AUTHORS PROFILE

Rekha S is working as an Assistant Professor in the Department of Electronics and Communication Engineering, Sreenidhi Institute of Science and Technology, Hyderabad, India. Her main focus area of research is antenna design, especially substrate integrated waveguide, slot antenna and its applications. She has 5 years of teaching experience and more than 10 publications in refereed international journals and conferences. She is a lifetime member of CSI.

S Ramani is working as an Associate Professor in the Department of Electronics and Communication Engineering, Sreenidhi Institute of Science and Technology, Hyderabad, India. She has 21 years of teaching experience in Engineering Colleges at various capacities. She has published more than 28 International Conference Papers and referred journals with 7 years of extensive experience in Research in the areas of Embedded Networking/Simulation.