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X- Band Slot Antenna based on Substrate Integrated Waveguide Transmission Technique

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***Abstract*—This document presents a novel X-band slotted substrate integrated waveguide (SIW) antenna. The structure consists of a slot between two periodic rows of metallic vias inserted along the thickness of the substrate. This antenna operates in TE_{10} mode of excitation of the SIW at resonant frequency of 9.73 GHz. Rogers RT/Duroid 5880 is used as a dielectric substrate having permittivity 2.2 and thickness 1.575 mm. A 50 ohm conventional microstrip feedline is used to perfectly match the SIW slot antenna. The slot dimension is kept to be $\lambda_g/2$, where λ_g is the guided wavelength. The gain, return loss and directivity plot of this SIW slot antenna is studied. The effect of increasing the number of via has also been analyzed. This structure is designed and simulated using ANSYS HFSS (High Frequency Structure Simulator) software.**

Keywords*—*Substrate Integrated Waveguide (SIW); microstrip transition; slot antenna; Tapered Transition.

I. INTRODUCTION

The electromagnetic spectrum these days is becoming more crowded with various wireless signals for communication and sensing services. For the efficient utilization of frequency spectrum resources the design and development of the system choose an appropriate transmission-line or waveguide technology. Metallic waveguide is a conventional transmission line for guiding microwave signals with low loss and high power handling capability [10]. The problem arised when metallic waveguides were not able to integrate the planar structures with the microwave or millimeter wave devices. This has led to the emergence and development of the concept of substrate integrated Waveguide (SIW) in which any nonplanar structure may be synthesized into planar form that makes it compatible with other planar circuits [9]. SIW provides low radiation loss, acceptable Q factor and high power handling capability as compared to traditional Rectangular waveguide structures, SIW also utilizes low cost and low profile structures [1].

X- Band is utilized for this structure as it performs better with smaller antennas and can handle higher power. Rain fading is dominant in radio frequencies above 10 GHz. Hence X Band does not have much interference from rain fading compare to other higher frequency bands such as Ku band and Ka band. It has lower noise and hence it is reliable band for high data and low noise data communications.

In this letter, a low-profile high-gain SIW slot antenna with suppressed cross polarization using is presented. The SIW technology is used to design the slot antenna which operates at 9.73 GHz. The structure is designed on Rogers RT/Duroid substrate with dielectric constant 2.2, permeability 1 and loss tangent 0.0009.

II. ANTENNA CONFIGURATION

A. Substrate Integrated Waveguide and its design techniques

Substrate Integrated Waveguide technology has provided a new approach in the design of microwave and millimeter-wave systems. Using SIW, rectangular waveguide based non-planar circuits can be synthesized into planar form. SIW consists of two periodic rows of metal via or holes which form a waveguide inserted within the substrate as in [1] – [4].

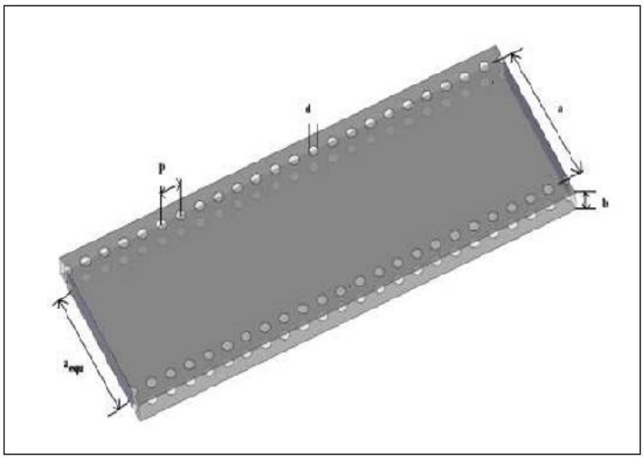

Fig. 1. Basic SIW structure

For SIW TE_{10} is dominant mode of operation as in rectangular waveguide. As shown in above figure ‘p’ is the period between the vias,‘d’ is diameter of vias, ‘b’ is the height of the substrate, ‘a’ is center to center distance between vias of both the rows, substrate dielectric constant ‘ε_r’, ‘a_{equ}’ is the width of the dielectric filled waveguide as discussed in [2]. If ‘a_{con}’ is the width of conventional wave guide and ‘ε_{con}’ is 1 (air) then its equivalent dielectric filled waveguide width is

$$a_{equ} = a_{con} / \sqrt{\varepsilon_r} \quad (1)$$

The cutoff frequency ‘fc’ can be calculated as

$$f_c = c/ (2\, a_{equ} \sqrt{\varepsilon_r}\,) \quad (2)$$

The TE_{10} mode related frequency region of interest is defined by

$$p > d \quad (3)$$

$$p/ \lambda_c < 0.25 \quad (4)$$

$$a_1 /k_0 < 1x\, 10^{-4} \quad (5)$$

$$p/ \lambda_c < 0.05 \quad (6)$$

where, ‘λ_c’ is the cut off wavelength, ‘a_1’ is the total loss and ‘k_0’ is wave number in free space [1]. Center to center distance between vias of both the rows ‘a’ can be calculated

$$a = a_{equ} + \frac{d^2}{0.95\,p} \quad (7)$$

B. Slot Antenna on SIW

Slot antennas are popular omnidirectional microwave antennas. Unique features of these antennas are horizontal polarization and omnidirectional gain around the azimuth. The slot length is generally $\lambda_g/2$ which is cut on the top wall of the waveguide. A slot cut into the wall of a waveguide interrupts the transverse current flowing in the wall, forcing the current to travel around the slot, which induces an electric field in the slot. The position of the slot in the waveguide determines the current flow [6].

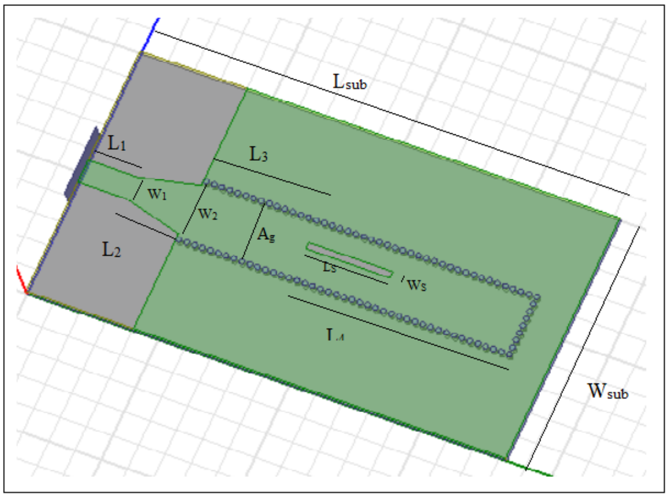

Fig. 2. SIW with design parameters

C. Feed Design

The proposed structure has been fed with a conventional microstrip line [5]. The microstrip transition between the feed and the radiating surface has been tapered for proper impedance matching [8]. This transition between port and the radiating surface is called 'Microstrip to-SIW Transition' [7]. The tapered transition is designed with the help of polyline. The full port impedance is 50 ohm with zero reactance.

Taper width 'W_2' and taper length 'L_2' are also important parameters for microstrip taper design [2]. The tapered width 'W_2' and tapered length 'L_2' can be determined as:

$$W_2 / A_g \approx 0.4 \quad (8)$$

$$(\lambda_g/2) < L_2 < \lambda_g \quad (9)$$

where, $\lambda_g = \lambda_c/\sqrt{\varepsilon r}$

III. ANTENNA DESIGN PARAMETERS

This SIW fed slot antenna operates at 9.73 GHz. The total length and width of the substrate that is L_{sub} and W_{sub} are 91.1 mm and 50mm respectively. Permittivity of the substrate RogersRT/Duroid is 2.2 and thickness 1.575mm. Copper material is assigned to the metal vias and the upper as well as bottom conducting layer which forms a closed rectangular waveguide inside the substrate called SIW. The other end of the SIW is closed with the copper conducting vias. The dimensions of the SIW Slot antenna are given below in the table:

TABLE I. SIW DESIGN PARAMETERS

Parameters	Dimensions (in mm)
L_{sub}	91.1
W_{sub}	50
L_1	9.5
L_2	11
L_3	22.02232
L_4	42.97768
W_1	4.6
W_2	10
W_3	12
L_S	15.79
W_S	1.2855

The periodic distance between the vias, p is 1.5mm and the diameter of each metal via, d is 1mm. The height of the substrate, h is 1.575mm.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The proposed antenna is designed and simulated in HFSS version 15. The return loss of the antenna is shown in fig. 3 which is -17dB at 9.73 GHz.

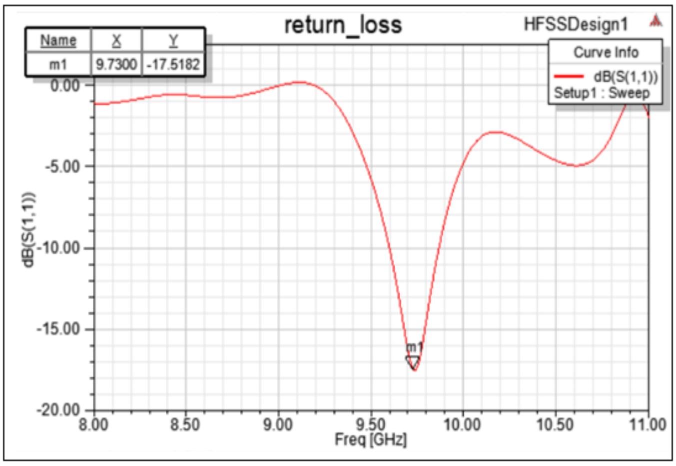

Fig. 3. Return Loss graph

The Corresponding VSWR Plot of the design is also plotted which gives a lowest value as low as 1.3070 at 9.73 GHz shown in fig. 4 and the value of VSWR stays less than 2 in the frequency range of 9.6388 GHz to 9.8271 GHz. Due to effective matching VSWR is found to be in the ideal range.

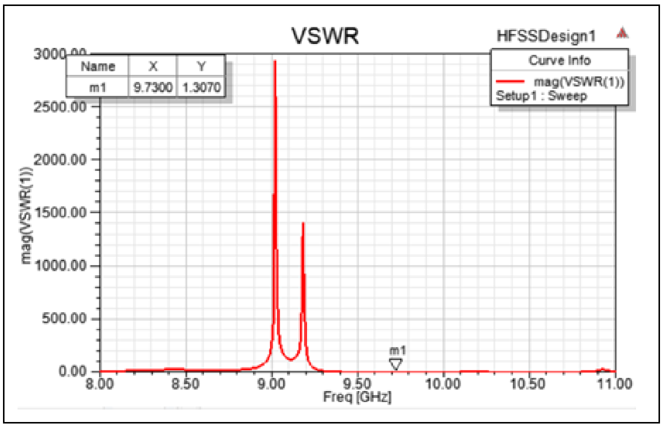

Fig. 4. Graph of VSWR

The radiation pattern in fig. 5 shows that most of the power lies in the major lobe and negligible amount of RF energy is in the back lobe direction which is essential for the antenna to radiate a significant amount of energy in the desired direction.

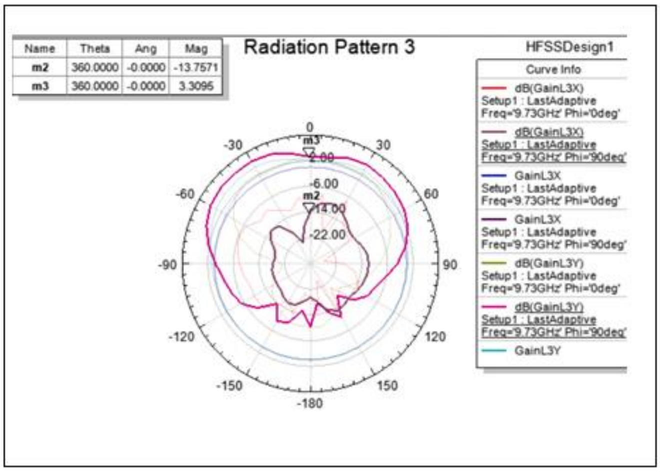

Fig. 5. Radiation Pattern at 9.73GHz

3D polar plot of the gain is also shown in fig. 6. Total gain is 6.9996 dB.

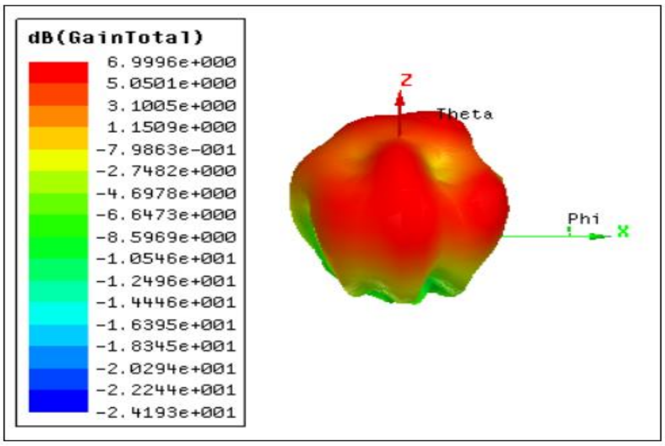

Fig. 6. 3D polar plot gain

The structure has been modified to increase the number of vias. In both the periodic rows the two vias are increased so that the length of the SIW is increased so that the electric field propagate easily inside the rectangular waveguide. The structure is simulated which shows much improved results. The gain of this antenna is now 7.0122dB as shown in fig. 7 and the return loss is -37.0241dB as in fig. 8.

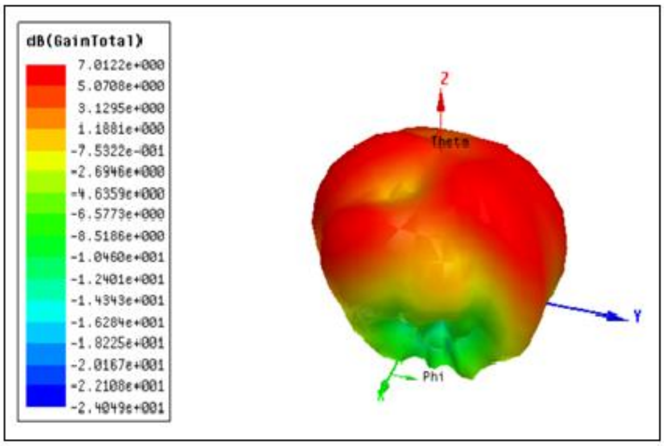

Fig. 7. 3D gain plot of modified structure

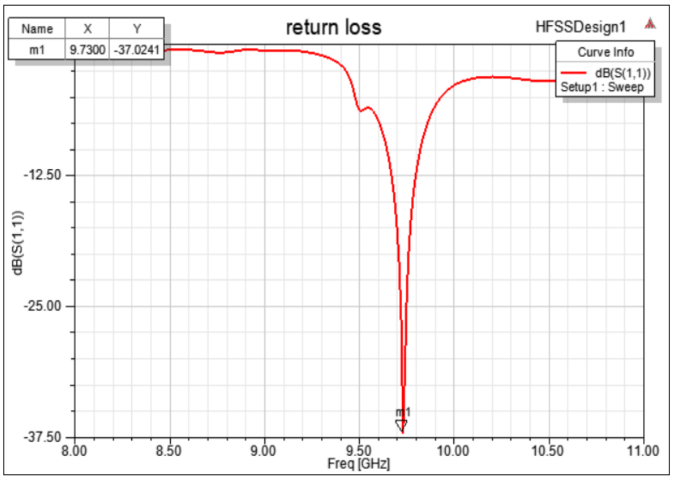

Fig. 8. Return loss of modified structure

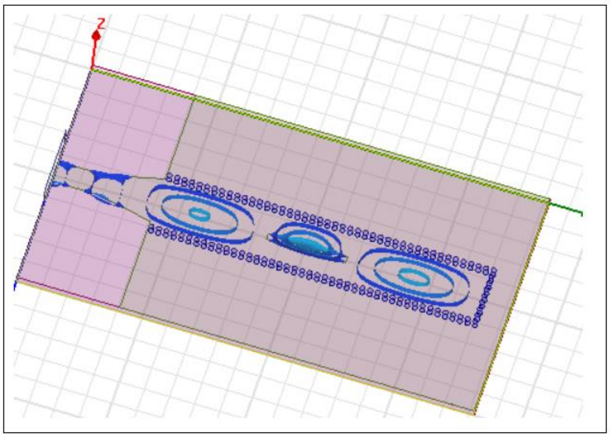

Fig. 9. Electric field distribution inside the SIW

The field inside the antenna is confined within the substrate integrated waveguide. The metal vias and the copper layers hold the electric field within the SIW structure originating from the source as shown in fig. 9.

V. CONCLUSION

Slot antenna based on SIW technology has been proposed in this document. This work will optimize gain, return loss, cross polarization suppression and directivity. A significant increment of gain and return loss parameter has been obtained by increasing the number of vias. The proposed antenna effectively addresses the standing wave by proper matching and maintaining low reflection coefficient and VSWR close to 2. The structure can find wide applications in X-band communication such as in RADAR, Spacecraft, Low earth orbiting satellite, unmanned aerial vehicle especially in military applications. The proposed antenna can be used in line-of-sight communications and remote sensing mechanism. In future, some new ideas can be incorporated in the proposed model for making this model more effective.

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