MINIATURIZED CAVITY BACKED SUBSTRATE INTEGRATED WAVEGUIDE ANTENNA FOR Ku-BAND APPLICATION

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Abstract - *In this work, a low profile wideband substrate integrated waveguide (SIW) cavity-backed (CB) unidirectional antenna design with planar configuration, operating in Ku-band is proposed. The design consists of a rectangular slot in the ground plane, the structure enclosed with closely placed vertical cylinders known as vias. The antenna performance is investigated in terms of gain, radiation pattern, S-parameter, fractional bandwidth, axial ratio and front-to-back ratio and resonance occurs at 14.43 GHz. All the simulations were performed using CST microwave studio software. For the proposed antenna, the impedance bandwidth (S11 < -10 dB) of 0.202 GHz (202 MHz) (1.4%) is achieved with maximum gain (IEEE) of 5.35 dBi, directivity of 6.26 dBi, with unidirectional radiation characteristics and high front to back ratio (FTBR) is 20. A good overall efficiency of 76.9% is attained. This antenna finds its applications mainly in satellite communications such as television transmissions, audio/voice, signal transmissions etc.*

Key Words*: *SIW (substrate integrated waveguide), FTBR (front-to-back ratio), gain, impedance bandwidth, mm (millimetre)

1. INTRODUCTION

The ever growing demand for speedy and high quality communications systems are the forces compelling researchers to come up with more efficient and better equipments. Fifth-generation (5G) wireless technology is considering Ka-band for high speed data transmission. Also this band is used for satellite communications, VSAT systems, close ranging radars aboard military planes etc. For these millimeter wave (MM) wave transmissions, the best suited structures are waveguides. Thus to eliminate the hindrance of integration of these waveguides with planar structures, substrate integrated waveguides (SIW) are preferred which is having the benefits of both waveguides and microstrip antenna such as low cost, high power handling capacity, ease of fabrication etc.

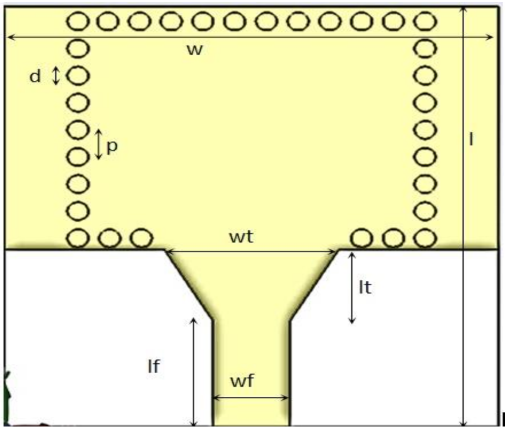
Substrate integrated waveguides (SIW) are guided structures having holes known vias. It is similar to dielectric filled waveguide [1-2]. The two conducting plates and vias acts as boundary walls restricting spurious radiations through side walls allowing only TE_{mn} modes, blocking propagation of TM_{mn} modes, because of discontinuity of magnetic field [3].

With SIW emerging as perfect alternative to non-planar structures, many attempts have been proposed to improve the characteristics of the antenna, however, gain, unidirectional pattern, bandwidth improvement, always remained the challenge.

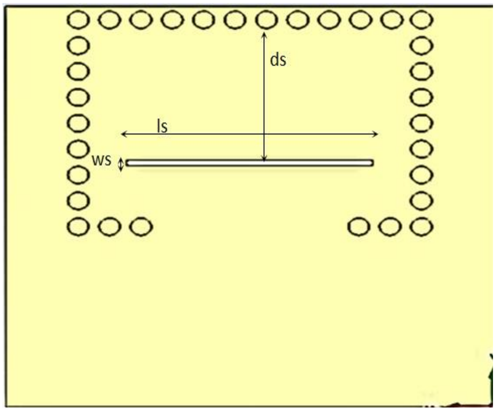
In this contribution, a novel technique to design a slot antenna is demonstrated. The conventional rectangular slot is etched in ground plane and the antenna radiates in its dominant TE_{10} mode. The slot dimension is set at quarter of the wavelength. Taper feed is preferred for better results and matching as proposed by many authors, to feed the antenna. Although, slot antennas have a drawback of low impedance bandwidth, as here, an impedance bandwidth of 1.4% is accomplished.

2. Design Principle

The planned aerial is as shown in figure 1.The rectangular slot is etched on the earth plane. All geometrical characteristic are listed in table 1. The SIW cavity is constructed as per the design rules to satisfy minimum leakage and little attenuation [4-5]. The dimensions of the cavity are determined as described



(a)



(b)

Fig -1: Geometry of the projected aerial (a) Front View (b) Back View

in precious works of authors. First of all, the dimensions of a conventional waveguide are calculated working in Ku-band. Since for a conventional waveguide, lower and higher cutoff frequencies are defined by

$$f_{low}=1.25f_c \qquad (1)$$

$$f_{high}=1.89f_c \qquad (2)$$

So, the cutoff frequency of conventional waveguide that would work in required band will be 15.6 GHz. Using this cutoff frequency, the broad wall dimension can thus be calculated as

$$a=\frac{c}{2f_c\sqrt{\epsilon_r}} \qquad (3)$$

c = speed of light, ϵ_r= relative permittivity, f_c = cutoff frequency. The cutoff frequency of different modes is given by

$$f_{mn}=\frac{c}{2\pi}\sqrt{\{(\frac{m\pi}{a})^2+(\frac{n\pi}{b})^2\}} \qquad (4)$$

For dominant mode; m=1, n=0

$$f_{10}=\frac{1}{2a\sqrt{\epsilon_r}} \qquad (5)$$

From here, the designing of the cavity start and the equivalent SIW width can be calculated by dividing "a" with $\sqrt{\epsilon_r}$, since now it will behave as a dielectric filled waveguide. So, the width of the SIW equivalent to waveguide will have dimension of

$$a_{equ}=\frac{a}{\sqrt{\epsilon_r}} \qquad (6)$$

Next the calculations of the distance between the vias walls is done to find out the center-to-center distance which is given as

$$a_{c-c}=a_{equ}+\frac{d^2}{0.95p} \qquad (7)$$

Where "d" is the diameter of a via and "p" is the spacing between two adjacent vias. The diameter and the spacing is chosen according to the rules which are given as

$$d<p\leq 2d \qquad (8)$$

$$0.05<(\frac{p}{\lambda_c})<0.25 \qquad (9)$$

$$d<\lambda_g/5 \qquad (10)$$

$$\lambda_g=\frac{\lambda_c}{\sqrt{\epsilon_r}} \qquad (11)$$

$$\lambda_c=\frac{c}{f_c}=2a \qquad (12)$$

Where λ_c is the cutoff wavelength and λ_g is the guided wavelength

After calculating the dimensions of the cavity, designing the feed line is the next target to achieve for best impedance matching for least reflections. The feed width for characteristic impedance of Z_0 ohm, to match with that of the port can be found from [6]. This is the conventional approach to calculate the width of microstrip feed line for any patch antenna. But here we have applied taper feed technique. To calculate the taper feed dimensions, many contributions have been proposed. Apart from taper feed, several other techniques such as inset feed, coaxial feed, modified taper feed etc. are prominent. Here, taper feed is preferred as it acts as a transformer which matches the 50 ohm port feed with the impedance of the SIW cavity, whose feed width calculations can be done from [7] as

$$W_t = \frac{c}{2f_c\sqrt{(\epsilon_r+1)/2}} \qquad (13)$$

and, the dimensions of the feed at the port end can be approximated as

$$\frac{W_f}{a_{equ}} \sim 0.4 \qquad (14)$$

This implies that the width of the taper at the port end is roughly 0.4 times the opening of the patch [8]. Here, W_t denotes the width at the feed end and a_{equ} is the opening of the patch. W is the distance across of the patch and H is the height of the substrate. The distance end to end of the taper is given by

$$l_t = \left(\frac{n\lambda_g}{4}\right) \text{ n=1,2,3……} \qquad (15)$$

The substrate used here is Rogers/RT Duroid 5880 with ϵ_r = 2.2 and tallness of 0.787 mm having loss tangent 0.0009 and the metal thickness is 0.0035mm. All the dimensions of the designed aerial are tabulated in table 1. The length of the slot is taken almost half of the guided wavelength.

Table -1: Parameters of design proposed

d = 0.66	ds = 8.5	h = 0.787	lf =3.9
lt = 2.635	ls = 7.8	p = 1	l = 15.495
wf = 2.42	ws = 0.2	wt = 5.5	w = 15.6

All lengths are in mm.

3. Results

The simulated and measured results are shown here. A appreciable low return loss is reached pointing towards low reflections and good impedance matching. The S-parameter is plotted in figure 2, considering the conductor and dielectric losses. From figure we can see that resonance occurs at single frequency at 14.43 GHz.

The radiation pattern in different cut planes that is E-plane (ϕ = 90°) and H-plane (ϕ = 0°) is shown in figure 3 which shows the unidirectional pattern [9].

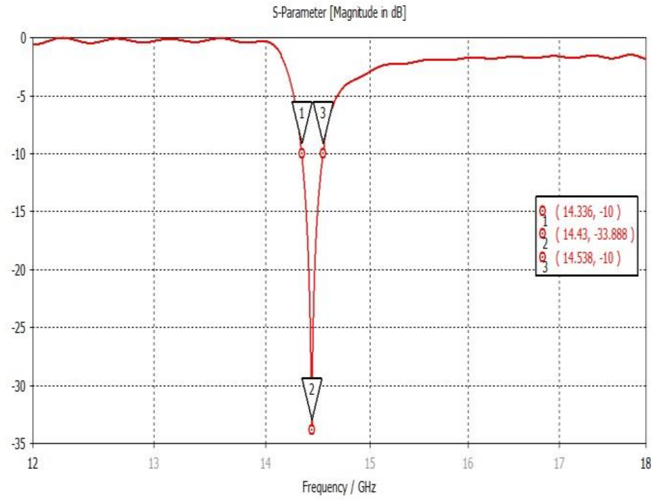
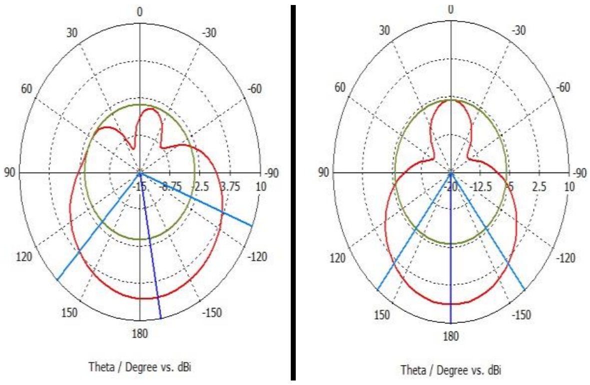


Fig -2: Simulated S11 of the proposed antenna.



E-Plane H-Plane

Fig -3: Calculated radiation patterns in different cut planes at 14.43 GHz.

The inference of unidirectional pattern can be verified by the front-to-back ratio which is quite high around 20. The negative sign shows the direction that the radiator radiates backwards or from backside.

Figure 5 provides us with the gain acquired by the antenna which is 5.35 dBi and the bandwidth as calculated from figure 2 is 202 MHz which shows that quite decent performance characteristics are achieved by the antenna. The antenna can be named as narrow-band antenna which is a drawback of SIW antennas. But, it can be increased by compromising gain, and then the latter can be increased using arrays and polarizations [10].

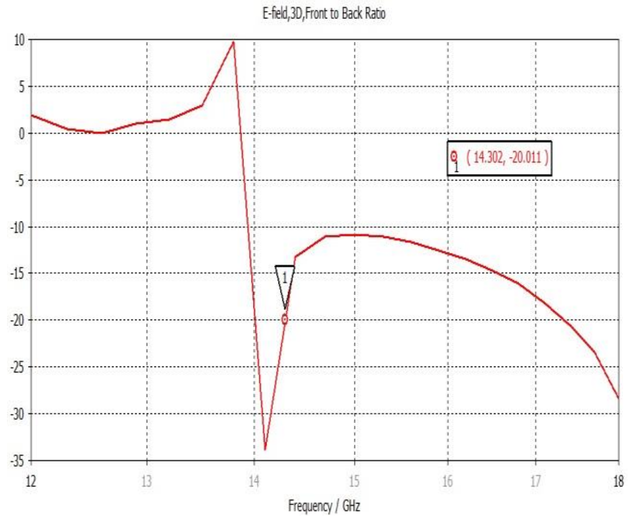


Fig -4: Simulated Front-to-back ratio

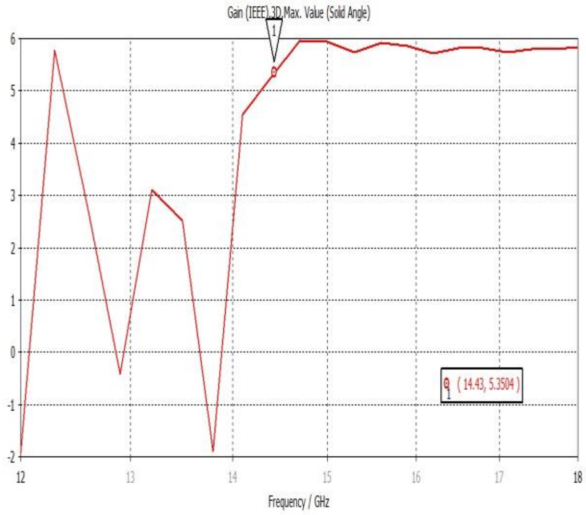
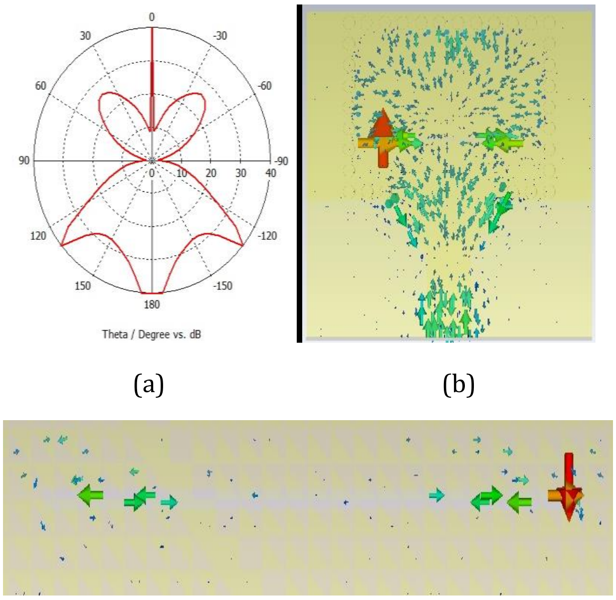


Fig -5: Simulated Gain

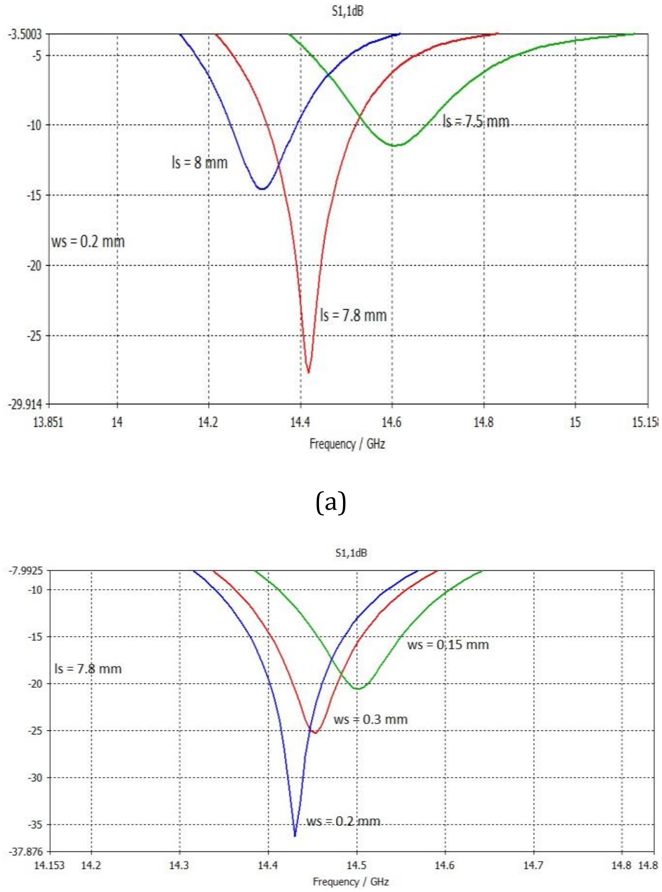
Figure 6(a) shows the axial ratio which shows that the antenna being horizontally polarized whereas figure 6(b) and 6(c) shows the current distribution through the structure and the rectangular slot respectively. It can be seen that the current is evenly distributed throughout the antenna confined within the boundations of the cylindrical vias. The electric field gets cancelled as the direction of the current along the horizontal boundary of the slot is having opposite directions.



(a) (b)

(c)

Fig -6:. Simulated (a) Axial ratio (b) Surface current and (c) Surface current through the slot



(a)

(b)

Fig -7: Parametric study of slot (a) width and (b) length

Figure 7 shows the parametric analysis of the various parameters which are, the length in (a) keeping width constant and the width in (b) keeping length constant and the optimized results are obtained.

4. Conclusion

The antenna is compact in size having dimensions of 15.635 mm X 15.6 mm. The antenna is having unidirectional radiation pattern. Rogers RT/ Duroid 5880 is chosen due to its low property variations and better performance at higher frequencies. Thus a low profile antenna is designed with good performances characteristics radiating in Ku-band which find its applications in satellites systems such TV communications, radar applications etc. The designs comply with all the design rules for the best results to be achieved. The gain and bandwidth of the antenna can further be improved by using arrays.

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