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Study of Broadband Substrate Integrated Waveguide Cavity Backed Dumbbell Slot Antenna

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ABSTRACT: A novel design technique for broadband substrate integrated waveguide (SIW) cavity backed slot antenna is presented in this paper operating in X-Band for terrestrial networks communications application. The proposed antenna replaces a conventional narrow rectangular slot with dumbbell shaped slot and is excited by a simple grounded coplanar waveguide (GCPW) feeding technique. This design is retaining the advantages of unidirectional radiation pattern of conventional cavity backed antenna. The proposed antenna shows uniform gain versus frequency characteristics within the range of 5.4 dB, the broadband response of 5.1% and a unidirectional radiation pattern for the full operating bandwidth.

KEYWORDS: Broadband antenna, cavity backed antenna, slot antenna, substrate integrated waveguide

I. INTRODUCTION

In recent times, a relatively new technology has emerged known as substrate integrated waveguide (SIW), which incorporates non-planar waveguide structures in a planar substrate by the use of rows of metallic vias that implements the sidewall of the waveguide-based circuits in planar substrates [1].Various wave guidance and leakage characteristics of the SIW were already discussed in [2] and [3]. The SIW scheme belongs to the family of SICs in which any other non-planar structures such as dielectric waveguides and coaxial lines can also be made in planar form [4]. The concept of Electromagnetic Band Gap (EBG) structure is used to provide a systematic way for designing the vias side-walls [5]. The width of the waveguide is determined by the desired cutoff frequency of the dominant mode. The necessity to connect the metalized vias with a conductive material to preserve the surface currents required for the propagation of TM and TE_{mn}, where $n \neq 0$, modes is reported in [6]. A bow-tie-shaped slot is also proposed to get broader bandwidth performance [7]. The modification in the slot shape helps to induce strong loading effect in the cavity and generates two closely spaced hybrid modes in electric field propagation which helps to achieve a broadband response.

In this letter, a study on a dumbbell-shaped slot backed by an SIW cavity is presented. The proposed antenna exhibits a broadband response of 4.5% bandwidth with a moderate gain and a unidirectional radiation pattern. The placement of the dumbbell shaped slot helps to get a wider bandwidth response. The technique also replaces a complex feeding mechanism with GCPW type feeding technique to simplify the design. The fabricated antenna shows uniform gain over the operating bandwidth while maintaining its planar form.

II. DESIGN PROCEDURE

The geometry of proposed antenna is shown in Fig. 1. The dumbbell shaped slot is etched at the top metallic plate and placed at a distance of “d_s” from one sidewall of the cavity. The SIW cavity is constructed in a single substrate by four rows of metallic

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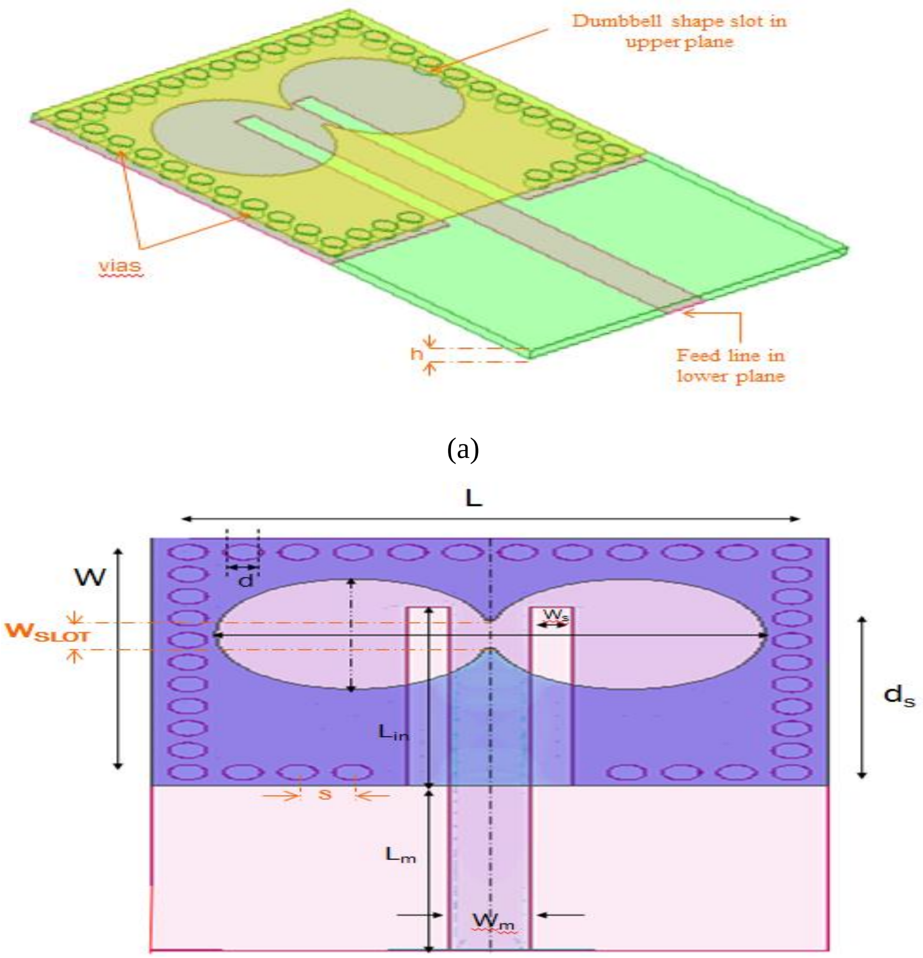
vias implementing four sidewalls of the cavity. The diameter (d) and pitch (s) of the via hole can be adjusted while maintaining the condition $d/s \geq 0.5$ and $d/\lambda_0 \leq 0.1$ to ensure minimum leakage of energy.



(a)

(b)

Fig. 1 Geometry of the proposed design (a) 3D-view (b)L=19.8mm, W=18mm, d=1mm, s=1.6mm, L_{slot}=17.2mm, W_{slot}=8mm, ds=11mm, L_{IN}=13, L_M=12, W_M=2.4mm, W_S=1.2mm

The material of proposed design is Rogers RT Duroid 5880 whose relative permittivity is 2.2 and dielectric loss tangent is 0.0009.The design specifications of microstrip Patch antenna are as follows:

2.1 Calculation of width (W) of patch

The width of the microstrip patch antenna is given by:

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (1)$$

Where, c=free space velocity of light, ε_r=dielectric constant of substrate, f = operating frequency (10.6 GHz), μ_0=permeability of free space (4πx 10^{-7} Henry per meter), ε_0=permittivity of free space (8.85 x 10^{-12} Farads per meter)

2.2 Height of the substrate (h)

$$h \le \frac{0.3c}{2\pi f\sqrt{\varepsilon_r}} \quad (2)$$

2.3 Effective dielectric constant

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+\frac{12h}{W}}}\right) \quad (3)$$

2.4 Calculation of length extension (ΔL)

$$\frac{\Delta L}{h} = \frac{(\varepsilon_{eff}+0.3)\left(\frac{w}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{w}{h}+0.8\right)} \quad (4)$$

2.5 Actual length of the patch (L)

$$L = L_{eff} - 2\Delta L \quad (5)$$

Where, $$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \quad (6)$$

2.6 Substrate length (L_S) and substrate width (W_S)

$$L_S = 6h + L \quad (7)$$

$$W_S = 6h + W \qquad (8)$$

The size of the proposed antenna is 30 mm*19.8 mm*0.6 mm. The design specifications of dumbbell having two circular slots are as follows:

2.7 Circular slot Radius

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi\varepsilon_r F}\left(\ln\left[\frac{\pi F}{2h}\right] + 1.7726\right)\right\}^{\frac{1}{2}}} \qquad (9)$$

$$\text{where, } F = \frac{8.791\times10^9}{f_r\sqrt{\varepsilon_r}} \qquad (10)$$

2.8 Effective Radius

By taking fringing effect into consideration which makes the slot electrically larger, the effective radius is used and is given by

$$a_e = a\left\{1 + \frac{2h}{\pi\varepsilon_r a}\left(\ln\left[\frac{\pi a}{2h}\right] + 1.7726\right)\right\}^{\frac{1}{2}} \qquad (11)$$

III. RESULTS ANALYSIS

The antenna is designed using FEM simulator named High Frequency Structure Simulator software (HFSS 14) and the simulated results are presented in this section.

a) Return Loss (S_{11})

The reflection coefficient (S_{11}) graph with respect to frequency is plotted in Fig.2 having value about -32dB. The value of S_{11} remain below -10dB for this antenna by which the bandwidth of the proposed antenna can be calculated. By the quick observation of the curve bandwidth is 0.517GHz.

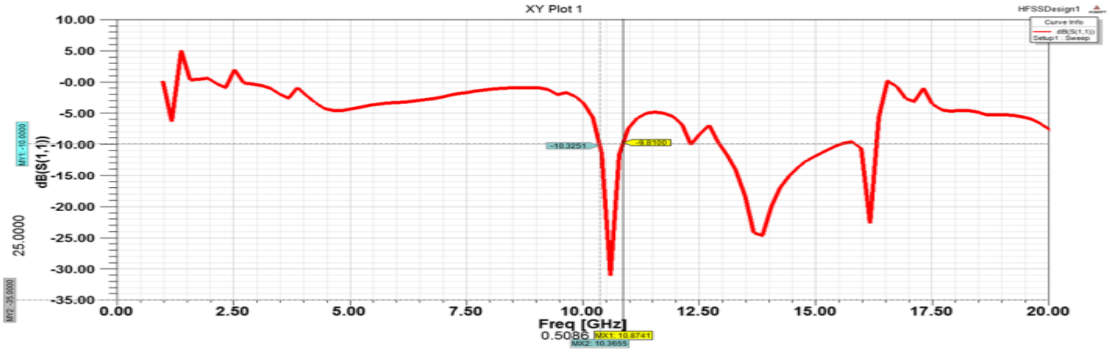


Fig.2 Return Loss magnitude Plot and bandwidth of the proposed antenna.

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(b) Directivity

The directivity, D, of an antenna is the maximum value of its directive gain D(θ,ϕ), and compares the radiation intensity(power per unit solid angle) U(θ,ϕ), that an antenna creates in a particular direction against the average value over all direction:

$$D(\theta,\phi)=\frac{U(\theta,\phi),}{P/4\pi}$$

$P/4\pi$: average power per unit solid angle

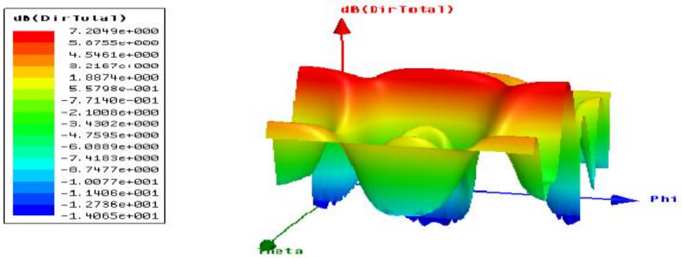

Fig.3 Directivity plot of the proposed antenna

c) Axial Ratio

The axial ratio is the ratio of orthogonal components of an E field. It explains the orientation of electric field propagation. Here, in this work, the axial ratio is of utmost importance as the antenna is designed for circular polarization.

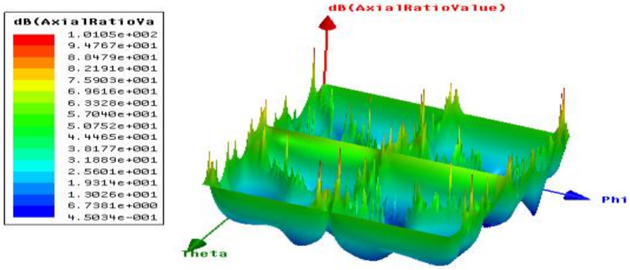

Fig.4 Graphical Axial ratio of the proposed antenna.

d) Radiated Antenna Gain Pattern

A Radiation pattern defines the variation of the power radiated by an antenna as a function of the direction away from the antenna. This power variation as a function of the angle is observed in the antenna's far field. The radiated power is 4.60 dB, at spherical co-ordinates theta 0 degree and phi 90 degree is shown in Fig.5. Here, the gain magnitude at 10.6 GHz frequency is represented in polar plot form as shown in Fig.6 which is mathematically stated as the power transmitted in the direction of peak radiation to that of an isotropic source and have the value 5.311dB.

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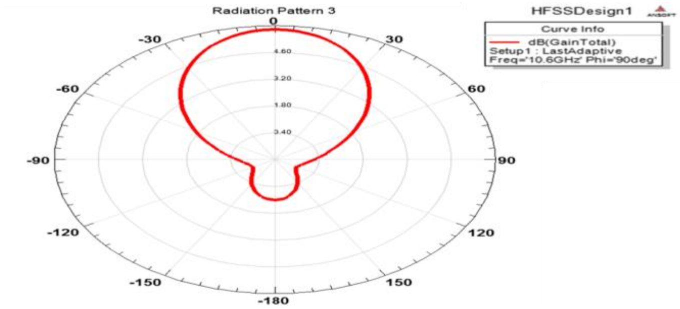

Fig.5 Radiated Power polar plot of antenna

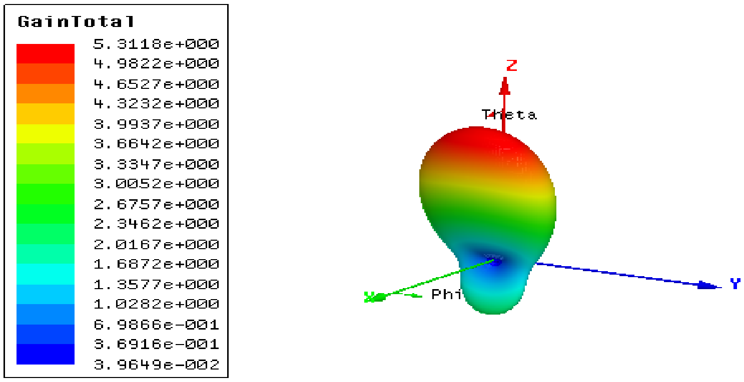

Fig.6 Radiated gain 3-D view of the proposed antenna

f) Current Distribution

The current distribution must be zero at the ends of the patch as current cant flow off the patch of microstrip antenna. The figure below shows the current magnitude with maximum current flowing in left direction.The maximum value of current distribution is 2.11×10^{2}A/m at certain points.

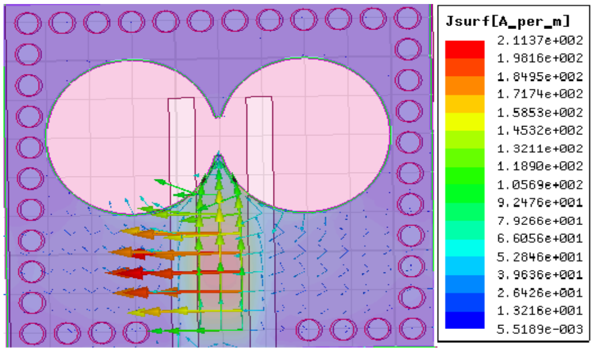

Fig.7 Current distribution for designed antenna

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j) Electric field

The electric field at a point in space is a measure of how strong the force would be on a unit point charge hence measure in Volts/meter. The maximum value of electric field at any point is 2×10^5V/m. A stronger E-Field incident upon an antenna will induce a larger voltage difference across the antenna terminals.

$$V=-\oint E\,.dl$$

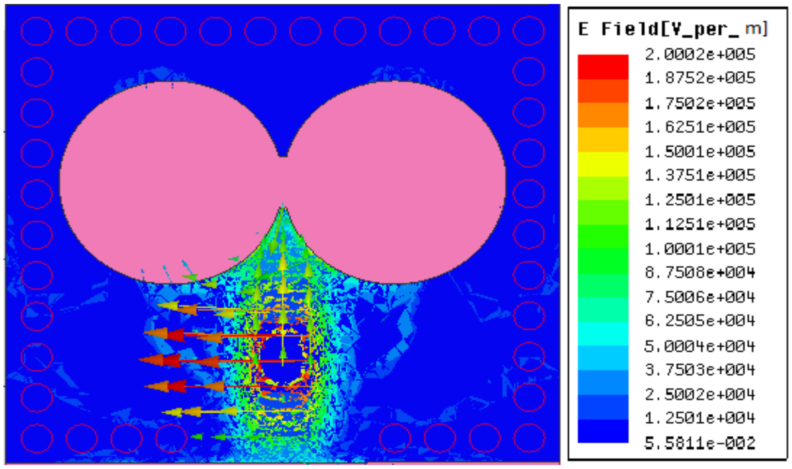

Fig. 8 Electric Field distribution

The electric field distribution here represents the orientation of radaition of signals from antenna. This direction of electric field shown here are responsible for the propagation of electric field from the antenna and finally the other parameters like directivity, gain and pwoer is calcualetda and studied.

While considering front to back ratio for the proposed antenna the magnitude is observed as 40.7117 which is quite good to prove the strong radiated field by antenna. The VSWR is 1.01 and the 3-dB beam-width is 3.768 dB for this design.

IV. CONCLUSION

A broadband substrate integrated cavity backed dumbbell slot antenna is presented in this paper. The conventional narrow rectangular slot is replaced here by a dumbbell shaped slot and is excited by a simple GCPW feeding technique. The dumbbell shape of slot leads to broadband response of 5.1% which is much higher than that of the conventional SIW cavity backed slot antenna (1.7%). This design holds the advantages of unidirectional radiation pattern of conventional cavity backed antenna. The proposed antenna shows uniform gain versus frequency characteristics within the range of 5-5.5 dBi and a unidirectional radiation pattern over the operating bandwidth, which makes it suitable for many practical applications such as RADARs, Terrestrial network communications and space communications.

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