Broadband High Gain SIW Cavity Square Slot Antenna for X-Band Applications

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***Abstract*—In this paper, square slot (SS) upheld by the substrate integrated waveguide (SIW) cavity is presented. A simple 50 Ω microstrip line is employed to feed this cavity. Then slot matched cavity modes are coupled to the slot and radiated efficiently. The proposed antenna features the following structural advantages, compact size, light weight and easy low cost fabrication. Concerning the electrical performance, it exhibits 15% impedance bandwidth for the reflection coefficient less than -10 dB and the realized gain touches 8.5 dB frontier.**

Keywords— Square slot antenna; SIW; Cavity; Antenna

I. INTRODUCTION

X-band or super high frequency (SHF) has an attractive characteristics render it the ideal candidate for military and satellite communications applications. These merits include interference resilience, data rates, remote coverage, ...etc. On the other hand, broadband technology exhibits the followings, allows for a higher bandwidth and therefore for a faster communication, allows for spreading the signal to encrypt it, lastly but not last, allows for notching out narrow noise sources in the spectrum. Therefore, broadband antenna is essential requirement nowadays.

Slot antennas are widely used in many practical applications such as radar and satellite communications, space vehicles, aircraft. They exhibit wider bandwidth, lower dispersion and lower radiation loss than microstrip antennas. SIW technology, which is firstly proposed by Wu [1], has the advantage of easy integration with planar circuits by replacing the conventional microstrip and strip line.

Also it has the merits of low loss, high power capacity, high Q-factor, low cost than conventional waveguide. Consequently, SIW slot antenna is very desirable in contemporary communication systems. Many SIW slot antenna are recently realized. An X-band dual-mode antenna using SIW is presented in [2]. Circular polarization antenna is realized in [3]. Finally, antenna with 12% bandwidth is designed in [4]. Circular slot is used in all these previous designs.

In this work, SIW cavity with SS antenna is investigated at X-Band. A very broadband high gain SIW slot antenna is accomplished. The designed antenna has 15% bandwidth and approximately 8 dB realized gain. To the best of our knowledge, these figures are considered the best till now.

II. SIWSS ANTENNA STRUCTURE

The configuration of the presented SIWSS antenna is depicted in Fig.1 and detailed in Fig. 2. The overall dimension is $L \times W$ and equals $25 \times 20\ mm^2$. The feeding structure is 50 Ω microstrip line and has width (W_{50}). The inset which is used to match the feed line to antenna has length (L_{inset}), while, the space between it and the upper metal of SIW is (W_{inset}). Concerning the SS, it is etched on square metal patch which has side length (W). Moreover, it has side length (W_{slot}) and gap width (g) respectively. Ultimately, a square cavity is created by deploying metallic Vias evenly around the square patch circumference. The diameter of the individual via (s) and the distance between each couple of Vias is equal. The Vias connect the patch to the ground of the substrate RT/Duroid 5880 (ϵ_r = 2.22 and substrate thickness (h) = 1.575 mm). The antenna parameters are listed in Table I. The simulations are performed using high frequency structure simulator (HFSS) 14 [5].

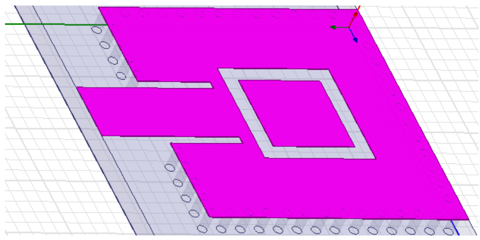

Fig.1. 3D view of the proposed antenna.

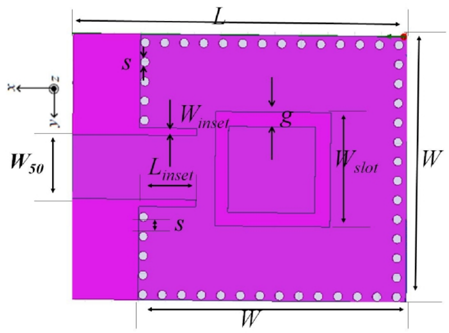

Fig.2. The SIWSS antenna schematic.

TABLE I. DIMENSIONS OF THE PROPOSED ANTENNA

Para.	Value (mm)	Para.	Value (mm)
L	25	L_{inst}	5.6
W	20	W_{inst}	0.651
$W50$	4.6	W_{slot}	8.6
s	0.65	g	2.3

The vertical Via array forms an equivalent electric wall to enable cavity modes. The bottom of the antenna is a complete copper ground plane. The first two cavity modes are TE_{101} and TE_{102}. Concerning the former one, the resonance at this mode is equivalent to parallel resonant type. Consequently, feed line is loaded by high impedance, and, the matching at this mode is very difficult. As shown in Fig. 3, around the frequency between 11 GHz to 13 GHz, the input impedance is fairly flat around 50 ohm. As a consequence a broadband operation is guaranteed.

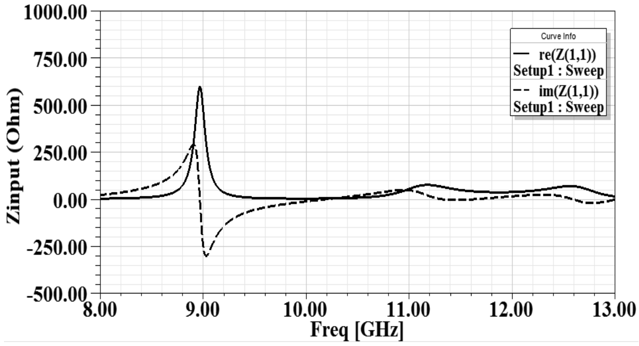

Fig. 3. The input impedance of the SIWSS antenna.

The reflection coefficient (S_{11}) is depicted in Fig. 4. The -10 dB bandwidth is extended from 11.10 GHz to 12.9 GHz. Relative to the center of the range, the antenna has 15% bandwidth. This obtained value is considered the best among the previous values, [4] as example.

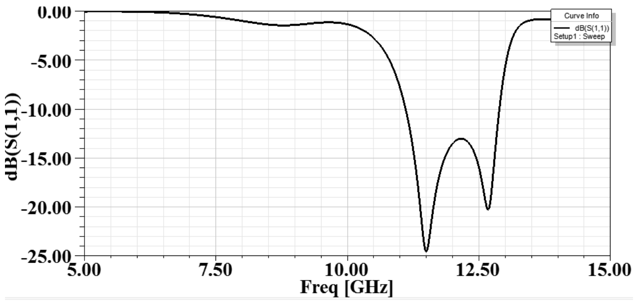

Fig. 4. The reflection coefficient of the SIWSS antenna.

On the other hand, the electric field distribution inside the cavity is depicted in Fig. 5. The figure explains visually the radiation mechanism inside the antenna. The maximum of TE_{102} coincides pretty well with all slot sides. However, the y-oriented slots constructively add to the broadside radiation. While, the radiation from the x- oriented slot cancel each other, as shown in Fig.6. On other words, two magnetic monopoles are equivalently generated and cause the strong radiation.

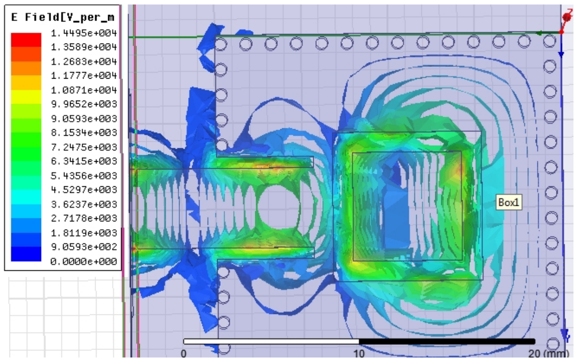

Fig.5. Electric field distribution inside the cavity.

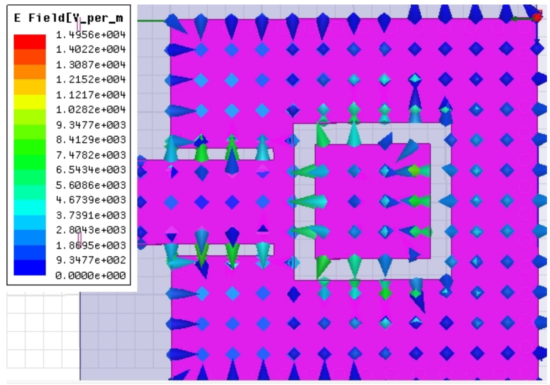

Fig.6. Electric field distribution at the patch.

The radiation pattern is shown in Fig. 7. The antenna has broadside radiation with very high gain of 8.5 dB at frequency of 11.5 GHz.

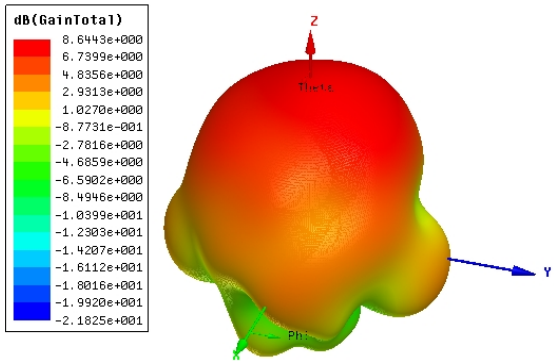

Fig.7. 3-D radiation pattern.

The radiation pattern at plane plane $\varphi = 0^{\circ}$ and $\varphi = 90^{\circ}$ are shown in Figs. 8-9 respectively. The designed antenna features a fairly low cross polarization level, it amounts -30dB. It is worth noting that the cross polarization level is not mentioned in [4]. Therefore, our one is considered the best till now.

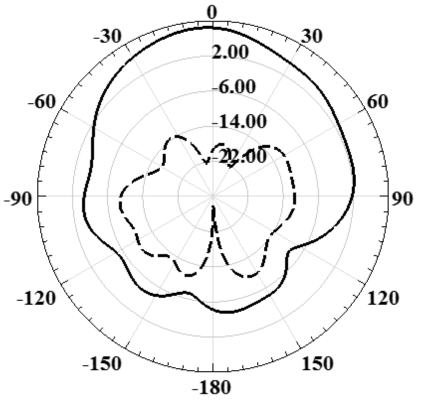

Fig.8. The radiation pattern at plane plane $\varphi = 0^{\circ}$, (-) co-pol and (- -) X-pol

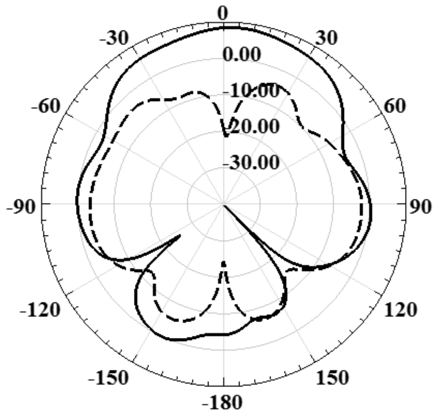

Fig.9 The radiation pattern at plane $\varphi = 90^{\circ}$, (-) co-pol and (- -) X-pol

To validate the proposed SIWSS antenna, time domain solver integrated in computer simulation technology (CST) Microwave Studio [6] is utilized to analyze the same predefined antenna presented beforehand. Fig. 10 depicts S_{11} parameter of the SIWSS antenna. Excellent matching is noticed between the obtained behaviour and the previous one computed using HFSS, shown in Fig. 4.

Moreover, the 3-D radiation pattern obtained by CST is shown in Fig. 11. Quite good agreement also observed between the radiation pattern out from CST and its corresponding one acquired by HFSS, shown in Fig. 7. Nearly one dBi gain is fewer than the exhibited by HFSS.

The slight differences at the previous comparisons could be attributed for the various numerical techniques that both of HFSS and CST use, as the former simulator utilizes finite elements method (FEM), while the later one is based on finite difference time domain (FDTD).

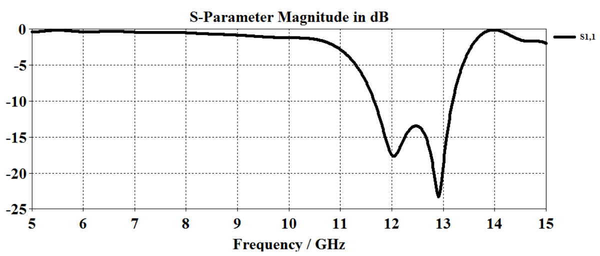

Fig. 10. S_{11} parameter of the SIWSS antenna computed using CST.

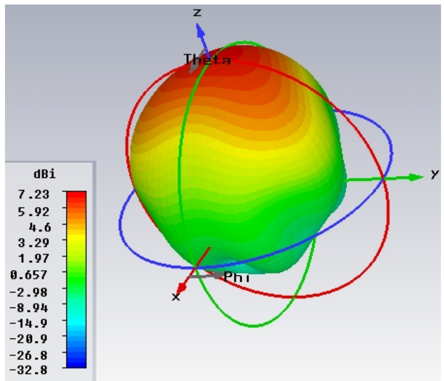

Fig. 11. 3-D radiation pattern as obtained using CST

III. Conclusion

In this paper, high gain broadband SIWSS antenna is proposed. Broadband TE_{102} SIW cavity mode is exploited and coupled to the SS. Besides, the antenna emits in broadside direction. The antenna exhibits interesting features such as broadband operation, high gain and low cross polarization level. The presented antenna is very useful for the following applications, but not limited to, radar, terrestrial communications and space communications.

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