36. Design of Dual-Band and Low-Profile SIW CavityBacked Slot Antenna for 5G Applications

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ABSTRACT

In this paper, the design of dual-band and lowprofile SIW cavity-backed slot antenna operating at K-band and Ka-band has been proposed. The dual-band antenna consists of the SIW cavity with two parallel slots which are etched on the ground plane of the conductor. In order to obtain dual-band, higher-order hybrid modes are tuned and combined to form the second band of the proposed antenna with a wider bandwidth. For dual-band antenna, fractional bandwidth of 5.26% and 6.15% are achieved with the maximum gain of 5.45 dBi and 6.15 dBi at 24.7 GHz and 27.8 GHz, respectively. In terms of antenna performances including reflection coefficient, bandwidth, gain, and radiation pattern, a cavity-backed antenna using via-hole along with the slot has been proposed. Via-hole establishes a connection between the top and bottom surfaces of the cavity creating a new path for the current to flow by shortening the effective length of the slot. The results show that the bandwidth of 4.2 GHz (15.32%) ranging from 25.3 GHz – 29.5 GHz, a gain of 7.8 dBi and 9.2 dBi have been achieved at 25.9 GHz and 28.8 GHz respectively. The overall volumetric dimension of both the proposed design including feedline is 20 mm x 14 mm x 0.508 mm.

Index Terms— *cavity-backed, substrate integrated waveguide (SIW), slot antenna, dual-band, 5G.*

INTRODUCTION

In recent years, 5G technology has been under the spotlight and researched extensively. Sub-6GHz 5G communication systems have been come into commercial use recently [1]. Meanwhile, the demand for higher data rates and broader communication bandwidth stimulates the exploitation of new spectral resources for 5G communication [1]-[2]. Millimeter-wave (mm-wave) bands have received much attention in recent years for high-speed communications resulted from abundant spectrum resources. Particularly, frequency in the range of 24 - 30 GHz has been selected as the 5G mm-wave communication band by many countries (e.g., China, USA, Korea and so on).

Dual-band slot antennas have been proposed for their characteristics such as their applicability to planar surfaces. They are easy to synthesize into planar circuits and realize high isolation between feeding elements. Microstrip antennas with two radiating slots have low radiation gain because of their bi-directional radiation patterns [3]. Substrate integrated waveguide (SIW) cavity-backed antennas are proposed, to overcome the limitations (in terms of bi-directional radiation patterns, gain, and bandwidth) as a solution [4]. SIW technique has been investigated because of the demand to achieve low-cost waveguide components with low temperatures and the conventional printed circuit board [5]. SIW technology can give effectively the conventional nonplanar waveguide to a planar substrate by using metallic via holes [5]. SIW cavities make the design of cavity-backed slot antennas more flexible and less expensive to fabricate. Several techniques have been investigated to enhance the bandwidth of the SIW-based cavity-backed antenna [6]-[8]. In [6], it has been reported a slot antenna with a cavity using a substrate removal, in which a partially higher bandwidth is obtained by removing the substrate lying beneath the resonating slot; in spite of the fact that removing substrate isn't a simple task—it makes the structure unpredictable and costly. The bandwidth of the proposed antenna has been increased to 2.16%. A compact cavity antenna with onesided ramp-shaped grooves has also been designed in [7] to force the structure to work in the first negative-order resonance. The other solutions to improve antenna’s bandwidth are to merge multiple resonant modes in an exceedingly single passband [8].

This paper presents, the design of dual-band and lowprofile SIW cavity-backed slot antenna supported for the fifth-generation (5G) wireless system for Europe, China (24.25 – 27.5 GHz), Korea (26.5 – 29.5 GHz), and USA region (27.5 – 28.35 GHz) [2]. Two parallel slots are utilized to obtain dual-band of the SIW cavity-backed antenna. To achieve wider bandwidth and high gain, a cavity-backed antenna using via-hole along with the slot has been also designed. The proposed antenna has a via-hole along with the slot to create a dual resonance.

ANTENNA DESIGN

A. DUAL-BAND SIW CAVITY-BACKED ANTENNA WITH PARALLEL SLOTS

The proposed slot antenna has been designed at 24-29 GHz on Rogers RT/Duriod 5880 copper laminated substrate with a substrate height of 0.508 mm, a dielectric constant of 2.2 and loss tangent (tanδ) of 0.0009. The proposed antenna configuration is illustrated in Fig.36-1. The geometrical parameters of the proposed structure are shown in Table 36-1. By using the resonant frequency equation, the primary dimensions of the cavity can be calculated.

$$a \approx \frac{580.95}{\sqrt{\varepsilon_r}} \sqrt{\frac{1}{4{f_H}^2 - {f_L}^2}} \qquad (1)$$

$$b \approx \frac{580.95}{\sqrt{\varepsilon_r}} \sqrt{\frac{1}{4{f_L}^2 - {f_H}^2}} \qquad (2)$$

Where a and b represents the length and width of the cavity, respectively (in mm), ε_r stands for the relative permittivity of the substrate, and f_L , f_H are the resonance frequencies (both are in GHz). These two equations are derived from the resonant frequency equation of the rectangular cavity [9]. Its rectangular backed cavity is realized by metalized vias arrays. The requisite conditions to make the SIW cavity identical to conventional metallic cavity are $d/s \geq 0.5$ and $d/\lambda_o \leq 0.1$. In order to avoid the bandgap effect, $d < s \leq 2d$ must be satisfied.

To provide the mechanical stability s/λ_o must be greater than 0.05. Two parallel slots are etched on the ground plane of the conductor. In order to obtain dual-band, an additional slot is introduced at the bottom plane of the cavity. It is observed that the Q factors of the two original modes are considerably reduced and also a new mode is excited in the SIW cavity. The strong capacitive load effect introduced by the slot changes the mode of the cavity to a lower frequency range and the first antenna band is generated at 24.7 GHz. By optimizing the positions, length and width of the slots, higher-order hybrid modes are tuned and combined to form the second band of the proposed dual-band antenna with a wider bandwidth.

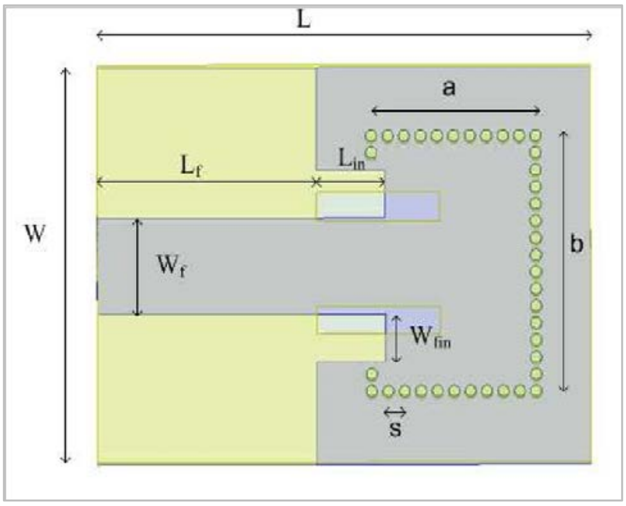


Figure 36-1 The geometrical configuration of the dual-band SIW cavity-backed antenna with parallel slots

Table 36-1 GEOMETRICAL PARAMETERS OF THE PROPOSED ANTENNA

Parameter	Value (mm)	Parameter	Value (mm)
L	18	a	6
W	14	b	9
W_f	3.37	S_L	4.5
L_f	8	S_W	1
L_{in}	2.5	d	0.4
W_{fin}	1.68	s	0.6
d1	3		

All the simulations are performed using a high-frequency structure simulator (HFSS) Ansys version 18.0, based on the finite element method (FEM) technique. The corresponding reflection coefficient is shown in Fig. 36-2. All material losses are taken into account when simulating the results. The simulated resonant frequencies are obtained at 24.7 GHz and 27.8 GHz. The simulated -10 dB operating bands are obtained in the range from 24.1 GHz to 25.4 GHz and from 26.8 GHz to 28.5 GHz with a fractional bandwidth of 5.26% and 6.15% respectively. Within the operating frequency band, the radiation diagrams in plane E and plane H are illustrated in Fig. 36-3 and Fig. 36-4. The level of cross-polarization in both planes is less than -35 dB with respect to copolarization in the direction of maximum radiation at 24.7 GHz and 27.8 GHz. The achieved simulated gain value is about 5.45 dBi and 6.15 dBi at 24.7 GHz and 27.8 GHz, respectively. To enhance the bandwidth and achieve high gain, siw based cavity-backed antenna via-hole along with the slot is designed.

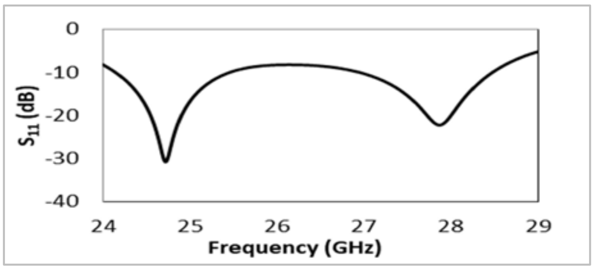


Figure 36-2 Simulated reflection coefficient (S11) of the dual-band SIW cavitybacked antenna with parallel slots.

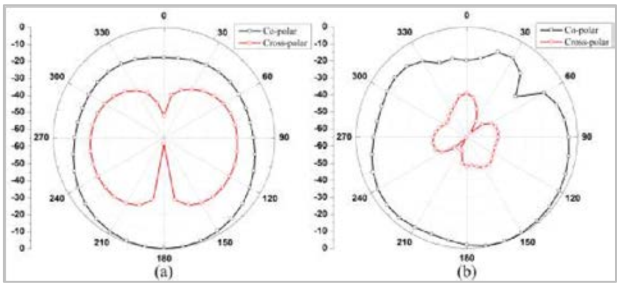


Figure 36-3 The radiation patterns of the proposed antenna at 24.7 GHz.

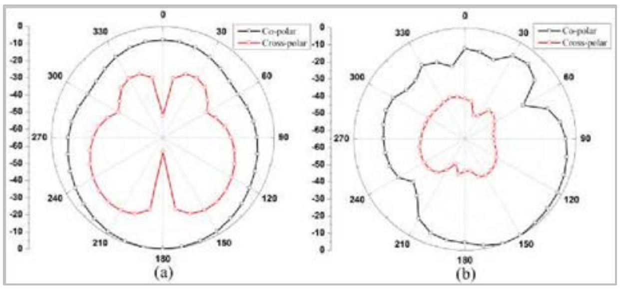
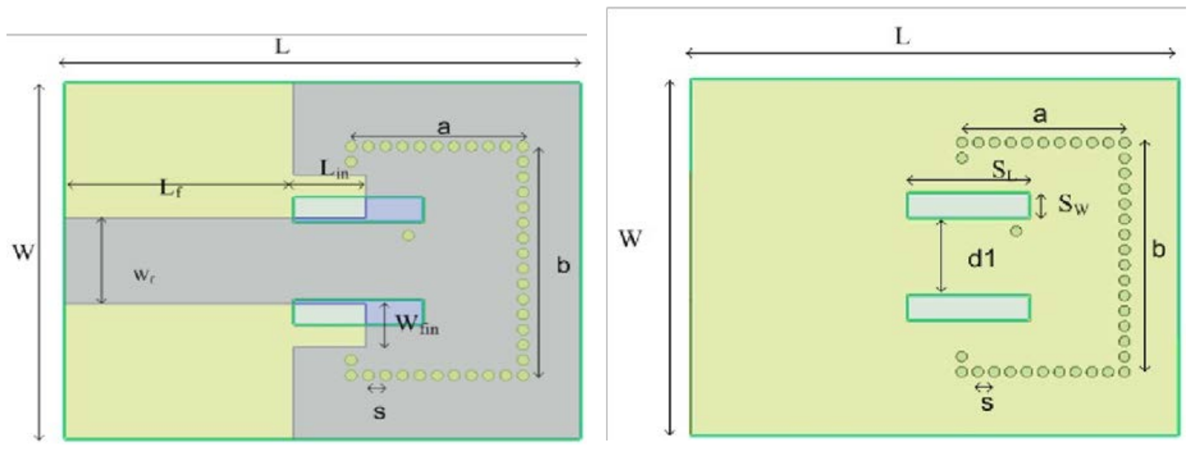


Figure 36-4 The radiation patterns of the proposed antenna at 27.8 GHz.

B. CAVITY-BACKED ANTENNA USING VIA-HOLE ALONG WITH THE SLOT

To enhance the bandwidth, a cavity-backed antenna using via-hole along with the slot has been proposed. All the design parameters are the same as discussed for dual-band siw cavity-backed antenna with Parallel slots. The proposed antenna configuration is illustrated in Fig.36-5. The occurrence of resonance is observed in a conventional cavity-backed slot antenna when the slot has a half wavelength at the operating frequency. The cavity size and slot length are two fundamental factors determining the frequency of this resonance. The current distribution during the first resonance comprises minimum current flowing to the center and a maximum current flows to the edges of the slot in the same direction. Via-hole establishes a connection between the top and bottom surface of the cavity creating a new path for the current to flow. At the time of second resonance, minimum current flows to the opposite side of via-hole and maximum current flow to the left edge of the slot. The effective length of the slot is shortened at a higher resonance frequency. By moving the position of via-hole, the second resonance frequency can be shifted to a higher or lower frequency without any significant effect on the first resonance frequency.

The Return loss i.e (S_{11}) of the antenna was obtained from the simulation in order to formalize the design of the antenna is shown in Fig. 36-6. The frequency range used in the simulation is 24 to 29 GHz with a 10 dB return loss bandwidth of 4.2 GHz. From the figure, it is observed that two resonances can be merged to ensure wideband matching. The fractional bandwidth obtained for $S_{11} < -10$ dB is 15.32% (25.3 GHz – 29.5 GHz). This result gives higher fractional BW much higher than the regular SIW slot antenna.



(a) Top View (b) Bottom View

Figure 36-5 The geometrical configuration of the cavity-backed antenna using via-hole along with the slot.

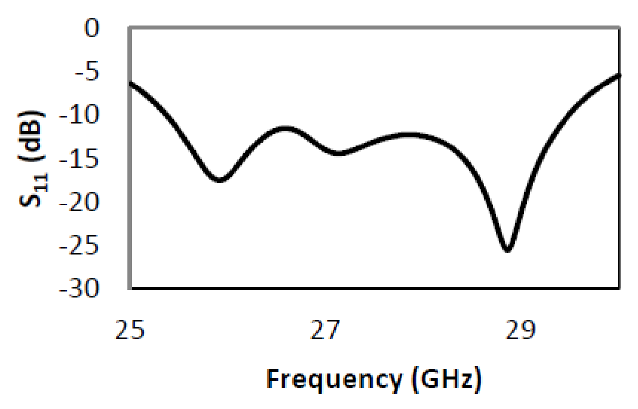
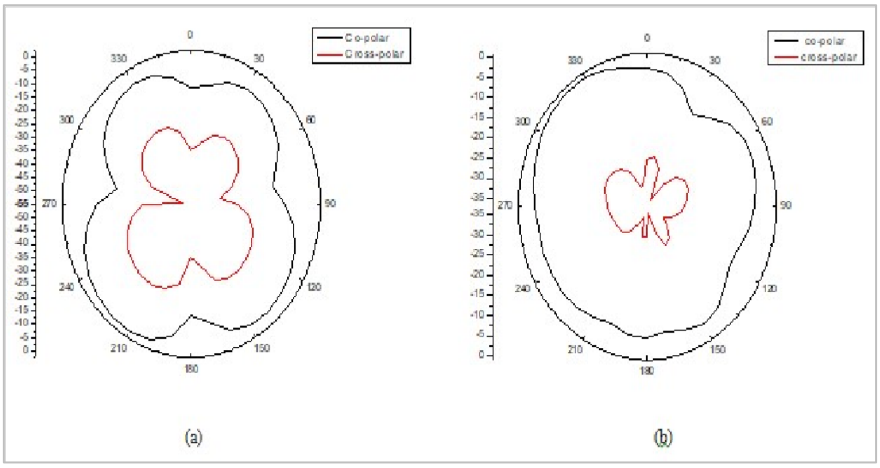


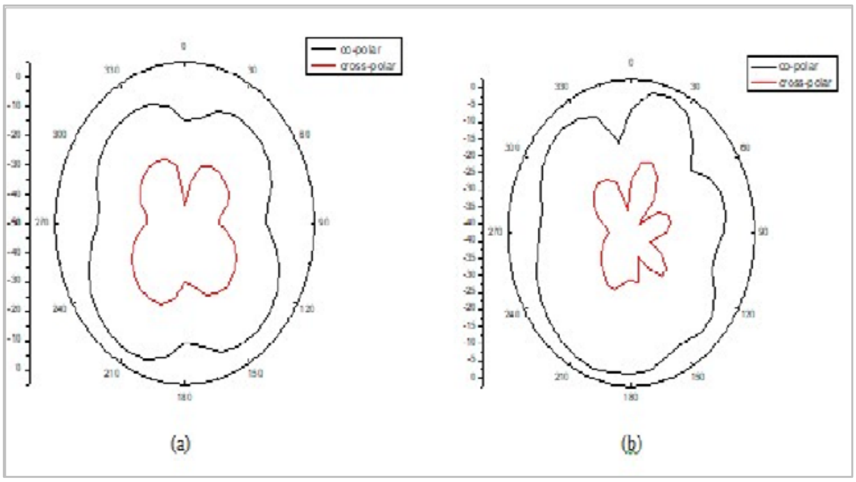
Figure 36-6 Simulated reflection coefficient (S11) of the cavity-backed antenna using via-hole along with the slot.

The radiation patterns in the plane E and plane H are illustrated in Fig. 36-7 and Fig. 36-8 at 25.9 GHz and 28.8 GHz respectively. The level of cross-polarization in E-plane is below -28 dB and H–plane is below -35.4 dB at 25.9 GHz resonance with respect to co-polarization. The level of crosspolarization in E-plane is below -25 dB and H–plane is below -38 dB at 28.8 GHz resonance with respect to copolarization. The simulated gain value is 7.8 dBi and 9.2 dBi is achieved at 25.9 GHz and 28.8 GHz respectively. This high gain and enhanced bandwidth acquired because of viahole along with the slot in the proposed structure. In addition, the planned antenna has an easy structure, lightweight, and planer configurations.



(a) (b)

Figure 36-7 The radiation patterns of the proposed antenna at 25.9 GHz.



(a) (b)

Figure 36-8 . The radiation patterns of the proposed antenna at 28.8 GHz.

CONCLUSION

The design of dual-band and low-profile SIW cavitybacked slot antenna for 5G applications has been presented. The design provides sufficient bandwidth at all frequencies (24.7 GHz, 27.8 GHz, 27.9 GHz, and 30.8 GHz) for the 5G applications. The radiation performance of the proposed antenna system is also acceptable. For the dual-resonance antenna, a wide bandwidth is achieved by shortening the effective length of the slot at the higher frequency using a single via-hole along with the slot. It has been shown that the antenna using via-hole along with the slot can achieve high gain and broader bandwidth performance when compared to dual-band antenna with parallel slots. It has been shown that the designed antenna system has a miniaturized size and simpler topology when compared with similar antennas [10][12], which is an ideal candidate for 5G communications. The simulated results show that the proposed antenna system is a good candidate for 5G applications in both the USA and Europe regions.

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