Bandwidth-Enhanced of Siw Cavity-Backed Slot Antenna By Perturbing Te210 Cavity Mode

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ABSTRACT

In this article, a technique is introduced for bandwidth enhancement of substrate integrated waveguide (SIW) based cavity-backed slotted antenna, inspired by the perturbing the cavity modes. To enhance the bandwidth, the proposed antenna uses a single cavity mode (TE₂₁₀) instead of multiple cavity modes, which is the most diverse approach as compared to the other SIW cavity antennas. Due to the strong loading effect of the rectangle slot, the proposed antenna perturbs the TE₂₁₀ cavity mode. As a result, two modes namely odd TE₂₁₀ and even TE₂₁₀ are successfully generated. Then a wideband response can be achieved by merging these modes in close proximity. The simulated findings show that the proposed design exhibits a fractional bandwidth of 12.8 % and a peak gain of more than 6 dBi. The cross-polarization radiation level of maximum – 31 dB and – 35 dB and identical polarization planes are obtained at 9.75 GHz and 10.65 GHz, respectively. Those amicable properties, e.g., light weight, ease of fabrication, cost effective, broadband response, unidirectional pattern, and high gain, make the design suitable for X-band applications.

KEY WORDS: SUBSTRATE INTEGRATED WAVEGUIDE, HYBRID MODE, WIDEBAND, IMPEDANCE BANDWIDTH.

INTRODUCTION

Substrate integrated technology (SIW) is the latest available technology that realizes the future wireless systems in planar form. The amicable benefits of this technology are the high-density integration with planar circuits and the low power losses [Kumar A et. al]. Several papers have been reported on SIW cavity-backed antennas. One of the major drawbacks of these antennas is the narrow bandwidth due to thin substrate. Low-profile planar slot antenna by using SIW technique is reported in [Luo GQ et. al], which generates the radiation by TE₁₂₀

mode of the cavity at 10 GHz. Nevertheless, due to low-height, the quality factor (Q) of the cavity is increased. As a result, the bandwidth is achieved nearly 1.7% with a gain of 5.3 dBi. In [Luo GQ et. al], fractional bandwidth of 6.3 % is obtained by coupling the two hybrid modes (combinations of the TE₁₁₀ and TE₁₂₀ modes) of the cavity in close proximity. In [Mukherjee S et. al], TE₁₂₀ mode is excited by using offset feeding technique. As a result, impedance bandwidth of 4.2% is achieved.

In [Mukherjee S et. al], the modified bow-tie slot perturbs the TE₁₁₀ and TE₁₂₀ modes to improve the bandwidth upto 9.4%. In [Baghernia E et. al], corner perturbation in the square cavity separates the TE₁₂₀ and TE₂₁₀ cavity modes, which in turn enhances the bandwidth (1.65%). In [Varnoosfadrani MV et. al], matching slot excite the TE₂₁₀ mode in the SIW cavity to attain the fractional bandwidth upto 8%. In [Dashti H et. al], TM₀₁₀ mode of the patch is stimulated through proximity coupling by half-mode SIW to improve the impedance bandwidth. In [Kumar A et. al], multi-resonant slots perturb the current distributions of both TE₁₁₀ and TE₁₂₀ modes. As a result,

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the antenna achieves an impedance bandwidth upto 11%. Development of wideband is presented in [Heydarzadeh F et. al], where TE₁₂₀ and TE₂₁₀ degenerate modes of the SIW cavity are greatly coupled by cutting the corners of the conventional SIW cavity with circular shape. This design achieves 5.7 % fractional impedance bandwidth. Bandwidth enhancement using bilateral slots have been reported in [Niu BJ et. al], in which three hybrid modes have been merged within the operating band. In [Feng C et. al], to enhance the impedance bandwidth up to 8.9%, the ellipse slot is employed in the circular SIW cavity. Several attempts have been discussed for bandwidth enhancement, by introducing two shorting vias nearby the inclined slot, by using stacked cavities, by using bilateral slots, by using metallic vias.

In this paper, low-profile slot antenna using SIW technology is proposed for obtaining wideband response. The proposed antenna utilizes a single cavity mode instead of multiple modes, which is the most distinct approach as compared to other approaches reported in the references. Due to the strong loading effect of the slot, the proposed structure disturbs the current distributions of the TE₂₁₀ cavity mode. As a result, two modes namely odd TE₂₁₀ and even TE₂₁₀ are successfully developed. Then a wideband response of 12.8% bandwidth can be obtained by merging these modes in close proximity. The simulated findings are compared with the previously reported works for more extensive study.

Antenna Design: The configuration and parameters of the proposed antenna is illustrated in Fig. 1. It consists of a SIW cavity, radiating slot and feeding circuit. The SIW cavity is fully created on a single PCB of height h , where the lateral walls of the cavity are realized by implanting metallic posts along the edges of the substrate. Rogers RT/duroid 5880 substrate ($\epsilon_r = 2.2$) is elected as the dielectric due to its exemplary features like low losses, less relative permittivity etc. The post diameter (d) and pitch (s) must pursue the prescribed criteria $d/s \geq 0.5$ and $d/\lambda \leq 0.1$ to minimize the energy leakage from the gap between successive metallic posts [Lokeshwar B]. The dimensions of the SIW cavity can be approximately determined from the equation (1). The radiating slot with size of $l_s \times w_s$ is printed on the ground plane. To facilitate the planar integration, a section of 50Ω micro-strip line is appended at the end of 50Ω grounded co-planar waveguide (GCPW), forming a feeding circuit to excite the proposed antenna.

$$f_r(TE_{210}) = \frac{1}{2\sqrt{\mu_0\epsilon_0\epsilon_r}} \sqrt{\left(\frac{m}{L_{eff}}\right)^2 + \left(\frac{n}{W_{eff}}\right)^2 + \left(\frac{p}{h}\right)^2} \quad (1)$$

where, m, n, p are positive integers, ϵ_r – dielectric constant, equivalent length and width of the cavity

$$(L_{eff} \text{ or } W_{eff}) = L_{cav} \text{ or } W_{cav} - \frac{d^2}{0.95 \times s}$$

respectively, d – diameter of the post, and p – spacing between the adjacent vias (pitch).

Figure 1: Configuration of the antenna a 3D View, b Schematic layout

Table 1. Dimensional parameters of the proposed design

Parameter	W_{cav}	L_{cav}	w_{50}	l_{ms}	l_m	g_m
Value(mm)	20.9	22.4	3.3	5.5	4.6	1.25
Parameter	l_s	w_s	dsu	s	d	h
Value(mm)	19	1.4	4.55	1.5	1	1.6

3. Working Principle: In order to figure out the behavior of the rectangle slot on bandwidth enhancement, the simulation of the SIW cavity is described by using ANSYS HFSS at first. One of the approach to improve the operating bandwidth of cavity-backed antennas is to increase the height of the substrate material. That's why, a standard thickness $h = 1.6$ mm is selected as substrate thickness. The dimensions of the SIW cavity are optimized and listed in the Table 1. Fig. 2 represents the input resistance plot ($Re(Z_{11})$) of the proposed design. When the SIW cavity alone is excited by micro-strip line feed, the dominant mode (TE₁₁₀) at 6.85 GHz and TE₂₁₀ mode at 10.25 GHz are generated. The aforementioned SIW cavity modes get perturbed by printing the rectangle slot (non-resonant slot) at the ground plane. As a result, the TE₁₁₀ mode shifts downward from 6.85 GHz to 6.1 GHz.

And, a new couple modes (odd TE₂₁₀ and even TE₂₁₀) are generated at 9.55 GHz and 10.85 GHz due to perturbations in TE₂₁₀ mode. These modes are merged together by placing the slot at optimum location, which widen the bandwidth. The surface current distribution of the proposed design at different resonances is depicted in Fig. 5. It is evident that the quality factor (Q) of the hybrid mode at 9.75 GHz is less than that of the hybrid mode at 10.65 GHz, which can be noticed by comparing Fig. 3a and b. At both the resonances, surface current is mostly concentrated above the non-resonant slot with a minimal amount of field in the lower half. To know the variations in the fractional bandwidth, the slot width is changed as shown in Fig. 4. As a result, the impedance matching properties has been greatly affected. At optimum $W_s = 1.4$ mm, the fractional bandwidth was obtained maximum. Mathematically, fractional (percentage) bandwidth is calculated from the equation (2).

$$\% \text{ Fractional Bandwidth} = 2 \times \frac{f_H - f_L}{f_H + f_L} \times 100 \% \quad (2)$$

Where f_L – lower frequency ($S_{11} < -10$ dB) ; f_H – upper frequency ($S_{11} < -10$ dB).

Figure 2: Real impedance (Z_{11}) plot

Figure 3: Surface current distribution at a 9.75 GHz and b 10.65 GHz

Figure 4: Changes in fractional bandwidth by varying slot width w_s

RESULTS AND DISCUSSION

The proposed design is completely designed with single substrate. The simulated result of the reflection coefficient (S_{11}) confirms the wideband response as depicted in Fig. 5. It can be substantiated from the figure that, the simulated frequencies resonances are 9.75 GHz and 10.65 GHz. The simulated impedance bandwidths (for below -10 dB) are 1.3 GHz (12.8 %) covering from 9.5 GHz to 10.8 GHz. The simulated gain performance of the antenna is included in Fig. 7. The gain remains

consistent, with a peak gain of 6.44 dBi and 7.1 dBi is achieved at 9.75 GHz and 10.65 GHz, respectively. From the gain expression (3), the gain is proportional to aperture (slot) area. It is also verified from the simulation as shown in Fig. 6.

$$G = \frac{4\pi}{\lambda^2} \epsilon_{ap} A_p \quad (3)$$

Figure 5: Simulated reflection coefficient (S_{11}) and gain of the proposed antenna

Figure 6: Analysis of gain of the proposed antenna for different values of slot width W_s

Figure 6: Radiation patterns of the wideband antenna at a 9.75 GHz b 10.65 GHz

The simulated far-field pattern of the antenna in two cut-planes, which are corresponding to XZ-plane ($\phi = 0^\circ$) and YZ-plane ($\phi = 90^\circ$) at two frequencies are shown in Fig. 8. It is found from the simulated results that, the peak cross-polarization level in the XZ-plane and YZ-plane is -31 dB and -21 dB, respectively at a lower resonant frequency in the broadside direction. At 10.65 GHz, the peak cross-pol level is -35 dB and -20 dB in the XZ-plane and YZ-plane, respectively. The

simulated front-to-back ratio (FTBR) of the proposed design is about 14 dB and 18 dB respectively at 9.75 GHz and 10.65 GHz. To indicate the essence of the proposed study, a comparison of different parameters of the proposed design and the previously published designs are

listed in Table 2. It may be observed that the proposed antenna showcase the flexibility in tuning impedance bandwidth and renders a better bandwidth performance at two frequencies as compared to works presented in Table 2 by using single cavity mode.

Table 2. Comparison among proposed antenna and some previously reported SIW CBSA

Properties	Year	Freq. band	FBW (%)	Gain (dBi)	Structure	h (mm)
Mukherjee S and Biswas A et. al	2012	X	6.3	6	Simple	0.5
Mukherjee and Biswas A S et. al	2014	X	9.4	3.7	Complex	0.787
Kumar A and Raghavan S	2017	Ku	11	8	Complex	1.57
Heydarzadeh F and Neshati MH	2018	Ku	5.7	6.4	Complex	1.57
Chaturvedi D	2020	C	5.2	7.15	Complex	1.524
Ali HA and Massoni E et. al	2018	S	3.72	4.42	Complex	1.52
This work	2020	X	12.8	7.1	Simple	1.57

CONCLUSION

A low-profile bandwidth-enhanced planar slot antenna using SIW technology is designed and analyzed in this article. The proposed design is loaded with a simple rectangle slot for radiating the electromagnetic waves. The radiating slot is engraved near to the upper wall of the SIW cavity, which perturb the TE₂₁₀ mode to achieve bandwidth enlargement. Radiation performance and effects of parameter have been investigated. The simulation findings show a maximum gain of 7.1 dBi and fractional bandwidth of 12.8 %. The proposed design still retains many benefits such as lighter weight, less fabrication cost, and easy integration with planar circuits.

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