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SIW cavity-backed patch antenna for X-band applications

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In this paper, substrate integrated waveguide (SIW) based cavity-backed patch antenna is presented. The performance of the proposed antenna in terms of gain and cross-polarization levels is improved by inserting a pair of shorting pins in nearby non-radiating edges of the rectangular patch. The maximum gain realized for the proposed design is 8.6 dBi at the resonant frequency of 10 GHz with 95 % efficiency, which is much higher than that of the conventional patch antenna. The proposed design exhibits an impedance bandwidth of 870 MHz, ranging from 9.59 GHz to 10.46 GHz. Moreover, the proposed design owns unidirectional and stable radiation characteristics in the boresight direction. The simulated results are validated with fabrication and measurement which show a close agreement with each other.

Keywords: Cavity-backed antenna, Patch antenna, Substrate integrated waveguide (SIW)

1 Introduction

All microstrip antennas suffer from an inherent property of the bidirectional radiation pattern and low-gain hence, are not suitable for many practical applications. In such situation, conventional metallic cavity-backed antennas are excellent candidates to exhibit a unidirectional radiation pattern with high gain value. But the manufacturing of the conventional cavity-backed antennas is a tedious process, as the configuration would need assemblage of metallic cavities along backside[1,2]. Also, the conventional metallic cavity-backed antennas are bulky and relatively expensive as well.

Consequently, substrate integrated waveguide (SIW) technology emerged as an alternate mode to design a planar cavity-backed antenna and array structures[2-15]. An SIW technology takes the advantages over conventional guiding media, including low-cost, easy integrability with planar circuits, light-weight and conformal in nature. Also, it owns the benefits of the bulky rectangular waveguide such as high-*Q*-factor due to closed structure, and high power handling capability. Moreover, SIW fed antennas are less likely to excite surface waves. In recent, many SIW based antennas and arrays have been reported for various applications[6-9].

In this paper, SIW based cavity-backed rectangular patch antenna is proposed for planar integration. The gain of the proposed design is improved by inserting a pair shorting pins at the non-radiating edges. The radiating rectangular patch antenna is unified with low-loss SIW based feeding network, as a result, the antenna exhibits a good impedance matching with high gain characteristics. Finally, antenna design is validated with measurement results.

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2 Antenna Design and Configuration

An SIW based cavity-backed rectangular patch antenna is designed as projected in Fig. 1. The antenna comprises an SIW cavity resonator, a radiating rectangular patch loaded with shorting pins and SIW based feeding network. The proposed antenna is designed on a substrate of RT/Duroid (5880) with a thickness of 1.57 mm. The dielectric constant is (ε_r) 2.2 and the loss tangent is 0.0009. The dimension of feeding waveguide is estimated by center frequency in X-band and a cutoff frequency 6.3 GHz of the dominant mode (TE_{10}) as enlightened in literature[4]. The lateral walls of the SIW are implemented by using continuous rows of metallic vias. To ensure the minimum leakage loss in between the metallic vias, the diameter '*d*' and pitch distance '*p*' is optimized in such a way that it satisfies the mandatory condition as highlighted in literature[2]. A rectangular patch shaped radiating element is etched on the top cladding of the SIW cavity resonator. The initial dimensions of the patch are determined by using conventional patch design equations[7]. To improve the gain of conventional patch antenna, a pair of shorting pins is inserted at non-radiating edges of the patch and their location is adjusted in such a way it yields maximum gain and good impedance matching. Also, the loaded pins are found useful to reduce undesirable surface waves. Thus, cross-polar level has been improved.

In the proposed design, the radiating element is excited by a coupling mechanism, through an inductive window of width 'w_{win}' maintaining a coupling gap of 'g' between the patch and feeder SIW. The parameter 'g' and 'w_{win}' is optimized such that the smooth energy transition from fundamental TE_{10} -mode of an SIW to TM_{10} patch mode can be maintained with matched impedance characteristics. The other end of the SIW feed is extended by a 50 Ω microstrip line with the tapered microstrip-to-SIW transition. Thus, the proposed design maintains the planar integrability. The open space between radiating patch and cavity resonator is optimized in such a way that it can radiate with maximum efficiency.

The total occupied dimensions of the antenna, including transition region is in terms of $\lambda_o$is 0.7 $\lambda_o\times$ 1.167λ_o × 0.05λ_o (21 mm × 35 mm ×1.57 mm). Where, $\lambda_o$is free space wavelength at the center frequency of 10 GHz. The optimized geometrical parameter values are tabularized in Table 1. The optimization process is executed by using a commercial CST-MWS full-wave simulator.

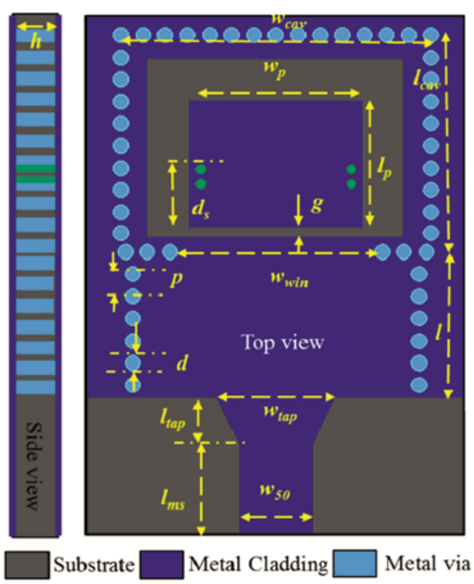

Fig. 1 — Proposed antenna configuration.

Table 1 — Dimensions of the proposed design

Parameters	Values (in mm)	Parameters	Values (in mm)
l_p	8.5	l_{ms}	7
w_p	11.7	l_{tap}	3.2
d_s	4.15	l_{cav}	14.7
w_{win}	14.4	w_{cav}	21
w_{50}	4.8	h	1.57
w_{tap}	8	l	9
d	1	p	1.5

3 Antenna Results and Fabrication

The proposed antenna is fabricated on Rogers's (RT/Duroid 5880) by using standard printed-circuit-board (PCB) procedures with the help of '*MITS Lab 11'* milling machine. The fabricated antenna prototype is shown in Fig. 2 vias of the SIW are filled with copper rivets that electrically short the upper and bottom copper laminations of the substrate, resultantly, form side walls.

To evaluate the performance of the proposed design, the simulated and measured results for the reflection coefficients (S_{11}) and gain characteristics of the proposed design is compared in Fig. 2. The simulated result shows that the antenna exhibits an impedance bandwidth of 870 MHz (9.59-10.46 GHz) with a resonant frequency of 10 GHz. A small degree of shift is observed in simulated and measured reflection coefficient curve, which may be attributed to fabrication errors and soldering losses. The proposed antenna shows a high gain of

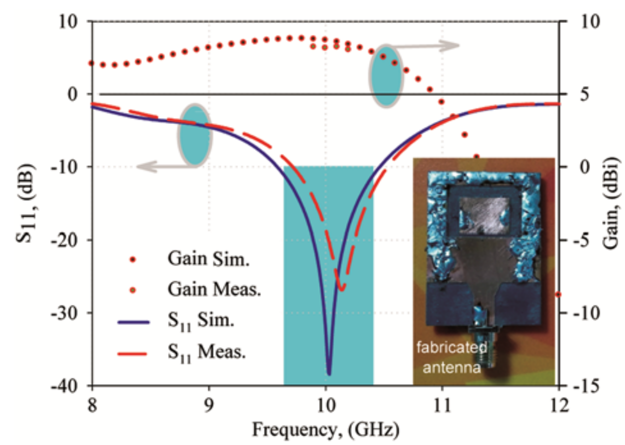

Fig. 2 — Comparision of simulated and measured results.

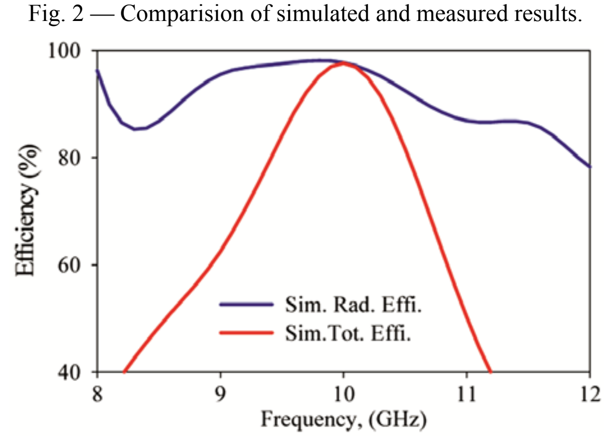

Fig. 3 — Simulated antenna efficiencies.

Table 2 — Comparison of refereed SIW cavity-backed antenna with proposed design

Properties	Frequency band	Substrate thickness (mm) ($\varepsilon_r = 2.2$)	Antenna size (in term of operating frequency)	Gain (dBi)	Feed-type
[2]	X (9.9 –10.18 GHz)	0.50	1.3 λ_o×1λ_o × .01λ_o (approx.)	4.2	Microstrip
[4]	X (8.82–11.15 GHz)	1.57	1.50 λ_o× 1.167λ_o × .05λ_o	7.79	SIW, Microstrip Line
[5]	X(9.09 –11.40 GHz)	1.57	0.86 λ_o× 1.5λ_o × .05λ_o	6.6	SIW, Microstrip Line
[8]	X (8.87–10.87 GHz)	1.57	0.83 λ_o× 1.4λ_o × .05λ_o	5.57	SIW, Microstrip Line
[9]	C (5.52–5.92 GHz)	1.57	0.8 λ_o× 0.9λ_o × .03λ_o	6.25	Microstrip Line
Proposed Work	X(9.59–10.46 GHz)	1.57	0.7λ_o× 1.167λ_o × .05λ_o	8.6	SIW, Microstrip Line

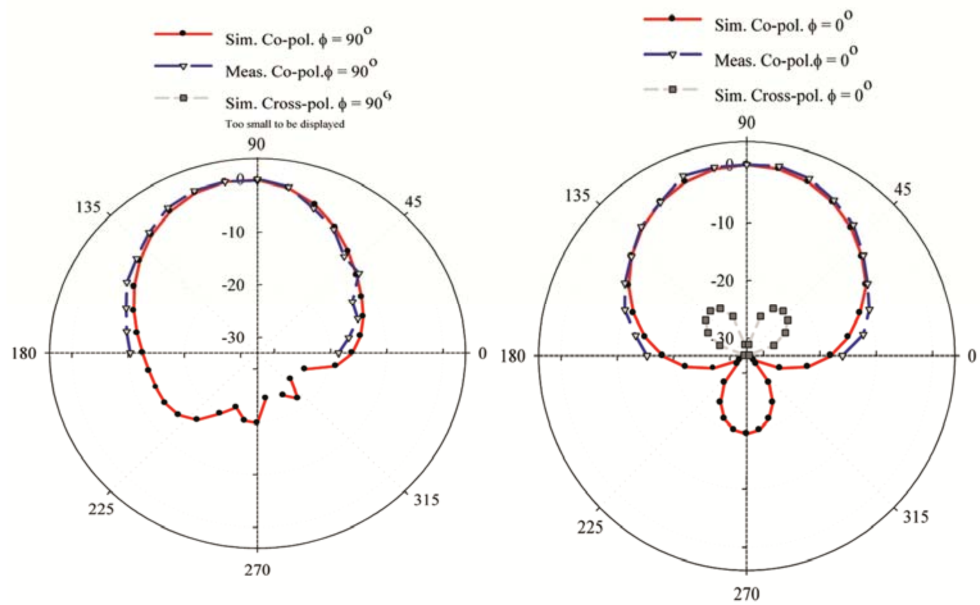

Fig. 4 — Radiation Pattern antenna at two cut planes (ϕ = 0° and ϕ = 90°) at 10.1 GHz.

over 8.0 dBi for the entire operating band. The simulated and measured gain value of the proposed antenna at the resonant frequency is 8.6 dBi and 8.2 dBi, respectively. The gain of the proposed design is higher than that of a conventional patch antenna[7].

Simulated antenna efficiency, i.e., radiation and total are represented in Fig. 3, which is almost greater than 95% over the entire operating band. The normalized radiation patterns at two principal cut planes ($\phi = 0$ and $\phi = 90$) are provided in Fig. 4 at the frequency of 10.1 GHz. The radiation patterns at both planes are stable and unidirectional characteristics, comparable to that of the conventional planar patch antennas in the boresight direction[7]. The measured and simulated radiation patterns are in close agreement. Moreover, the simulated cross-polarization level is also plotted in Fig. 4, it shows the very low cross-polarization levels (-25 db) in the two cut-planes. The cross-polarization in the plane $\phi = 90$ was too small to be displayed on the plot. To certify the performance of the proposed antenna, a comparison between the measured results of the proposed work with previously reported SIW based designs is summarized in Table 2.

4 Conclusions

An SIW based cavity-backed patch antenna is proposed for X-band (8–12 GHz) application with improved gain characteristics with low cross-polar levels. The gain of the conventional SIW based patch antenna is improved by inserting a pair of shorting pins nearby its non-radiating edges. The proposed antenna exhibits an impedance bandwidth of 870 MHz, ranging from 9.59-10.46 GHz with a gain of 8.6 dBi at a resonant frequency of 10 GHz. A fabricated antenna prototype is used to validate the design. Moreover, this antenna possesses eccentric features such as wide impedance bandwidth (8.7%), unidirectional and stable radiation characteristics, while, it maintains the planar integrability. The total occupied volume of the antenna, including feeding network is 21 mm×35 mm×1.57 mm.

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