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Design of compact rectangular SIW-based cavity-backed slot antennas for WiMAX communication in Asia–Pacific regions

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Abstract
In this paper, a rectangular cavity-backed substrate integrated waveguide antenna is designed and fabricated at 3.3 GHz in WiMAX IEEE 802.16 band to be used with other electronic devices in Asia–Pacific regions. Three different types of slots are inserted in the ground plane for radiation purpose. The first antenna with 'I' and inverted 'U'-shaped slots produces a gain of 1.8 dBi at the dominant TE_{101} mode. The second antenna with 'L'-shaped slot produces a gain of 2.2 dBi, while the third antenna with 'A'-shaped slot produces a gain of 1.9 dBi. Parametric studies are carried out to achieve best antenna performance in terms of both return loss and gain. Detail performance analysis is performed for different shapes of antenna slots, and a comparative study of the proposed antenna is conducted with the existing reported ones. Simulations are done using ANSYS make HFSS v15.0. The antennas are fabricated using FR4 epoxy material, and the parameters are experimentally measured. The simulated and measured results are compared and reflect a close resemblance with each other.

Keywords Substrate integrated waveguide (SIW) · Cavity-backed slot antenna · Antenna gain · Worldwide interoperability for microwave access (WiMAX) · IEEE 802.16 protocol

1 Introduction

Worldwide Interoperability for Microwave Access (WiMAX) is one of the acclaimed wireless technologies operating in the spectrum bands of 2.3/2.5/3.3/3.5/5.8 GHz in Asia–Pacific regions supporting point-to-multipoint wireless network systems. IEEE 802.16 standards are dedicated for WiMAX applications in 10.66 GHz spectrum including both licensed and non-licensed spectra from 2–11 GHz. It provides LOS and non-LOS services for frequencies as low as 11 GHz to as high as 66 GHz. Orthogonal frequency division multiplexing (OFDM) is used in WiMAX and provides good resistance to multipath. It supports high peak data rates of 74 Mbps for 20 MHz wide spectrum and allows multiple-antenna usage. Its MAC layer provides support for many services like multimedia and voice.

The wide popularity of WiMAX is accounted for its support in satisfying different kinds of access needs like providing broadband capabilities for subscribers, filling gaps in cable, DSL and T1 services. WiMAX can be integrated into both wide-area third-generation (3G) mobile and wireless and wireline networks. Besides it can be used as a wireless loop of IEEE 802.11 access hotspots, to connect Wireless MAN with operator's backbone network.

Despite much significant technical advancement, there is still a rise in demand for development of good antenna systems for better deployment. It is herein that substrate integrated waveguide (SIW) technology plays a pivotal role in providing the right platform to design low cost, mass producible antennas to be installed with other communication devices for WiMAX applications.

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SIW technology is an obvious choice as it retains the advantages of conventional metallic waveguides with respect to high-quality factor and superior power handling capabilities. Various SIW active circuits such as oscillators [1, 2], mixers [3], amplifiers [4], and SIW based antennas such as leaky-wave antennas [5] and cavity-backed antennas [6] can be designed. The cavity-backed antennas and arrays provide better radiation performance, gain augmentation and low values of mutual coupling. The cavity-backed slot antennas can be fed by metal waveguide [7], SIW or probe. The cavity beneath the slot facilitates generation of high-gain unidirectional radiation characteristics [8, 9]. Several SIW-based cavity-backed antennas are reported in the literature. In [10], the authors have proposed a compact self-quadruplexing antenna based on SIW quarter-mode cavity with enhanced isolation. The isolation obtained between any two ports is 32 dB with a gain of 7.8 dBi at operating frequencies. In [11], a SIW cavity-backed antenna is proposed for X-band applications. The antenna produces 8.6 dBi gain at 10 GHz with 95% efficiency. In [12], a SIW cavity-backed self-diplexing leaky-wave antenna with 16 slots elements is reported. In [13], a planar triplexer Y-shaped slot antenna backed by SIW cavity is proposed at 5.7/6/6.4 GHz frequencies. The antenna produces high gain at all designed frequencies with 24 dB average isolation between ports. Another author in [14] designed a self-triplexing slot antenna at 6.53/7.65/9.09 GHz frequencies with gains of 3.1/4.7/3.9 dBi. An isolation of 19 dB is achieved between any two ports. In [15, 16], the authors have proposed SIW-based circular cavity-backed slot antenna at WLAN frequency of 5.33 GHz with a gain of 4.9 dBi. In [17], a low profile slotted SIW cavity-backed antenna is proposed for frequency agility within a range of 1.8–2.18 GHz. In [18], the authors have developed a low-profile multi-band antenna fed by SIW cavity resonator for X-band applications. A wideband circular cavity-backed slot antenna for wireless transmission is proposed [19] which exhibits conical radiation pattern. In [20], a dual-band SIW-based resonant cavity is designed to operate between 3.3–4.2 GHz for 5G networks. The cavity resonates at the frequencies of 3.4 and 4 GHz. In [21], a tunable SIW cavity-backed slot antenna is presented with resonating frequency varying within a wide range of 0.9 GHz with 4.5 dBi gain. Compact cavity-backed antennas can be designed on textile substrate material at 2.53 GHz for emergency situations as discussed in [22]. The bandwidth of the SIW antenna can be either enhanced with the removal of substrate [23] or, introduction of via- hole above the slot [24] or by using unbalanced shorting vias [25]. Other SIW-based similar antennas are also available in the literature [26–33].

In this paper, the authors have designed SIW-based rectangular cavity-backed slot antennas to resonate at the IEEE 802.16 WiMAX frequency of 3.3 GHz for wireless applications in Asia–Pacific regions. Initially, a rectangular SIW-based cavity is designed to resonate at 3.3 GHz, and two narrow slots are introduced in the ground plane for radiation purpose. Thus, the parent antenna comprises of one 'I' shaped and the other 'inverted-U'-shaped slots in the ground plane. The radiation is along broadside direction at an angle of $\theta = 180^0$ as slots are placed in the back side. The gain of the antenna obtained is 1.8 dBi at the designed frequency. The antenna is further modified by replacing both the slots by a single rectangular slender 'L'-shaped slot in the middle of the ground plane. The antenna is now found to resonate at the same designed frequency of 3.3 GHz with a gain of 2.2 dBi at $\theta = 180°$. Finally, a third antenna is designed at 3.3 GHz for WiMAX applications by introduction of an 'A'-shaped slot in the ground plane. This antenna exhibits a gain of 1.9 dBi at $\theta = 180°$. All the antennas are fabricated using FR4 substrate, and simulation results obtained using ANSYS make HFSS v15.0 are tallied with the experimentally measured antenna parameters.

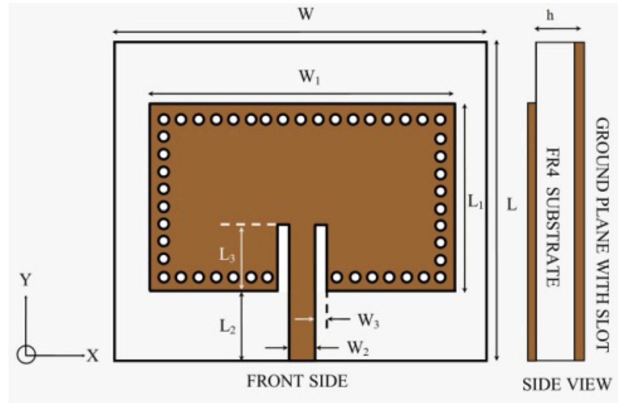

Fig. 1 Geometrical dimensions of SIW rectangular cavity-backed slot antenna (Front side only)

Table 1 Size of various parameters of the proposed SIW-based cavity-backed slot antenna (in mm)

L	W	h	L_1	W_1	L_2	W_2	L_3	W_3
70	70	1.6	38	27.9	21	2.13	10	1.065

2 SIW-based rectangular cavity-backed slot antenna

Theoretical Background and Antenna configuration The rectangular cavity-backed antennas with different types of slots in the ground plane are proposed in this paper for WiMAX frequency of 3.3 GHz for Asia–Pacific regions. For a metallic cavity resonator confining the electromagnetic energy, the electric and magnetic energies stored inside it determine its

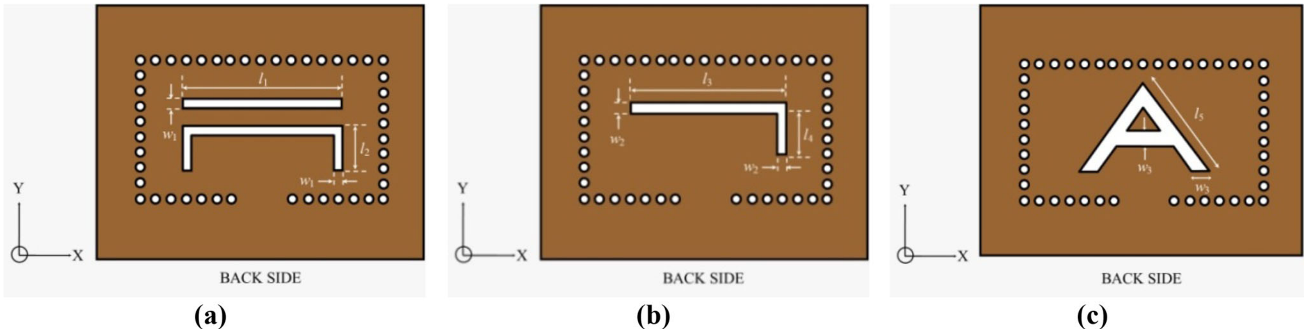

Fig. 2 Geometrical dimensions of SIW rectangular cavity-backed slot antennas (Back sides only); **a** Antenna with I and inverted U-shaped slots; **b** Antenna with L-shaped slot and **c** Antenna with A-shaped slot

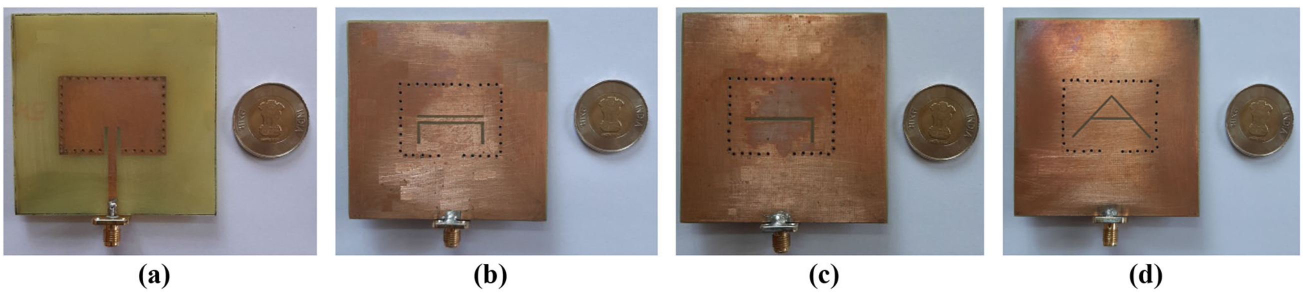

Fig. 3 **a** Fabricated antenna prototypes (Front side of all antennas); **b** Antenna with I and inverted U-shaped slots (Back side); **c** Antenna with L-shaped slot (Back side) and **d** Antenna with A-shaped slot (Back side)

equivalent capacitance and inductance. Also, its equivalent resistance is determined by the dissipation of energy through finite conductivity of walls. The peak energies stored in electric and magnetic fields become equal when the frequency of an impressed signal becomes equal to the resonant frequency. For a lossless dielectric, the resonating frequency for a rectangular cavity with dimensions a × b × d is expressed as [34]:

$$f_r = \frac{1}{2\pi\sqrt{\mu \in}}\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 + \left(\frac{p\pi}{d}\right)^2} \tag{1}$$

where m, n, and p are the number of half-wave periodicity in x-, y- and z-directions, respectively. For a > b < d, the expression for resonating frequency considering dominant TE_{101} mode (m = 1, n = 0, p = 1) is modified as:

$$f_r = \frac{1}{2\sqrt{\mu \in}}\sqrt{\left(\frac{1}{a}\right)^2 + \left(\frac{1}{d}\right)^2} \tag{2}$$

The rectangular cavity resonator is realized using substrate integrated waveguide technology on a rectangular metallic patch. The array of metallic vias placed on the surface of the metallic patch acts as perfect electrical conducting (PEC) walls, thereby confining the electromagnetic energy within it. Different types of slots are then introduced in the ground plane to make the cavity resonator radiate out the trapped electromagnetic energy; thus acting as a SIW cavity-backed antenna.

The overall dimension of the designed antenna is 70(L) × 70(W) × 1.6(h) mm^3. An array of metallic vias representing PEC walls, placed on the periphery of the metallic patch, materializes a rectangular cavity of dimensions 38(L_1) × 27.9(W_1) mm^2. The vias are of diameter 1 mm with center-to-center distance between two consecutive vias being 1.5 mm following necessary conditions such as $s/p < 2.0$ and $p/w < (\frac{1}{5})$ [35], where p is the diameter of the via, and s is the center-to-center distance between the two vias. The inner dimensions between the vias constituted cavity boundary walls are 36 × 25 × 1.6 mm^3. Thus, the designed rectangular cavity shown in Fig. 1 is supposed to have a theoretical resonating frequency of 3.43 GHz using Eq. 2. Inset feeding is used to excite the cavity. The length (L_2) and width (W_2) of the inset feed are 21 mm and 2.13 mm, respectively, and the optimized insertion depth (L_3) is 10 mm to excite the fundamental TE_{101} mode inside the rectangular cavity. The inset feed realizes a 50 Ω impedance matching for maximum transfer of power. The various dimensions of the proposed cavity with inset feed are enlisted in Table 1.

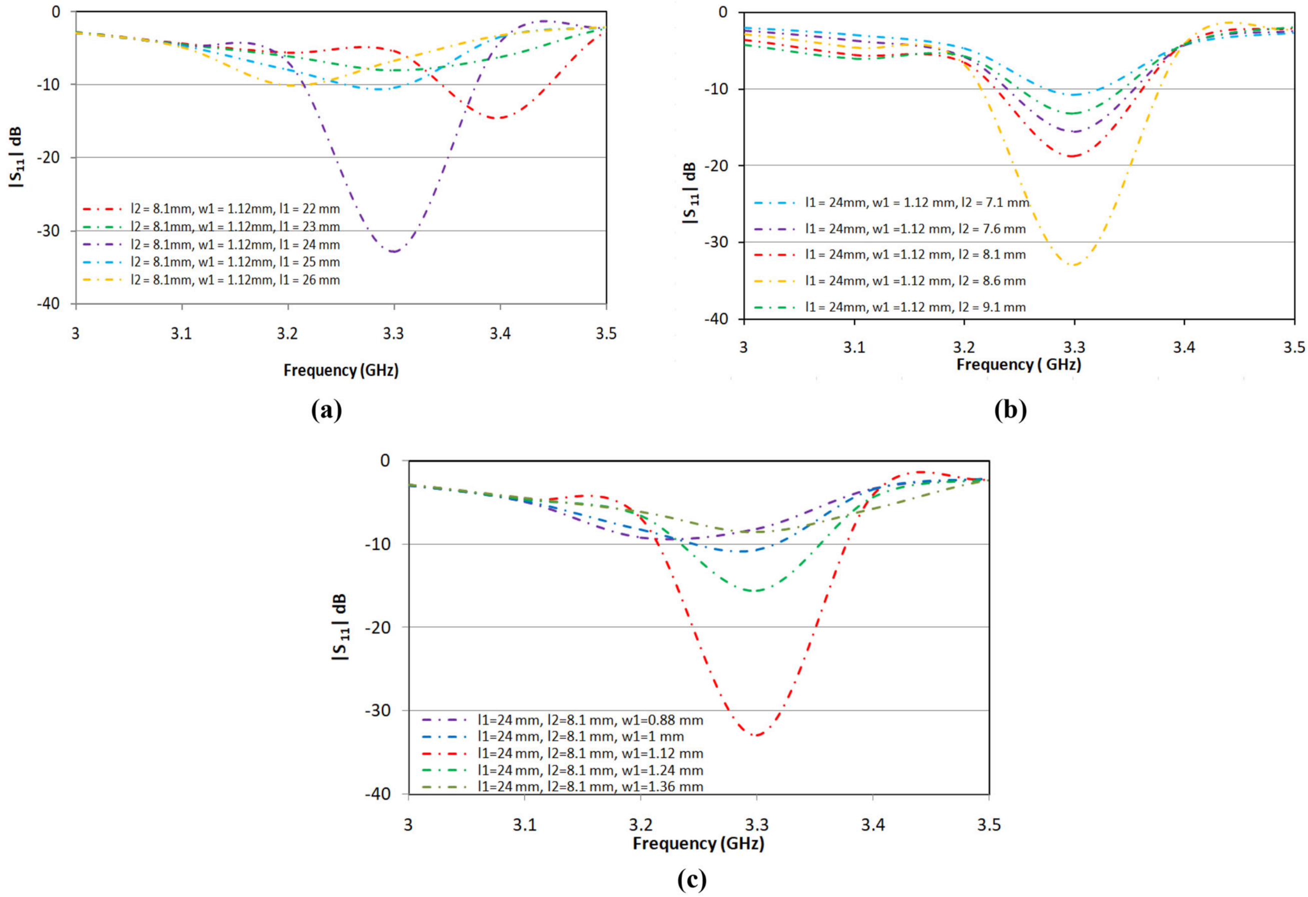

Fig. 4 Parametric variations of slots dimensions of cavity-backed antenna with I and inverted U- shaped slots; **a** Variation in length l_1 of the 'I'-shaped slot keeping length l_2 and width w_1 constant; **b** Variation with change in length l_2 of inverted 'U'-shaped slot keeping length l_1 and width w_1 constant and **c** Variation in width w_1 of both slots keeping length l_1 and length l_2 constant

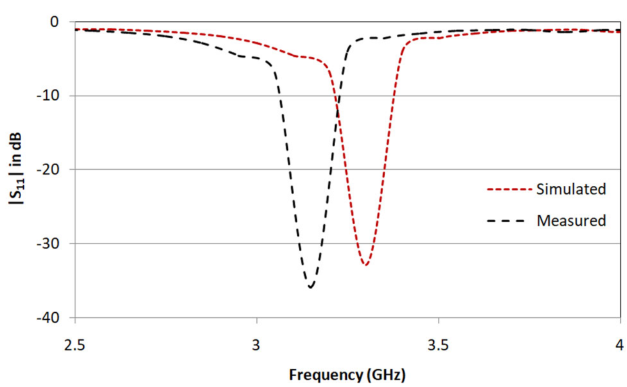

Fig. 5 Simulated and measured values of return loss characteristic of Antenna-1

2.1 Antenna-1: cavity-backed antenna with 'I' and inverted 'U'-shaped slots

Antenna-1 represents a cavity-backed antenna with 'I' and inverted 'U'-shaped slots. The schematic structure of the proposed antenna with 'I' and inverted 'U'-shaped slot in the ground plane depicting its geometrical dimensions is shown in Fig. 2a with its front side identical to one shown in Fig. 1. Owing to the power fed on the upper metal surface and slots being introduced in the ground plane, the antenna is expected to radiate in the backward directions. The antenna-1 is fabricated using FR4 epoxy substrate with $\varepsilon_r = 4.4$, loss tangent $\tan\delta = 0.02$ and height $h = 1.6$ mm as shown in Fig. 3a and b.

2.2 Antenna-2: cavity-backed antenna with 'L'-shaped slot

Antenna-2 portrays a SIW-based rectangular cavity-backed antenna with 'L'-shaped slot. The ground plane of the antenna-2 is modified with inclusion of a narrow, slender 'L'-shaped slot placed at its middle. Its various dimensions are shown in Fig. 2b with its fabricated prototype shown in Fig. 3a and c. Here also, the same FR4 epoxy material is used to fabricate the antenna. It is quite obvious that the antenna would radiate backwards due to the presence of slot in the ground plane.

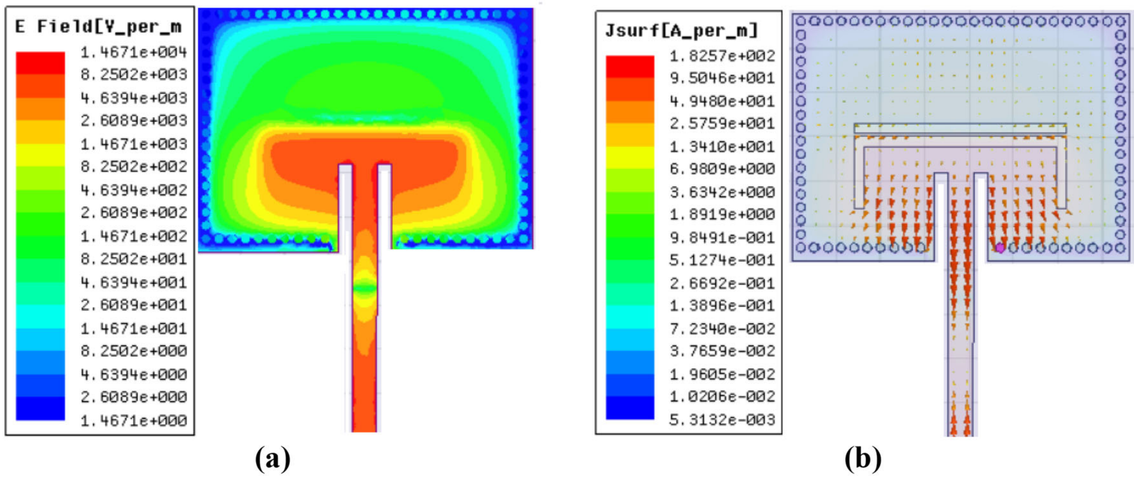

Fig. 6 **a** Electric field distribution and **b** Surface current distribution of Antenna-1

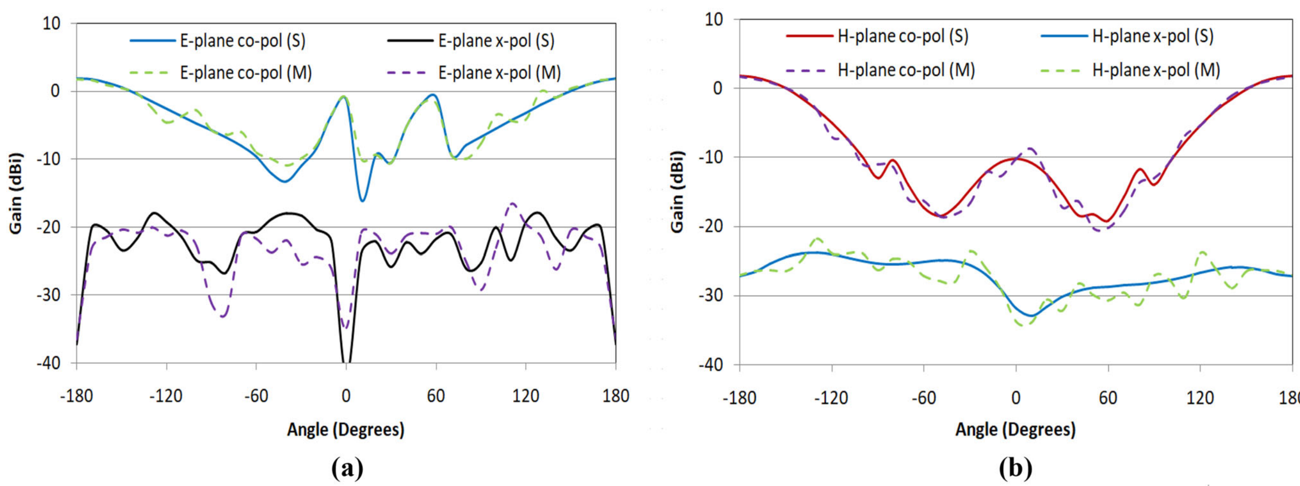

Fig. 7 Simulated (S) and Measured (M) radiation pattern of Antenna-1 at 3.3 GHz **a** E-plane and **b** H-plane

2.3 Antenna-3: cavity-backed antenna with 'A'-shaped slot

Antenna-3 comprises of SIW-based rectangular cavity-backed antenna with 'A'-shaped slot. The 'A'-shaped slot is introduced in the middle of the ground plane as shown in Fig. 2c along with its dimensions. Fabricated prototype is designed using FR4 epoxy substrate having backward radiations as shown in Fig. 3a and d.

3 Results and discussion

3.1 Antenna-1: cavity-backed antenna with 'I' and inverted 'U'-shaped slots

The parameters of the designed antenna are simulated using ANSYS make HFSS v15.0. The dimensions of both the 'I' and inverted 'U'-shaped slots are optimized for better results of return loss and gain. Parametric studies are carried out through variations of l_1, l_2 and w_1 for better results. The plots of parametric studies are depicted in Fig. 4. Figure 4a depicts the variation of reflection coefficient with variation in length l_1 of the 'I'-shaped slot keeping length l_2 and width w_1 of the other slot constant. Figure 4b represents the similar variation with change in length l_2 of inverted 'U'-shaped slot keeping length l_1 and width w_1 of respective slots constant. Similarly, Fig. 4c portrays variation in width w_1 of both slots keeping length l_1 and length l_2 of both slots constant. From the figures, it is evident that for the best antenna performance, the optimized values for slot dimensions are $l_1 = 24$ mm, $l_2 = 8.1$ mm and $w_1 = 1.12$ mm. The antenna is found to resonate at the fundamental frequency of 3.3 GHz for the dominant TE_{101} mode with simulated $S_{11} = -32$ dB. Thus, a close agreement between theoretically calculated and simulated values of resonating frequency is observed. The impedance

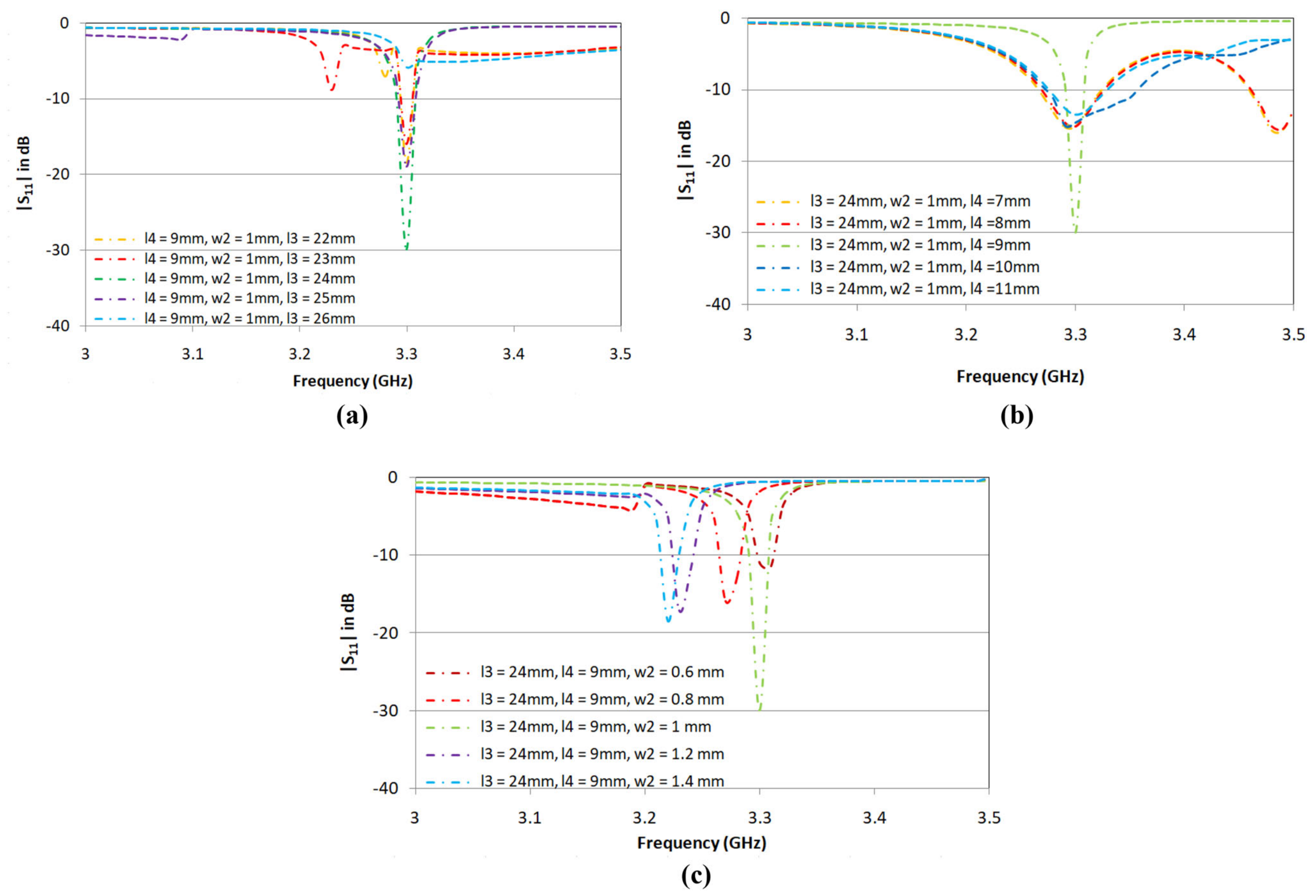

Fig. 8 Parametric variations of slots dimensions of cavity-backed antenna with L-shaped slot; **a** Variation in length l_3 keeping length l_4 and width w_2 constant; **b** Variation in length l_4 keeping length l_3 and width w_2 constant and **c** Variation in width w_2 keeping length l_3 and length l_4 constant

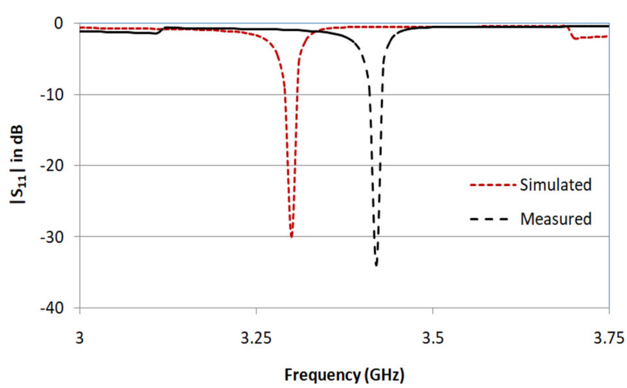

Fig. 9 Simulated and measured values of return loss characteristic of Antenna-2

bandwidth of the designed Antenna-1 covers a frequency band from 3.2 GHz to 3.4 GHz.

The antenna measurements are carried out for the fabricated antenna using Anritsu make VNA model MS2025B, and the reflection coefficient is found to be −35 dB at 3.15 GHz. A comparative plot of simulated and measured return loss of Antenna-1 for TE_{101} mode is shown in Fig. 5, wherein slight deviation between simulated and measured values is witnessed on account of mismatch in SMA connector with the circuit and tolerance arising out of material manufacturing. The electric field and surface current distribution of the designed Antenna-1 are depicted in Fig. 6a and b, respectively, at the fundamental frequency of 3.3 GHz for the dominant TE_{101} mode. The radiation pattern of the antenna is measured using Hittite HMC-T2100 microwave signal generator (10 MHz −20 GHz) and a Krytar 9000B power meter. A plot of simulated and measured electric field radiation pattern is shown in Fig. 7a. For the fundamental TE_{101} mode, the electric field co-polarized simulated gain obtained is 1.8 dBi, while its measured value is found to be 1.7 dBi at $\theta = 180°$. Likewise, the simulated and measured H-field co-polarized gains are obtained as 1.7 dBi and 1.6 dBi, respectively, as shown in Fig. 7b.

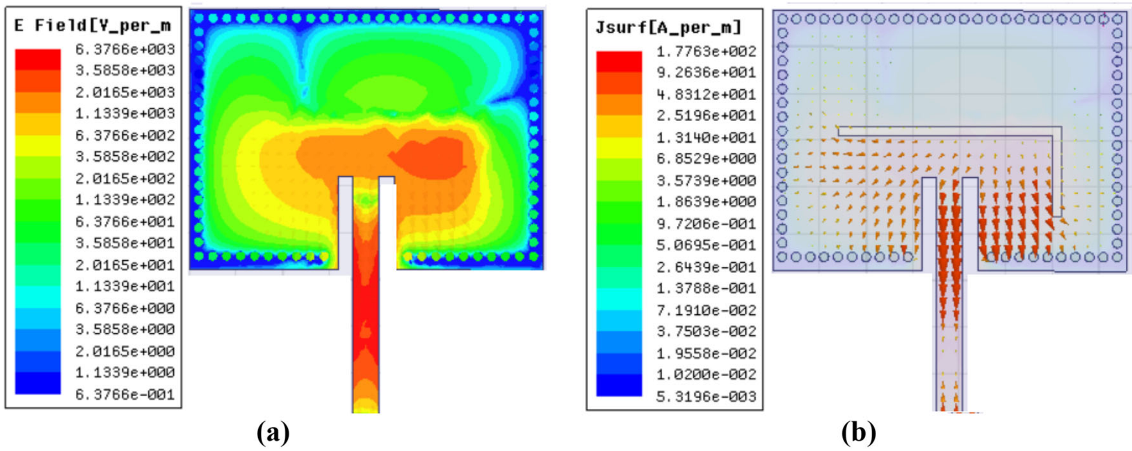

Fig. 10 **a** Electric field distribution and **b** Surface current distribution of Antenna-2

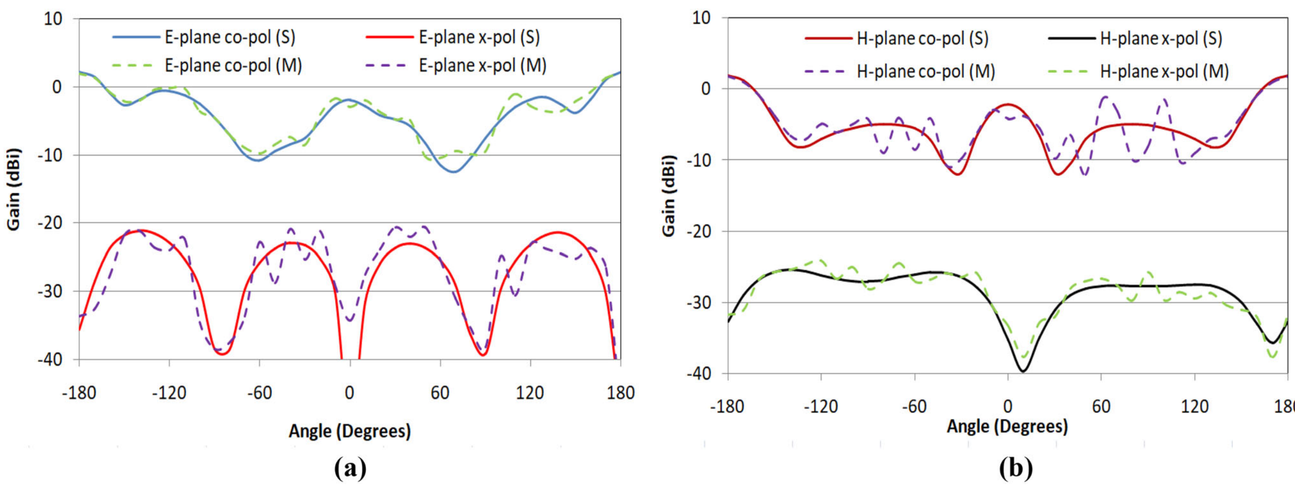

Fig. 11 Simulated (S) and Measured (M) radiation pattern of Antenna-2 at 3.3 GHz **a** E-plane and **b** H-plane

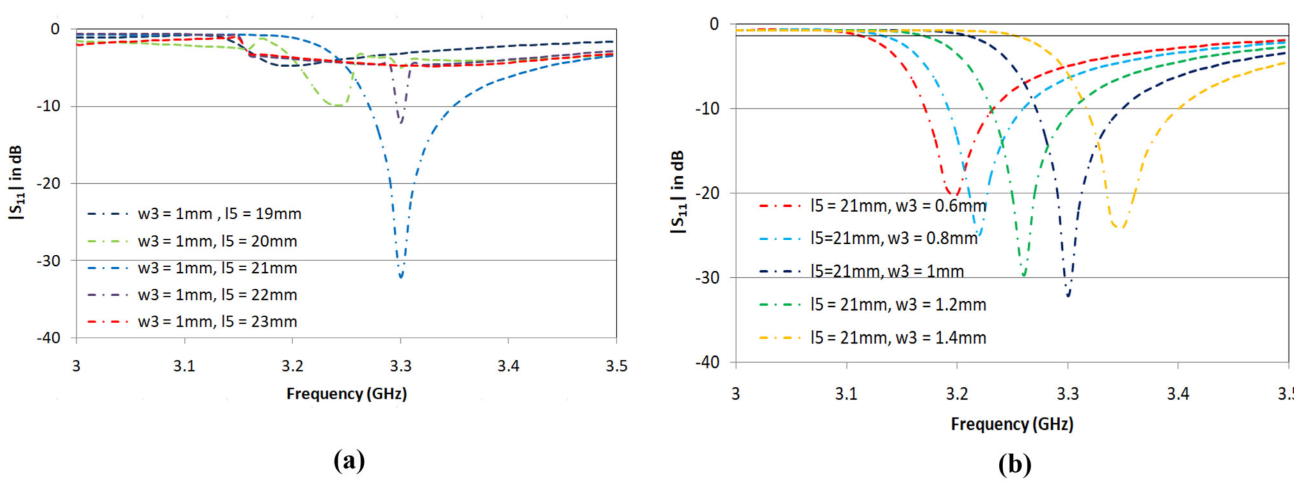

Fig. 12 Parametric variations of slots dimensions of cavity-backed antenna with A-shaped slot; **a** Variation in length l_5 keeping width w_3 constant and **b** Variation in width w_3 keeping length l_5 constant

3.2 Antenna-2: cavity-backed antenna with 'L'-shaped slot

Simulation of the parameters of the designed antenna −2 is done using HFSS v15.0. In order to achieve best results for return loss and gain, antenna slot dimensions are amended. The parametric studies for lengths (l_3 and l_4) and width (w_2) of the 'L'-shaped slot are performed, and the resulting plots are shown in Fig. 8. The reflection coefficient is varied with the variation in length l_3 keeping length l_4 and width w_2 fixed as shown in Fig. 8a, while the result of varying length l_4 keeping l_3 and w_2 constant is represented in Fig. 8b. Likewise, Fig. 8c illustrates the width w_2 variation of the slot keeping lengths l_3 and l_4 constant. It is thus clearly seen from the figures that the best-optimized performance of antenna −2 is observed for slot dimensions $l_3 = 24$ mm, $l_4 = 9$ mm and $w_2 = 1$ mm.The simulated return loss (S_{11}) for the resonating frequency of 3.3 GHz for the dominant TE_{101} mode is found to be −29 dB. A close proximity in theoretically calculated and simulated value of resonant frequency is witnessed. For the designed antenna-2, the impedance bandwidth covers a frequency band from 3.29 GHz to 3.31 GHz.

Anritsu make VNA model MS2025B is used to perform the antenna measurements and it is seen that the fabricated antenna displays a return loss of −33 dB at 3.42 GHz. Figure 9 shows the analogy between the simulated and measured return loss for antenna-2 in case of TE_{101} mode; though a slight deviation between them is seen for the same obvious reasons. For Antenna-2, at the fundamental frequency of 3.3 GHz for dominant TE_{101} mode, the electric field and surface current distribution are shown in Fig. 10a and b, respectively. Radiation pattern for Antenna-2 is measured using Hittite HMC-T2100 microwave signal generator (10 MHz–20 GHz) and a Krytar 9000B power meter. Figure 11a shows the plot for simulated and measured electric field radiation pattern. The co-polarized simulated and measured gains for electric field for the fundamental TE_{101} mode obtained are 2.2dBi and 1.9dBi at θ=180°. Similarly, the simulated and measured H-field co-polarized gains are 1.9dBi and 1.7dBi as shown in Fig. 11b. In both cases, the corresponding cross polarized values are found to be 20–30 dBi less than their co-pol counterparts. Hence, the designed antenna-2 at 3.3 GHz depicting gain of approximately 2 dBi can be utilized for safer public communications and other WiMAX-based communication systems.

3.3 Antenna-3: cavity-backed antenna with 'A'-shaped slot

ANSYS make HFSS v15.0 is used for the simulation of the designed antenna-3. To obtain best results for antenna performance in terms of return loss and gain, the dimensions of 'A'-shaped slots are optimized. A complete parametric study is executed by varying the length l_5 and width w_3 of the 'A'-shaped slot. The results of the parametric studies are illustrated in Fig. 12. The length l_5 is varied keeping the width w_3 of slot fixed and the corresponding results are shown in Fig. 12a, whereas Fig. 12b portrays the variation of width w_3 keeping length l_5 constant. Hence, the best-optimized results revealed from figures are obtained for slot length $l_5 = 21$ mm and slot width $w_3 = 1$ mm. The simulated return loss is -32 dB, and the antenna is found to resonate at 3.3 GHz frequency for dominant TE_{101} mode. Hence, the theoretically calculated and simulated values of resonating frequency obtained are almost same. Frequency range from 3.27 GHz–3.34 GHz is the impedance bandwidth coverage for the designed Antenna-3.

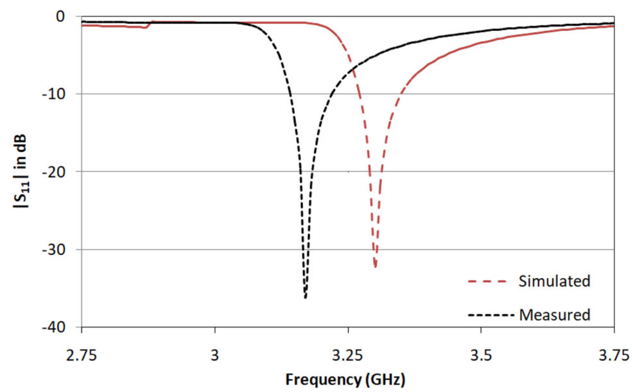

Fig. 13 Simulated and measured values of return loss characteristic of Antenna-3

An antenna measurement for the fabricated antenna is performed using Anritsu make VNA model MS2025B, and the return loss is found to be −36 dB at 3.17 GHz. A relative plot of simulated and measured return loss for antenna-3 is illustrated in Fig. 13. However, modest variation is observed due to material defects and inconsistency in SMA connector mismatching. Figure 14 represents the electric field and surface current distribution for the designed antenna-3 operating at a frequency of 3.3 GHz in TE_{101} dominant mode. Using Hittite HMC-T2100 microwave signal generator (10 MHz–20 GHz) and a Krytar 9000B power meter, the radiation pattern of the antenna-3 is measured. Simulated and measured electric field radiation pattern is plotted, and the result is shown in Fig. 15a. For the fundamental TE_{101} mode, the electric field co-polarized simulated gain obtained is 1.9 dBi, while its measured value is found to be 1.8 dBi at θ=180°. On the other hand, the simulated and measured H-field co-polarized gains are obtained as 1.7 dBi and 1.6 dBi, respectively, as shown in Fig. 15b. It is observed that for both the cases, the corresponding cross-polarized values are found to be 20–30 dBi less than their co-polarized values. Hence, the designed antenna-3 provides a wireless alternative to cable and digital subscriber line (DSL) for "last mile" broadband access at

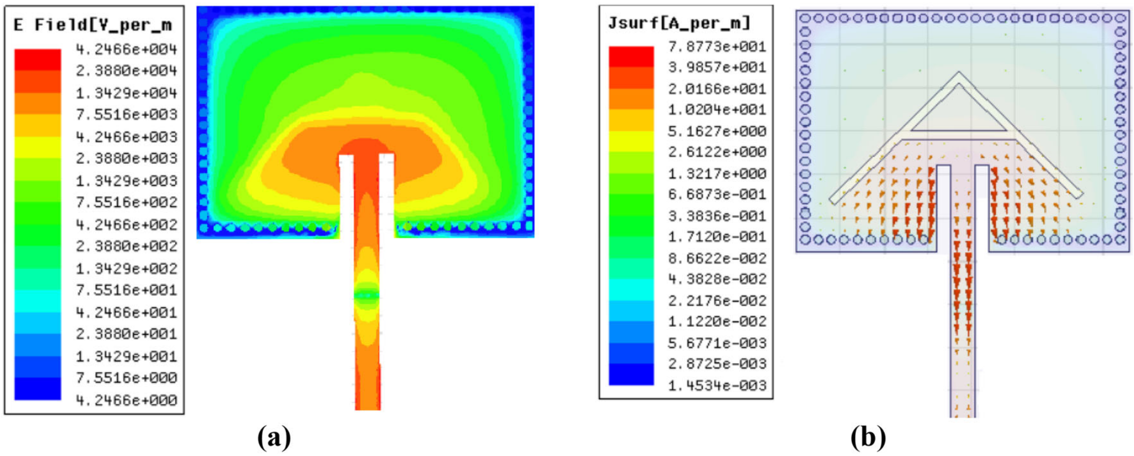

Fig. 14 **a** Electric field distribution and **b** Surface current distribution of Antenna-3

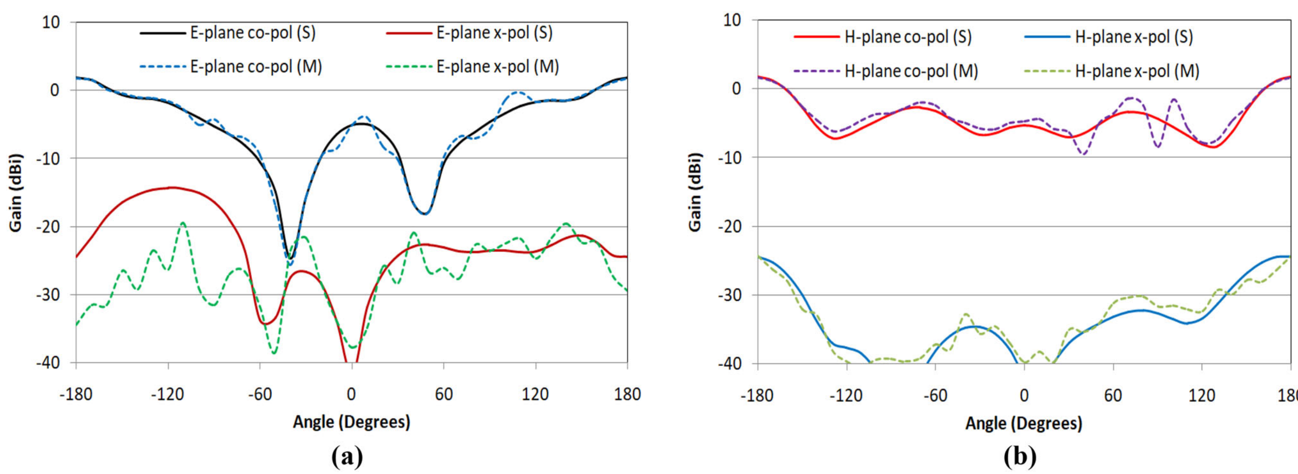

Fig. 15 Simulated (S) and measured (M) radiation pattern of Antenna-3 at 3.3 GHz **a** E-plane and **b** H-plane

the resonating frequency of 3.3 GHz for the TE_{101} dominant mode.

A complete summary of performance characteristics for the three different cavity-backed antennas with slots (Antenna-1, 2 and 3) is enlisted in Table 2. A comparison of the antenna parameters for the proposed rectangular cavity-backed slot antennas with other such types of antennas available in literature is enlisted in Table 3.

The antenna designed in [6] consists of a complex feeding mechanism involving coplanar waveguide and SIW technique, whereas in [11], tapered microstrip feeding is used with the SIW transition making it a complicated design. Also, the SIW vias are filled with copper rivets to electrically short the upper and bottom copper laminations. Authors in [15] have designed a wideband circular SIW cavity-backed slot antenna by placing dielectric resonator on top, but the composite antenna-DR structure requires more volume. The slotted SIW cavity-backed antenna [17] has a major drawback of complex feeding network with diodes for frequency agility reducing its potential for portable use. In [22], a complex folded cavity structure on a textile material is designed, whereas the substrate removal technique to enhance bandwidth in [23] is difficult to implement in different antenna designs. For the planar SIW cavity-backed antenna [33], the concept of meandered and lateral slots was initially used but, then the lateral slots were removed to see the impact on the design of antenna. These drawbacks of complicated slot structure or complex feeding mechanism led to the idea of proposed narrowband antenna design. Since, the proposed antenna is a narrowband, it has high-quality factor and adequate selectivity. The inset feeding mechanism helps in matching the feed line impedance with the patch without the requirement of any additional element. Though the surface wave and spurious radiation increase as the substrate thickness is increased. Also, as per the knowledge of authors, there are very few single-frequency SIW cavity-backed antenna for WiMAX applications.

Table 2 Performance analysis of the three designed rectangular cavity-backed slot antennas

Antenna	Slot type	Freq.(GHz)	S_{11} (dB)		Impedance Bandwidth (GHz)	Co-polarized Gain (dBi)			
						E-Field		H-Field	
			S	M		S	M	S	M
1	I and Inv-U	3.3	− 32	− 35	3.2–3.4	1.8	1.7	1.7	1.6
2	L	3.3	− 29	− 33	3.29–3.31	2.2	1.9	1.9	1.7
3	A	3.3	− 32	− 36	3.27–3.34	1.9	1.8	1.7	1.6

Table 3 Performance analysis of the proposed rectangular cavity-backed slot antennas with that of other similar type antennas

Antenna	Frequency	Substrate details	Return Loss(dB)	Gain(dBi)	Impedance Bandwidth
SIW fed cavity-backed slot antenna [6]	10.2 GHz	Rogers Duroid 5880	Less than − 10 dB	5.4	10.04–10.28 GHz / 240 MHz
SIW cavity-backed patch antenna [11]	10 GHz	Rogers RT Duroid 5880	− 39	8	9.59–10.46 GHz / 870 MHz
Circular SIW cavity-backed slot antenna [15]	5.33 GHz	Arlon AD270	− 28	4.9	5.305–5.355 GHz / 700 MHz
Slotted SIW cavity-backed antenna [17]	2.3 GHz	Rogers	− 33	3.2	100 MHz
Cavity-backed Antenna on textile [22]	2.53 GHz	Flectron	Less than − 10 dB	5.3	155 MHz
Rectangular Cavity-backed slot antenna [23]	2.45 GHz	FR-4 Epoxy	< −10 dB	–	~ 500 MHz
Planar SIW cavity-backed antenna [33]	3.02 GHz (with lateral slot) 5.21 GHz	Duroid 5880	− 25 dB –	9.3 6.12	700 MHz 1400 MHz
Rectangular SIW cavity-backed slot antenna (proposed)	3.3 GHz	FR4 epoxy	− 32	1.8	3.2–3.4 GHz / 200 MHz

4 Conclusion

Inset feed coupled rectangular cavity-backed SIW antennas with different slots are designed to resonate at 3.3 GHz in the WiMAX IEEE 802.16 band. All the antennas are fabricated using FR4 substrate material, and the various antenna parameters are thoroughly investigated. The antennas exhibit compactness with narrow impedance bandwidth and good gain of approximately 2 dBi to be useful for communications at 3.3 GHz WiMAX frequency in Asia–Pacific regions. The same antennas can be modified with alterations of cavity dimensions to resonate at other WiMAX frequencies of 2.3/2.5/3.5/5.8 GHz. A multi-element array can be implemented for application in wider areas. Thus, the present work promises and puts forward many challenges for the research community worldwide to design suitable antennas at WiMAX frequencies for augmenting wireless communications.

Declarations

Conflict of Interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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