Broad-Band I-Shaped SIW Slot Antenna for V-Band Applications

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Abstract **─** In this article, the broad-band SIW slot antenna is proposed for V-band applications, I shaped slot is used in this design and useful for millimeter-wave communication applications. The material used in this design is RT-Duriod 5880 with ε_2=2.2 with a thickness of 0.381mm and copper thickness is 35um. The proposed antenna is designed, simulated, printed and tested. The antenna has an impedance bandwidth of 5.1GHz ranges from 57GHz to 62.1GHz and discusses the parameters like VSWR, radiation patterns, gain. The antenna has validated with comparison of simulation and measured results.

Index Terms **─** Gigabit fidelity (GIFI), millimeter waves (MMWs), substrate integrated waveguide (SIW), system on substrate (SoS), waveguide (WG).

I. INTRODUCTION

The microwave frequency is not sufficient to fulfill the requirements of the present day to day scenario and need to switch next frequency is called millimeter-wave [2, 11] and covers a frequency range from 30 to 300GHz. In the last decade, the trends of the millimeter-waves were rapidly growing due to growth of academia, industry and personal applications. The millimeter wireless communication application is one unlicensed band in the millimeter-wave frequency with 7GHz bandwidth: covers a frequency range 57-64GHz [2, 4-5] and named has 60GHz band for automotive radar applications discussed in [1].

The researchers and academics have more interest in 60GHz band due to its huge availability of bandwidth. The wireless system plays a predominant role in gigabit-fidelity (GiFi) in wireless communication [2]. The 60GHz communication limits its range due to high levels of rain attenuation, oxygen absorption in 60GHz propagation characteristics and it is striking for short range applications [3]. This is also a highly secure and interference free communication due to operating for short range applications.

The high frequency applications, mostly preferred transmission line is SIW [4], one from of substrate integrated circuits (SICs). It has etched two rows of vias connected in top to bottom plane through substrate and also implemented for active, passive components, antenna due to system on substrate (SOS) technology used for development.

The cut off frequency of dielectric filled rectangular waveguide is represented in equation 1.The dominant mode of the rectangular waveguide is TE_{10} and simplified formulae for a width of the rectangular waveguide as mentioned in equation 2:

$$f_c = \frac{c}{2\pi * \varepsilon_r}\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2}, \quad (1)$$

$$a = \frac{c}{2 * f_c * \varepsilon_r}. \quad (2)$$

DFW is filled with two rows of holes is called SIW and their representation as shown in Fig. 1 (c). The standard equation is used to find the width of the SIW is represented in equation 3:

$$a_R = a_S - \frac{d^2}{0.95s}. \quad (3)$$

The diameter of vias (d) and spacing between vias (s) plays very important role in SIW, reduce radiation as well conductor loss. The standard conditions are revealed in equation 4. [5-7]:

$$d \leq \frac{\lambda_g}{5} \quad \text{and} \quad s \leq 2d. \quad (4)$$

The some of the literature discussed has follows, Tomas et al. [6] introduced array based microstrip patch antenna fed by microstrip for high gain applications with 6x8 array. It has an impedance bandwidth of 1.1GHz, gain is 21.6dBi. Shrivastava et al. [7] proposed a SIW feed antipodal linear tapered slot antenna (ALTSA) for millimeter wireless applications that has a resonant frequency of 60GHz with 1.5GHz bandwidth, gain is 16.3dBi and slot loaded with different dielectric shapes for gain improvement; rectangular, triangular, and exponential are reported.

The SIW feed SIW based slot antenna is proposed by Gong and his team [8] for millimeter wireless applications. They are investigated wide width slot to satisfy the operating band of millimeter wireless applications, impedance bandwidth is 3.25GHz and gain is 6dBi. Ramesh et al. [9] introduces a SIW feed exponentially tapered slot antenna for 60GHz applications with a bandwidth of 0.8GHz and gain of 10dBi. The 1x2 array based exponentially tapered slot antenna is invented by Ramesh et al. [10] for V-band

Submitted On: March 13, 2019
Accepted On: May 12, 2019

applications and resonates at 60GHz; impedance bandwidth is 1.3GHz and gain is 11.2dBi.

Yue et al. [11] proposed a slot antenna with CPW to slot transition for polarization reconfigurability. It has 600MHz bandwidth at 2.4GHz and pin diode used to generate two polarizations those are horizontal and vertical polarization. Yui et al. [12] proposed a CPW fed slot antenna for dual polarization, one as 670MHz bandwidth at 2.4GHz and another as 840MHz bandwidth at 2.4GHz. The monopole fed with hybrid slot was presented by Guoping et al. [13] for wireless communication applications. This design has more bandwidth compared to slot, monopole and has a bandwidth of 3.8GHz.

The detail enlargement of the article is as follows. The design appraisal of an antenna, the optimal parameters is used for the design is represented in Section 2. The Section 3 give the clear outline of the generalized antenna parameters and also discuss the comparison of simulation, measurement results. Finally, the conclusion is explored in Section 4 followed by the references.

II. GEOMETRIC CONFIGURATION

The Fig. 1 represents schematic representation of the proposed antenna, length of microstrip is quarter wavelength ($\lambda/4$) and tapering wavelength can be considered any value to improve the performance [15]. The Fig. 1 (a) shows a top view of two antennas, antenna 1 has rectangular slot and indicated with symbol $1. The antenna 2 has shape of I shaped slot, indicated as $2. The width (W3) and length (L3) of the slots are represented below:

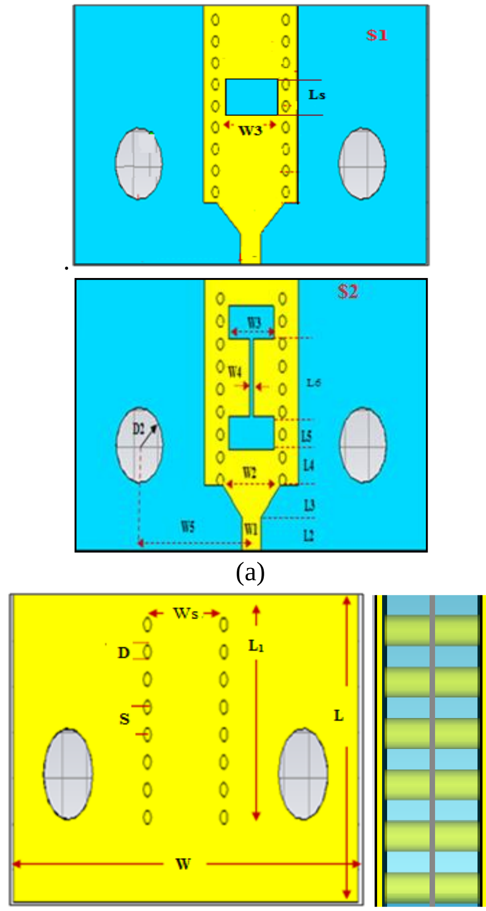
$$\lambda/_4 \leq W_3 \leq \lambda/_2, \quad (5)$$

$$L_s \leq W_3 \, . \quad (6)$$

The rectangular slot achieves a 2.1GHz bandwidth. To improve bandwidth, two parallel rectangular slots are introduced and finally, shape is modified to I shape, indicated as $2. This structure has a bandwidth of 5.1GHz and their design parameters are described in Table 1. The Fig. 1 (b) and Fig. 1 (c) represent the bottom view and side view of an antenna. The material used in this design is Rogers substrate with dielectric value of 2.2 and thickness is 0.381mm.

Table 1: Specifications used for the design

Parameters	Dimensions (mm)	Parameters	Dimension (mm)
W1/W2/W3	0.85/2.4/1.93	L1/L	5.6/7.1
W	14	L2=L3	0.85
W5	4.755	L4/Ls	0.95/1.2
D2/D/S	1/0.3/0.6	L5/L6	0.87/2.02
Ws	2.93	W4	0.15

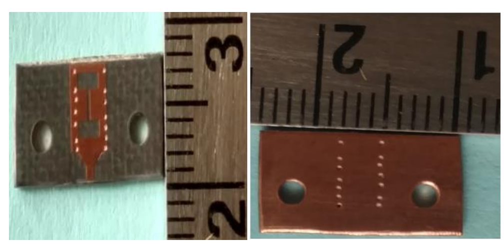


(a)

(b) (c)

Fig. 1. Proposed antenna structure: (a) top view, (b) bottom view, and (c) side view.

The fabricated prototype of a proposed antenna is represented in Fig. 2 and 1.85mm diameter female connector model is used to measure the results. The diameter D_2 in both sides of structure was introduced to hold the connector and is separated by W_5 from the middle of the feed.

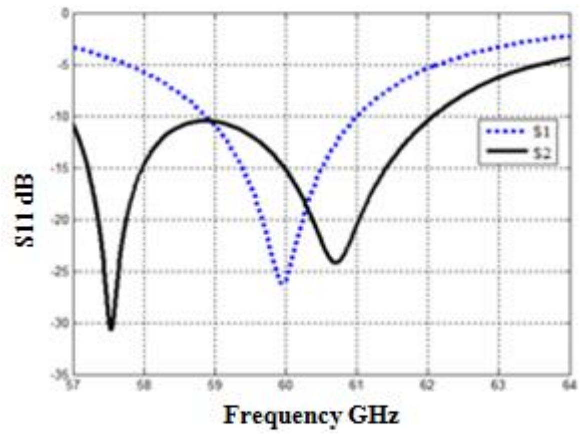


(a) Top view (b) Bottom view

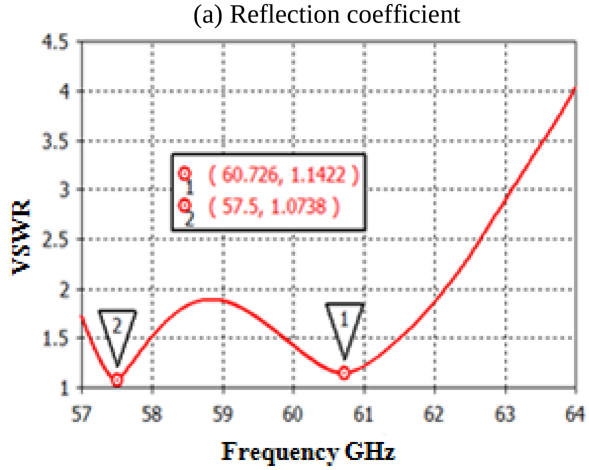
Fig. 2. Fabricated prototype: (a) top view and (b) bottom view.

III. RESULT AND DISCUSSION

The computer simulation technology studio suite software is used to design and simulate the antenna. The simulation results of this design in terms of S_{11} and VSWR is revealed in Fig. 3.



(a) Reflection coefficient



(b) VSWR

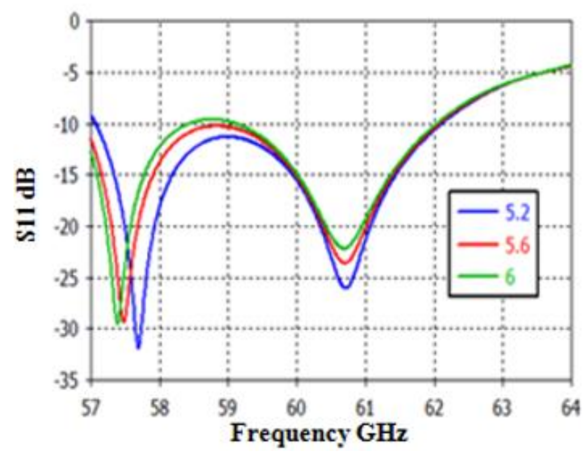
Fig. 3. Simulation results: (a) reflection coefficient and (b) VSWR.

The Fig. 3 (a) represents the reflection coefficient of two antennas, those are rectangular slot and I shaped slot. The antenna 1 ($1) has an impedance bandwidth of 2.1GHz with a resonant frequency of 60GHz and their S_{11} is -31dB. The proper alignment of antenna 2 ($2) that is I shaped slot will produce an impedance bandwidth of 5.1GHz and ranges from 57GHz to 62.1GHz. It resonates 57.493GHz, 60.7GHz frequencies respectively and their reflection coefficient values are -29.137dB, -23.604dB. The main aim is to improve the bandwidth and antenna 2 (I shaped slot) results are discussed in further. The Fig. 3 (b) describes the VSWR of a proposed antenna and it also produces 5.1GHz bandwidth with reference of the VSWR=2 line. The VSWR values are 1.0738 at 57.493GHz and 1.1422 at 60.70GHz.

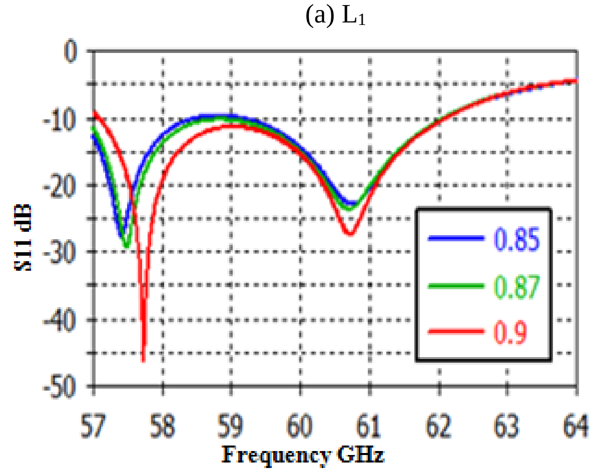
A. Parameter optimization

The Fig. 4 represents the parameter optimization of a proposed design those are SIW length (L_1), slot length (L_5), and the gap between two slots (L_6). The Fig. 4 (a) represented S_{11} for SIW length (L_1) for three values 5.2mm, 5.6mm, 6mm respectively. The change of L_1 will affect the resonant frequency and moves upward to the -10dB reference line. The increasing length will decrease the bandwidth due to moving above the -10dB line. The main aim of the design is to improve the bandwidth and L_1=5.6mm is best optimized parameter compared to another two values.

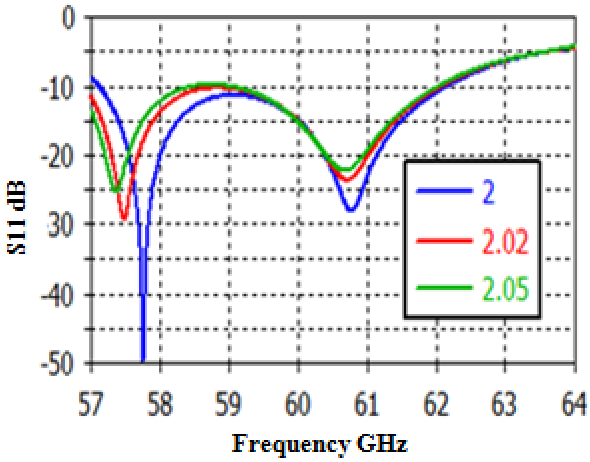
The Fig. 4 (b) represents S_{11} for different values of slot length (L_5) those are 0.85mm, 0.87mm, 0.9mm and their bandwidth are 4GHz, 5.1GHz, 5GHz. Based on the bandwidth, L_5=0.87mm chosen for the design. The S_{11} for different values of L_6 (gap between two rectangular slots) is described in Fig. 4 (c) and three values are considered for analyzation of S_{11} performance and mainly bandwidth is considered for a chosen of L_6 value. The change in L_6 will affect the bandwidth and L_6=2.02mm is chosen for this design and provides the better bandwidth.



(a) L_1



(b) L_5



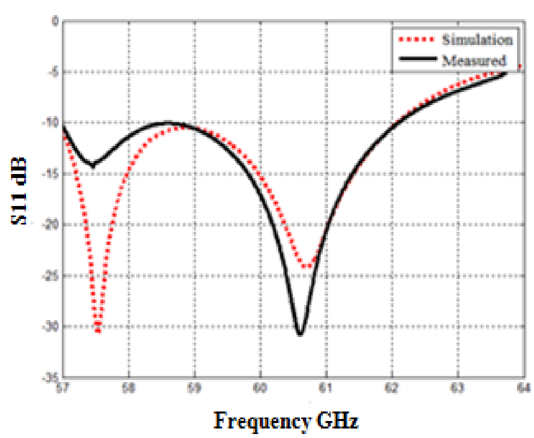
(c) L_6

Fig. 4. Frequency versus S_{11}: (a) L_1, (b) L_5, and (c) L_6.

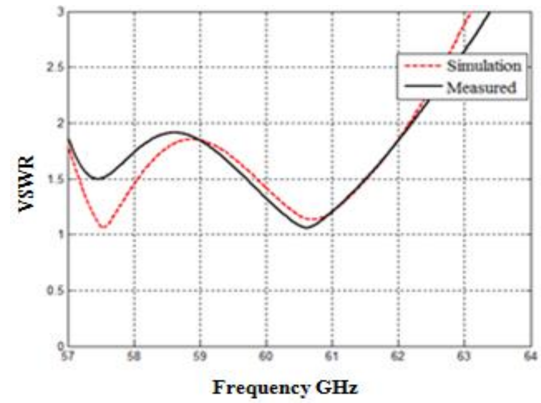
B. Simulation versus measurement results

The comparison of simulated and measured result is represented in Fig. 5 and the Fig. 5 (a) indicate frequency versus S_{11}. The simulation and measurement bandwidth value (5.1GHz) is same but differ resonant frequency values. The Fig. 5 (b) represent VSWR result, match with reflection coefficient and clear differences of simulated, measured results are tabulated in Table 2. Where SR representes simultion results and MR representes meaasurment results.

The radiation pattern at two resonant frequencies (57.5GHz and 60.7GHz) is represented in Fig. 6. The Figs. 6 (a) and 6 (b) describes the E-field, H-field pattern and different colors are used to differentiate the results. The E-field provides bi-directional radiation patterns and H-field provides omini directional pattern. The stable radiation pattern are observed and fit to use in millimeter wireless applications.

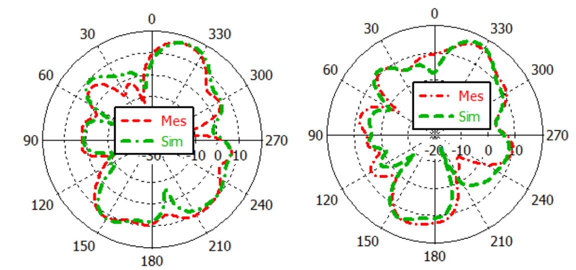


(a) Reflection coefficient



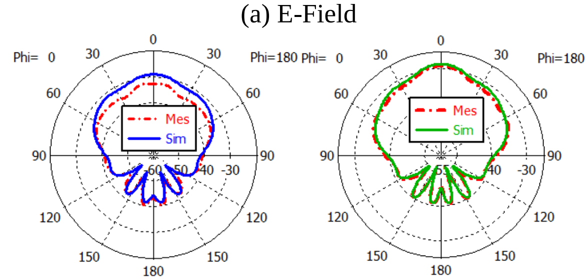
(b) VSWR

Fig. 5. The comparison of simulation and measurement results: (a) reflection coefficent and (b) VSWR.



57.5 GHz 60.7GHz

(a) E-Field



57.5 GHz 60.7GHz

(b) H-Field

Fig. 6. Farfield patterns at resonant frequencies: (a) E-Field and (b) H-Field.

The frequency versus gain (dBi) of a proposed antenna is represented in Fig. 7 and different color lines are used to distinguish the simulation (blue) and measurement (red) results. The close match is observed between simulation, measured results and their values are 7.6dBi, 7.61dBi at 57.5GHz, 9dBi, 8.9dBi at 60GHz and 8.75dBi, 8.65dBi at 60.75GHz. The comparison of existing literature with proposed design is tabulated in the Table 3 and observed that the proposed design as improved bandwidth is around two times with existing literature, size miniaturization and average gain.

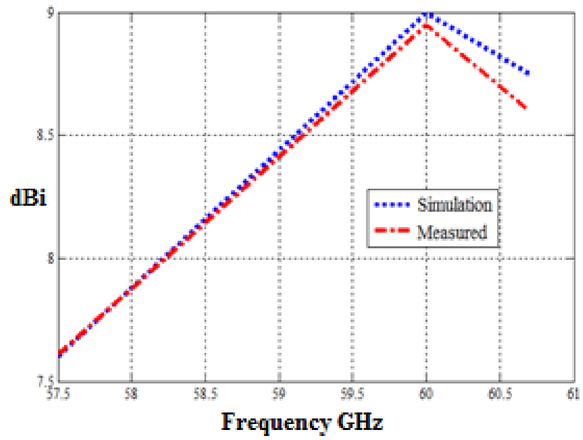


Fig. 7. Frequency vs. gain (dBi).

Figure 8 represents the E-field pattern of two antennas at 60GHz and shows the flow of fields. The efficiencies of this design has been revealed in Fig. 9 with a frequency between 57GHz to 62GHz; observed radiation efficiency is approximately 86% and 82% of transmission efficiency.

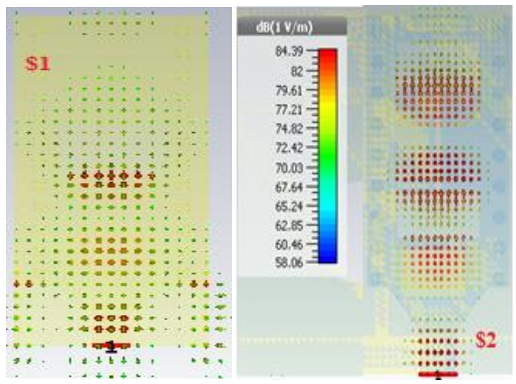


Fig. 8. E-field distribution at 60GHz.

Table 2: Comparision of simulation and measurement

S.No.	Method	Resonant Frequency (GHz)	Reflection Coefficient (dB)	VSWR
1	SR	57.493	-29.173	1.0738
	MR	57.48	-13.99	1.498
2	SR	60.70	-23.604	1.1422
	MR	60.71	-30.75	1.06

Table 3: Comparison with existing literature

S.No.	Ref.	Antenna Size [mm^3]	Substrate used in the Design	Gain (dBi)	Bandwidth (GHz)
1.	[11]	34 x 24.75 x 0.85	Rogers, ε_r =2.2	21.6	1.1
2.	[12]	44.61 x 9.93 x 0.381	Rogers, ε_r =2.2	13.7	3
3.	[13]	25 x 16 x 0.635	Rogers, ε_r =2.2	6	3
4.	[14]	33.5 x 18 x 0.787	Rogers, ε_r =2.2	10	0.8
5.	[15]	35.5 x 18 x 0.787	Rogers, ε_r =2.2	11.2	1.3
6.	**Proposed**	**15 x 10.7 x 0.381**	**Rogers, ε_r =2.2**	**9**	**5.1**

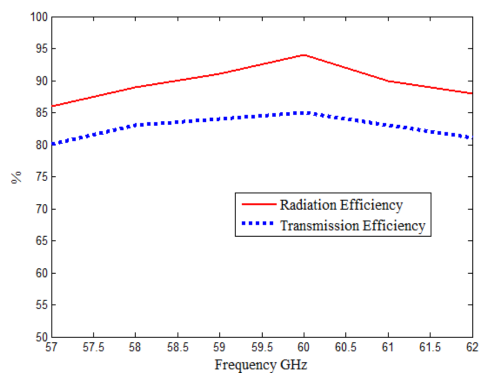


Fig. 9. Efficiencies of an proposed antenna.

IV. CONCLUSION

The I shaped SIW slot antenna has been introduced for millimeter-wave wireless applications and size is 15x10.7x0.381mm. The antenna is designed, simulated by computer simulation technology (CST) studio suite and tested generalized parameters of antenna like reflection coefficient, VSWR, radiation pattern, and gain are discussed. The measured impedance bandwidth is around 5.1GHz ranges from 57.02 to 62.09 GHz and gain at 60GHz is 8.9dBi. The antenna has good agreement between simulation and measurement results. This antenna is suitable for short-range, broadband, high data rate due to its operating frequency and used for applications like WLAN, GIFI, WPAN.

ACKNOWLEDGMENT

The author's now gratitude to MEITY Scheme (Visvesvaraya Ph.D. Fellowship) for their financial support to do the Research work and thanks to Jerald technologies for their measurement support.

REFERENCES

[1] M. N. Kumar and T. Shanmugnantham, "Division shaped SIW slot antenna for millimeter wirelesss/ automotive radar applications," *Journal of Computer and Electrical Engineering*, vol. 71, pp. 667-675, 2018.

[2] S. K. Yong, P. Xia, and A. V. Garcia, *60 GHz Technology for Gbps WLAN and WPAN*, 1st ed., Chichester, UK: John Wiley and Sons Ltd, 2011.

[3] P. Smulders, "Exploiting the 60 GHz band for local wireless multimedia access: Prospects and future directions," *IEEE Communication. Magazine*, vol. 2, no.1, pp 140-147, 2002.

[4] Y. Li and K. M. Luk, "Low cost high gain and broadband substrate integrated waveguide fed patch antenna array for 60GHz band," *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 11, pp. 5531-5538, 2014.

[5] Z. Zhang, X. Cao, J. Gao, S. Li, and J. Han, "Broadband SIW cavity-backed slot antenna for end fire applications," *IEEE Transactions on Antennas and Propagation*, vol. 17, no. 8, pp. 1271-1275, 2018.

[6] T. Mikulasek, J. Lacik, J. Puskely, and Z Raida, "Design of aperture coupled microstrip patch antenna array fed by SIW for 60 GHz band," *IET Microwave Antennas Propagation*, vol. 10, no. 3, pp. 288-292, 2016.

[7] P Shrivastava and T. R. Rao, "60 GHz radio link characteristic studies in hallway environment using antipodal linear tapered slot antenna," *IET Microwave Antennas Propagation*, vol. 9, no. 15, pp. 1793-1802, 2015.

[8] K. Gong, Z. N. Chen, X. Qing, P. Chen, and W. Hong, "Substrate integrated waveguide cavity-backed wide slot antenna for 60GHz bands," *IEEE Transactions on Antennas and Propagation*, vol. 60, no. 12, pp. 6023-6026, 2012.

[9] S. Ramesh and T. R. Rao, "Planar high gain dielectric loaded exponentially TSA for millimeter wave wireless communications," *Wireless Press Communication (Springer)*, pp. 3179-3192, June 2015.

[10] S. Ramesh and T. R. Rao, "High gain dielectric loaded exponentially tapered slot antenna array based on substrate integrated waveguide for V-band wireless communications," *International Journal of Electronics and Communications*, vol. 69, pp. 48-55, 2015.

[11] M. N. Kumar and T. Shanmugnantham, "Design of substrate integrated waveguide back to back π-shaped slot antenna for 60GHz applications," Journal: *Lecturer Notes in Electrical Engineering (Springer)*, pp. 215-224, 2018.

[12] Y. Li, Z. Zhang, W. Chen, and Z. Feng, "Polarization reconfigurable slot antenna with a novel compact CPW-to-slotline transition for WLAN application," *IEEE Antennas Wireless Propagation Letters*, vol. 9, pp. 252-255, 2010.

[13] Y. Li, Z. Zhang, W. Chen, and M. F. Iskander, "A dual-polarization slot antenna using a compact CPW feeding structure," *IEEE Antennas Wireless Propagation Letters*, vol. 9, pp. 191-194, 2010.

[14] G. Pan, Y. Li, Z. Zhang, and Z. Feng, "A compact wideband slot-loop hybrid antenna with a monopole feed," *IEEE Trans. Antennas Propagation*, vol. 62, no. 7, pp. 3864-3868, July 2014.

[15] M. N. Kumar and T. Shanmugnantham, "Broadband H-spaced head shaped slot with SIW based antenna for 60GHz wireless communication applications," *Microwave and Optical Technology Letters*, John Wiley, vol. 61, pp. 1911-1916, Feb. 2019.

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