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Design, Development and Interpretation of FMSIW and HMSIW for K and Ka Band Applications

Cowsigan.S.P, Saraswady.D, Sri Sowbharanya.K.S, Priya Dharshini.V, Pravin Raj.K.S

***Abstract*: The main motive of the miniaturized sensing antennas is low profile, compact square antennas to operate in K and Ka band applications. Since Substrate integrated waveguide (SIW) technology exhibits low copper loss, reduced surface waves and low dielectric loss property it is involved in the design. In this paper, a square waveguide resonator is proposed to covers frequency range of 20 to 45 GHz and the electrical parameters of the antenna like return loss, gain, radiation pattern, and VSWR are investigated. The square resonator has conducting cylinders know as via-holes along the sides of the patch which makes it a good electrical conductor (EC) and from other side a good magnetic conductor (MC). The proposed square resonators contribute to the design of compact structure. The structure of HMSIW has Triple band which has maximum return loss of -20.5 dB at 36.75 GHz whereas FMSIW square shaped antenna has Hepta band maximum return loss of -21.5 dB at 40.5 GHz..**
***Keywords*: Half-Mode SIW (HMSIW), Full-Mode SIW (FMSIW), Flame Redundant Type 4(FR4) Substrate.**

I. INTRODUCTION

In the era of modern science, communication plays a vital role in today's world and at the same time it must be a low band application. It helps people to communicate all over the world through many devices such as mobile phones, laptops etc., Antenna is an important tool in communication engineering. The frequency ranging from 3 KHz to 300 GHz are used for communications or radar signals. It is mainly used in satellite communication and radars. The 5th generation mobile networks are based on the K and Ka band frequency ranging from 18 – 40 GHZ. Substrate integrated waveguide is the technology used for sensing antennas. This global urging technology is used worldwide in different domains.

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* Correspondence Author
Cowsigan.S.P*, ECE department, Pondicherry engineering college, KPR institute of engineering and technology, Coimbatore, India. Email: cowsigan.sp@kpriet.ac.in
Saraswady.D, ECE department, Pondicherry Engineering College, Pondicherry, India. Email: dsaraswady@pec.edu
Sri Sowbharanya.K.S, ECE department, KPR institute of engineering and technology, Coimbatore, India. Email: kssrisowbharanya@gmail.com
Priya dharshini.V, ECE department, KPR institute of engineering and technology, Coimbatore, India. Email: vpriya6251@gmail.com
Pravin Raj.K.S, ECE department, KPR institute of engineering and technology, Coimbatore, India. Email: pravin8499@gmail.com

A. *SIW Technology:*

A new form in transmission line is Substrate Integrated Waveguide (SIW). It represents a very promising and emerging technology for components operating in planar and non-planar region's development. The structures based SIW will bring a revolutionary change in the field of communication. It gives numerous advantages in the electronic components integration on the substrate proceeding to system-on-substrate and system-in-package. A planar antenna comprises simple, low profiles and low fabrication cost, easy integration with planar circuits. They are cheap to manufacture using modern printed circuit technology. The role of bridge is done by SIW between planar (microstrip) and non-planar technologies. This technique is used in various domain such as wireless networks, satellite communication, food processing, medical imaging, radar systems, Nano-technology, biological and medical areas.

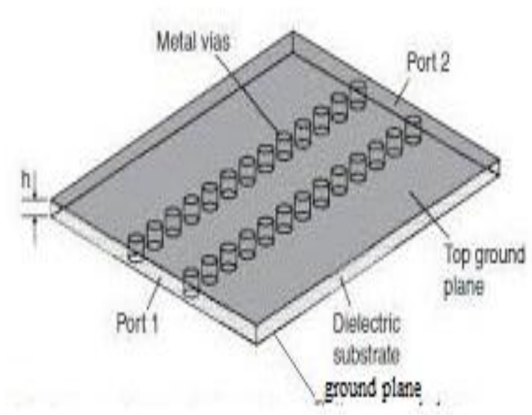

Fig. 1: Substrate integrated waveguide

B. *K And Ka Band*

K band has range of frequency operating from 18 GHz to 27 GHz whereas Ka band has range from 26 GHz to 40 GHz. The Ka band has wide applications in satellite communication transmission, close range targeting radars aboard military airlines, vehicle speed detection for enforcing law. Wavelength range of IEEE Ka band is 1cm-7.5mm. The K band, on the other hand, in microwave domain is used for satellite and radar applications.

K band in infrared domain is used for astronomical purposes. The wavelength range of IEEE K band is 1.67–1.11cm. It is designed as antennas which are compact for K and Ka applications of band. The fundamental frequency is scaled down to 36.8 GHz at Ka band and further scaled down to 26.25 GHz at K band. More bandwidth can be extracted from Ka-band system with a higher frequency, which further causes a data transfer rate which is higher with high performance. The stimulation of Square resonator is done by ANSYS HFSS v19 from which stimulated results are obtained and compared for Full-mode and Half-mode structures.

II. SQUARE SUBSTRATE INTEGRATED WAVEGUIDE

At first, a rectangular SIW resonator in which width and length are designated as W_c and L_c is designed. The substrate SIW resonator's thickness is given by h. S and D are spacing between adjacent vias and via diameter respectively. Later the SIW's width and length are made equal ($W_c = L_c$) for forming a square SIW resonator. The square SIW resonator is developed using FR4 Substrate. It contains two metallic plates in which a dielectric material is sandwiched. The above layer is called patch and the third layer is called ground. There are three main design parameters that needed to be considered namely; the width (W_c) of the SIW, the metallic posts has a distance between them which are commonly called as pitch (p) and diameter (d) of SIW. The metallic vias are constructed using copper on all the sides on the FMSIW and HMSIW square resonator with via diameter and via spacing. Microstrip patch square antenna has various methods of feeding techniques. As these antennas have dielectric substrate with the two edges of the resonator structure are same on both sides and the radiating element on both sides it provides good radiation characteristics.

Table I: Design specifications

S.no	Parameters	Value
1.	Frequency	K & Ka band
2.	Substrate	FR4
3.	Dielectric constant (**ε_r**)	4.3
4.	Loss Tangent (**δ**)	0.025
5.	Dissipation factor	0.020

A. *FMSIW*

FMSIW structure is proposed with following dimensions. The substrate is constructed with same scale of 36mm which is common for both length and width. The substrate's height is 0.508mm. The overall dimension of proposed Full-mode SIW–CB antenna is 36*36*0.508mm^3.The thickness of the copper in patch as well as ground is 0.017mm. The design of patch is in Z-axis. It is further rotated to 45degree. The feed-1 and feed-2 are constructed on the both sides of the patch. The feed-1 is constructed in the position (-1, 32, 0) and feed-2 at (-1,-0.3, 0). The feed-1 and feed-2 are united with the patch as shown in Fig. 2.The vias are constructed with spacing of 2 mm and a diameter of 1mm. The port-1 and port-2 are constructed on both the ends of the feed.

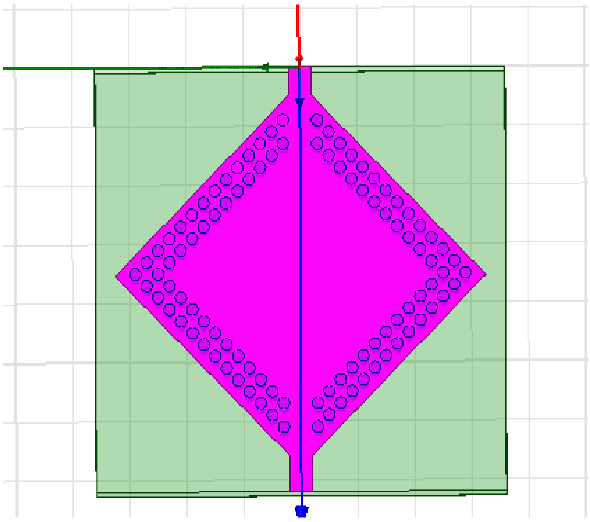

Fig. 2 FMSIW structure

A. *HMSIW*

The FMSIW is divided along the quasi-magnetic wall into two halves; each part of half is called HMSIW which can support nearly half of its original field distribution. The configuration is exactly divided in FMSIW square resonator.

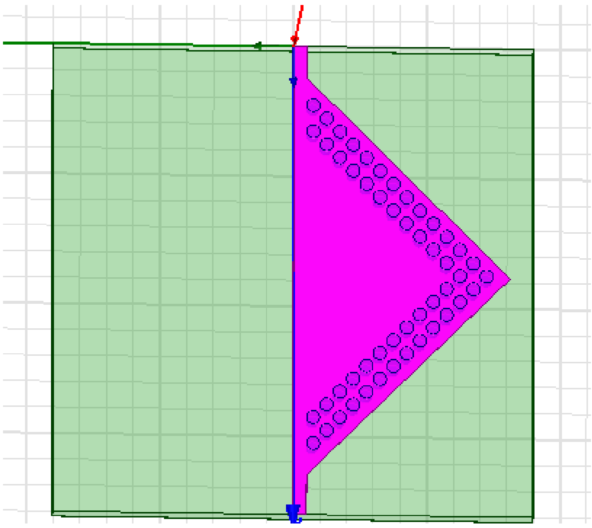

Fig.3 Proposed HMSIW structure

The substrate is constructed with same length and width of 36mm whereas the patch length and width are 18mm each. The height of the substrate is 0.508mm. The overall effective dimension of proposed Half-mode SIW–CB antenna is 18*18*0.508mm^3.The entire patch dimension is effectively halved. The thickness of the copper in patch and ground is 0.017mm. The patch is designed in Z axis. It is further rotated to 45degree. The feed-1 and feed-2 are constructed on the both sides of the patch. The feed-1 is constructed in the position (-1, 32, 0) and feed-2 at (-1,-0.3, 0). After the construction it is exactly dissected into two halves.

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The feed-1 and feed-2 are united with the patch as shown in Fig. 3. The vias are constructed with spacing of 2 mm and a diameter of 1mm

III. HFSS SOFTWARE

The HFSS otherwise called as High Frequency Structure Simulator is one of the commercial tools which is used in designing antenna and also in the complex radio frequency electronic circuit elements. It is a high performance Electromagnetic field source simulator. This device is a 3D volumetric passive modeler. Simulation, visualization, solid modeling and automation are integrated. The typical uses of this HFSS are antenna, mobile communications, waveguide, filters, EMC/EMI, package and PCB board modeling.

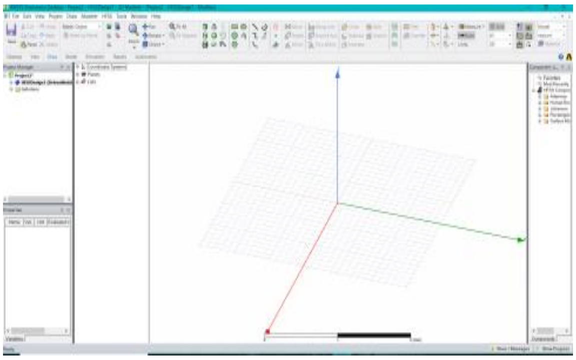

Fig.4 Design window of HFSS software

IV. Simulated Results

The various parameters such as return loss, VSWR, radiation pattern and 3D radiation pattern for FMSIW and HMSIW are obtained.

A. FMSIW Results

The power of the returned signal or a discontinuity which is reflected in a transmission line is called Return loss. Both standing wave ratio (SWR) and reflection coefficient (Γ) are related to Return loss. From the Fig. 5 thereturn loss(S_{11}) are observed to be -12.5 dB at 33 GHz, -20.5 dB at 36.75 GHz and the last resonance occurs at 40.6GHz with a value of -17dB.Hence FMSIW return loss shows a Triple band characteristics.

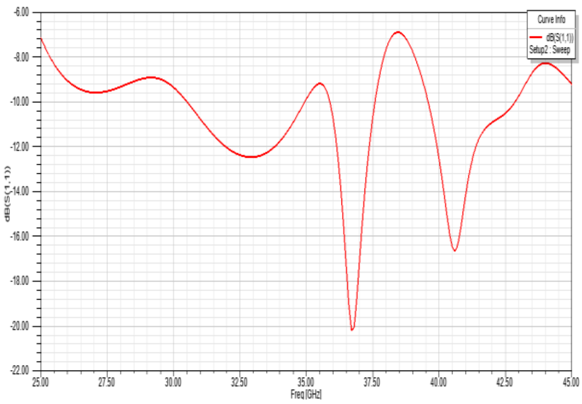

Fig.5 Return loss of FMSIW antenna

VSWR describes standing waves from the antenna, which is a reflection coefficient's function. The VSWR value of 1.20 at 36.8 GHz is considered suitable for antenna applications. The VSWR values for the resonant frequencies are less than 1.6 which is in the acceptable range. VSWR characteristics of the proposed antenna are shown in Fig 6.

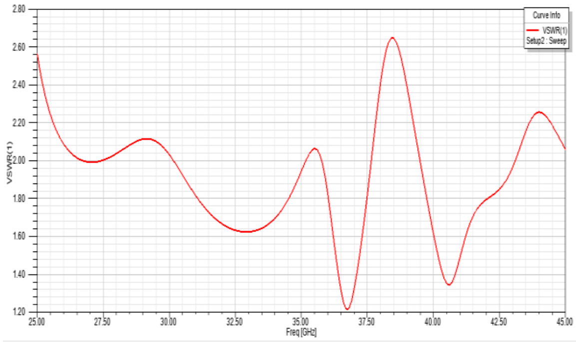

Fig.6 VSWR of FMSIW antenna

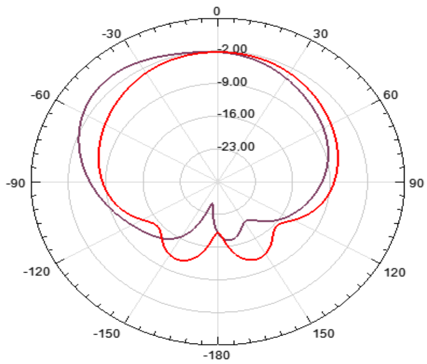

Fig. 7 Radiation Pattern of FMSIW antenna

FMSIW antenna's radiation pattern is broad and also has low radiation power and narrow frequency bandwidth. The radiation pattern is shown in Fig. 7. The antenna shows unidirectional pattern for E- plane and H- plane. In Fig.8 Three-Dimensional radiation pattern is shown. The angle theta is swept to create a planar cut and it is relative to z-axis. The angle Theta is swept from -180 to 180 degrees, whereas the angle Phi is swept from 0 to 360 degrees. The angle Phi is relative to the x-axis.

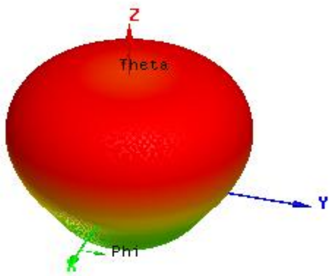

Fig.8 3D Radiation Pattern for FMSIW antenna

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B. HMSIW Results

Return loss of HMSIW shows a Hepta band characteristics. It is observed that simulated result has a maximum return loss of -21.5 db at 40.5 GHz. The other return loss values for the corresponding resonant frequencies are -12.5 dB at 26 GHz, -14.3 dB at 27.8GHz, -19.5dB at 31.2GHz. -19 dB at 36.8 GHz,-18.6 dB at 42 GHz and -18 dB at 44.5 GHz.

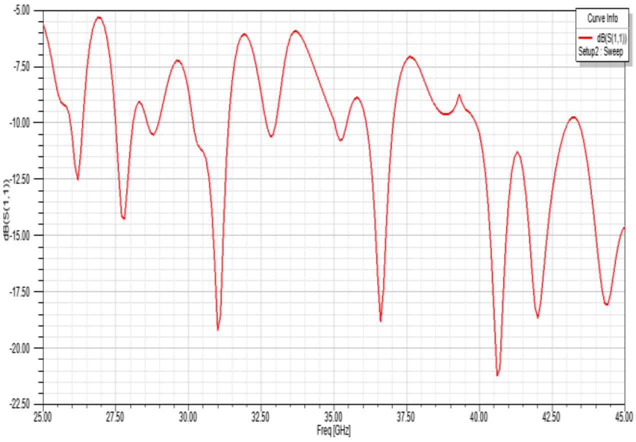

Fig.9 Simulated return loss of HMSIW antenna

VSWR describes the power reflected from the antenna and it depends on Return loss values. The value changes of VSWR at different stages are shown in the Table 2 below. VSWR characteristics show excellent values for the resonant frequencies.

Table II. Freq vs. VSWR

Freq(GHz)	VSWR
26	1.6
27.8	1.5
31.2	1.25
36.8	1.25
40.5	1.2
42	1.25
44.5	1.25

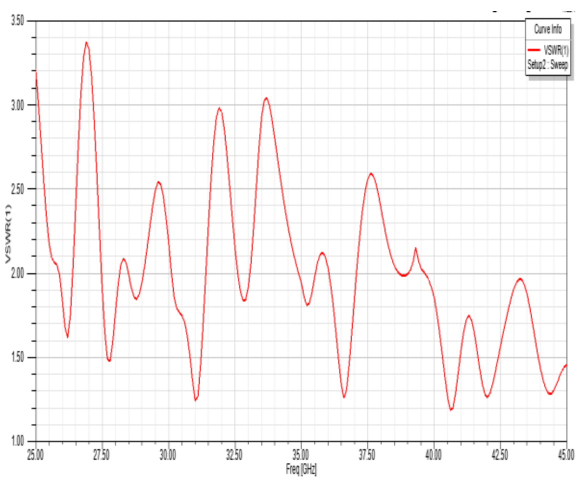

Fig. 10 VSWR of HMSIW antenna

The HMSIW antenna's radiation pattern is shown in Fig. 11. The antenna shows unidirectional pattern for the planes of E and H.

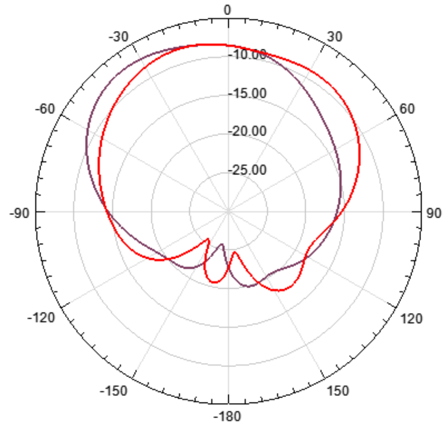

Fig. 11 Radiation Pattern of HMSIW antenna

In Fig.12 Three-Dimensional radiation pattern is shown. The angle Theta is swept to create a planar cut and it is relative to z-axis. The angle Theta is swept from -180 to 180 degrees, whereas the angle Phi is swept from 0 to 360 degrees. The angle Phi is relative to the x-axis.

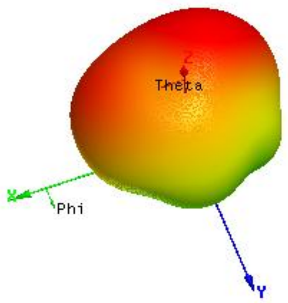

Fig. 12 3D Radiation Pattern for HMSIW antenna

V. CONCLUSION

The compact FMSIW and HMSIW based square antennas are structured, designed, simulated, analyzed and compared to sensing elements' act for K band and Ka band application. A systematic investigation on square resonator has been carried to examine different antenna parameters. The benefits of SIW technology have been combined with FR4 substrate to produce Triple band and Hepta band characteristics for FMSIW and HMSIW antenna respectively. The simulated results exhibit attractive and promising values to operate in K and Ka band of 18 - 40 GHz with expected radiation characteristics.

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AUTHORS PROFILE

S.P.Cowsigan received his M.Tech degree in Electronics and Communication from Pondicherry Engineering College, Pondicherry University, Pondicherry in the year 2012. He completed his B.Tech degree in Electronics and Communication Engineering in Pondicherry Engineering College, Pondicherry in the year 2007. He is pursuing Ph.D in Pondicherry Engineering College from Jan 2016 in the Microstrip (SIW) antenna domain. His research interests include Antenna, Microstrip antenna, SIW Technology, Ultra Wide Band Communication, Omni-directional antennas and high performance directional antennas. He is currently working as Assistant Professor (Sr.G) in the Department of Electronics and Communication Engineering, KPRIET, Coimbatore. He is having 7.5 years of teaching experience in various engineering colleges across tamilnadu. He is also having 1.6 years of Industrial experience in Patni Computer Systems Ltd., Mumbai. He has published 8 papers in International Journals, 9 papers in International and National Conferences. He is Life member of EMIC, IAENG and IRED.

D. Saraswady received her Doctor of Philosophy (Ph.D) from Anna University, Chennai in the Year 2008. She completed her M.Tech degree in Electronics and Communication from Pondicherry Engineering College, Pondicherry University, Pondicherry in the Year 1994 and completed her B.Tech degree in Electronics and Communication Engineering in Pondicherry Engineering College, Pondicherry in the Year 1992. She is currently working as Professor in the Department of Electronics and Communication Engineering, Pondicherry Engineering College, Pondicherry University, Pondicherry. She is having more than 24 years of teaching experience. Her research interests include Special Communication Networks, High Performance Networks, Antenna and Cognitive Radio Networks. She is presently guiding 4 scholars and guided 5 researchers previously. She has published more than 28 Research articles. She is a Life member of ISTE, IAENG and IRED.

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Ms. Sri Sowbharanya .K.S. comes from India and pursuing her B.E degree in Electronics and Communication engineering. She is currently a student in KPR institute of engineering and technology. She is graduating in 2021. Her research work is based on antenna and microwave design based on k-band and Ka-band applications and finding the electrical parameters for the following applications. She is the current member of IETE.

Ms. Priya Dharshini V is an undergraduate student in the department of Electronics and communication engineering at KPR Institute of Engineering and Technology and will be graduating in 2021. She is now working as a designer as an assistant in a private company. Her research interface incorporates the field of radio wire application and computer field.

Mr. K.S.Pravin Raj pursuing his undergraduate degree in Electronics and Communication Engineering. He is a student in KPR institute of Engineering and Technology. He has done a mini project “Smart drip irrigation system” based on IOT which provides irrigation whenever the field gets dry, the dryness can be sensed by sensors provided in that field. After dryness detected, it sends notification to application installed in mobile through Wi-Fi module. Through mobile the required field can be irrigated. It can be accessed from any irrespective distance with internet through mobile phone. Currently he is doing research in antenna design. He is now working as research trainee in a private sector