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A Review on Design of SIW Antenna array

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ABSTRACT: Micro Strip antennas have limitations such as Lower gain, Narrow bandwidth, Low power handling capacity. Its Structure radiates from feeds and junction points. Similar propagation characteristics such as field pattern and dispersion characteristic can be achieved from SIW antenna with slight modification in conventional rectangular waveguide. Substrate integrated waveguide (SIW) structure constitutes of two parallel conducting plates connected by two rows of metallic posts. Metallic ground planes are added to the top and bottom of a dielectric substrate to create Integrated waveguide-like and planar structure. The top and bottom ground planes are connected by two periodic rows of metallic vias or slots.

In contrary to non-planar rectangular waveguides, SIW has planar structure and hence can be fabricated using planar processing techniques. The new SIW structure can be used to design and fabricate various antennas such as slotted SIW antennas, leaky-wave SIW antennas, cavity-backed SIW antennas and SIW horn antennas. The SIW antenna can operate at high frequency. All components including active and passive components as well as antennas on the same substrate. The limitations microstrip antennas are overcome by Surface Integrated waveguide as this antenna results in high quality factor, high power handling capabilities, and self-consistent electrical shielding. As literature review various papers on SIW antenna design are studied and their parameters are compared.

I. INTRODUCTION

In this review paper various substrate integrated waveguide (SIW) fed antenna designs are summarised and modification in SIW antennas for improving gain are presented. Initially the SIW antenna design parameters are discussed. Later in section III The Design of High Gain Substrate Integrated Waveguide Antennas" by Caroline Sebastian. [1] In this section the design and implementation of circularly polarized substrate integrated waveguide (SIW) antenna in X Band is reviewed. In section IV design of SIW slot antenna for circular polarisation and its simulation results are reviewed. In section V and VI the paper Design and analysis of new substrate integrated waveguide resonance antennas by Mohammad Majedi [2] is summarised. An open-ended substrate integrated waveguide (SIW) resonator antenna is designed and analysed. The open-ended SIW resonator is analysed using two different methods. In the first method the waveguide concept and in the second method the transmission line (TL) based metamaterials concepts are used.

II. SURFACE INTEGRATED WAVEGUIDE (SIW) ANTENNA DESIGN

The surface integrated waveguide antenna design parameters are as below.

Basic Parameter to design SIW.

- Width of the waveguide (a)
- Diameter of metallic vias (d)
- Distance between two consecutive vias (p)
- Height of dielectric substrate (h)

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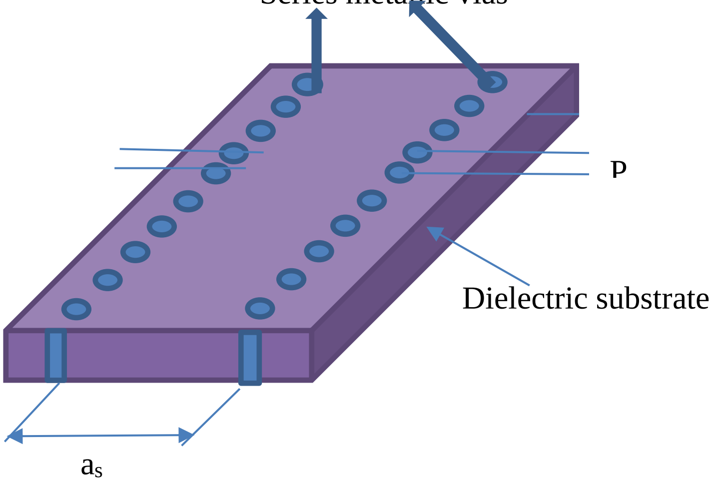


Fig. 1. SIW antenna design

SIW devices is a form of dielectric filled waveguide (DFW), For TE_{10} mode, the dimension "b" is immaterial as it does not affect the cut off frequency of the waveguide. Therefore, the substrate thickness is immaterial. It only affects the dielectric loss. If substrate is thicker loss will be lower.

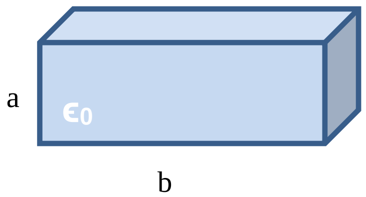


Fig. 2: Dimension definition of rectangular waveguide

For a rectangular waveguide, cut off frequency of arbitrary mode is calculated as:

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

Where c is speed of light, m, n are mode numbers, a, b are dimensions of the waveguide.

For TE_{10} mode, the simplified formula of f_c is as below.

$$f_c = \frac{c}{2a}$$

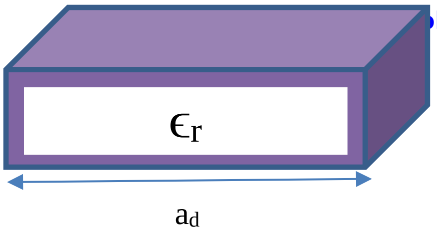
For Dielectric Filled Wave Guide with same cut off frequency, dimension a_d is:

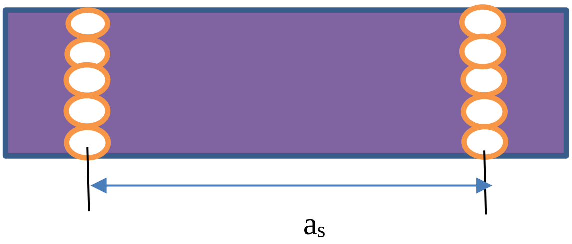
$$a_d = a / \sqrt{\epsilon_R}$$

Having determined the dimension "a" for the Dielectric Filled Wave Guide, we can now pass to the design equations for SIW.

$$a_s = a_d + d^2/.95p$$

- where d is the diameter of the via & p is the pitch i.e., distance between the vias.





- The two conditions are

  P<2d
- Where guided wavelength is:

$$\lambda_g = \frac{2\pi}{\sqrt{\frac{\varepsilon_R (2\pi f)^2}{c^2} - \left(\frac{\pi}{a}\right)^2}}$$

III. THE DESIGN OF HIGH GAIN SUBSTRATE INTEGRATED WAVEGUIDE ANTENNAS BY CAROLINE SEBASTIAN [1]

The design and implementation of circularly polarized substrate integrated waveguide (SIW) antenna in X Band is explained in this section.

The SIW antennas are used for the transmission and reception of electromagnetic energy. The design techniques used in this method for SIW with slots and the integration with microstrip. This achieves the broad perspective of the SIW in circular polarization. After simulation in HFSS Software it is observed that gain has increased in SIW structure with slots for circular polarization as compared to SIW structure without slots.

The transmission of electromagnetic energy is carried out normally by two conductor lines such as parallel line, coaxial cables and two wire cables. When the energy travel through normal electrical wire results in great losses such as radiation loss, copper loss, dielectric loss and skin effect. Also, it is difficult to interconnect the transmission lines with the planar circuits due to its non-planar nature. Hence Waveguides are the best option for the transmission of electromagnetic energy in comparison with transmission lines. Since waveguides are non-planar and bulky, SIW can be an option for the transmission of the electromagnetic energy. It has the advantages of conventional waveguides such as high-power handling capability and high-quality factor. In the transmission line the wavelength of the signal in the transmission line is comparable to the transverse size of the line so maxima and minima are occurred in transmission lines.
Substrate integrated waveguide (SIW) is a form of transmission line which permits a non-planar arrangement of an antenna converted into a planar form by compacting it on a single substrate. This results in a structure called SIW and this technique is used to make the planar rectangular waveguide. SIW is designed by same method discussed in section I. It has advantage of both microstrip and waveguide. Advantages of microstrip are compact dimensions and laid-back

integration. Advantage of waveguide is low radiation loss, and can lead to well-organized microwave circuits and antennas. Communication systems make use of either linear (vertical or horizontal) or circular polarization.

MICROSTRIP TRANSISTION to WAVE GUIDE: The design of the SIW structure in planar circuits has to integrate with conventional transmission lines such as microstrip line. The portion of radiating surface in the microstrip line is made taper with the SIW structure for the proper impedance matching. Thus, the design of SIW with microstrip is needed. The width to height ratio of the microstrip antenna is Wt / Ag = 0.4. The tapering is done to achieve connection with microstrip width to waveguide width. Also, the wavelength of waveguide and cut-off wavelength is related as

$\lambda c = c / fc \quad \& \ \lambda g = \lambda c / \sqrt{€_r}$

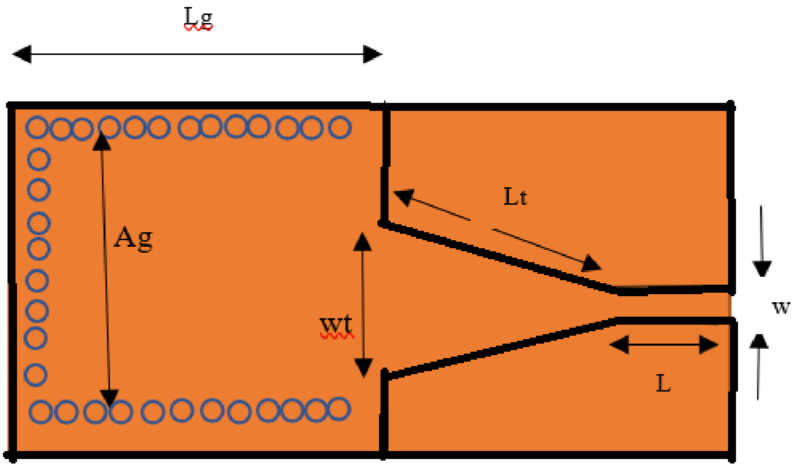


Fig. 3 Microstrip transition to the waveguide

IV. DESIGN OF SIW SLOTTED ANTENNA FOR CIRCULAR POLARISATION [1]

For achieving circular polarisation in X band applications slotted SIW structure is designed and simulated. The length of slots is calculated as

$$L = \lambda 0 / \sqrt{2(€_r+1)}$$

The length from the wall of waveguide to centre of slot is considered as $\lambda g / 4$ and distance between the slots is taken as $\lambda g / 2$. Using this equation, the dimensions of slots can be obtained for antenna design with circular polarization. The design shows good properties if the reflection coefficient is less than -15 db. The width of conventional waveguide is used as 18.71mm.

SIW parameters and its microstrip transition:

wt	W	Lt	λc	$€_r$	λg	Ag
7.5	3.23	18.75	37.5	4.4	17.88	18.75

In the design parameters of SIW and its microstrip transition the length is indicated in millimetre and frequency is indicated in GHz. Fig. 4 shows the simulation result for SIW in circular polarization. Fig. 5 shows E- field pattern

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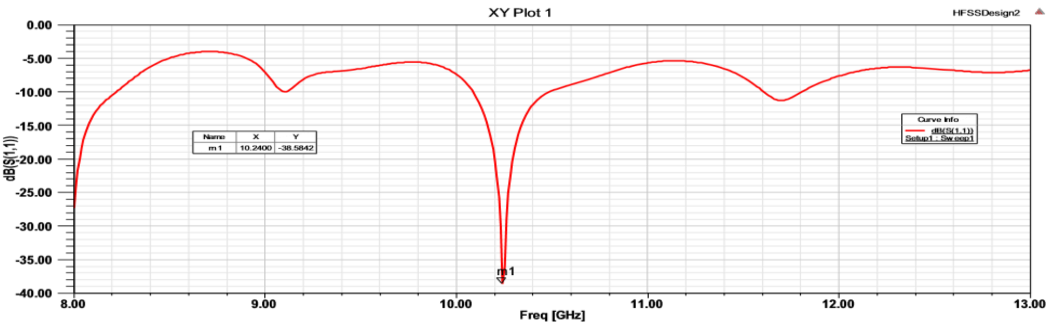

Fig. 4 The graph showing reflection coefficient and frequency of SIW structure without slots

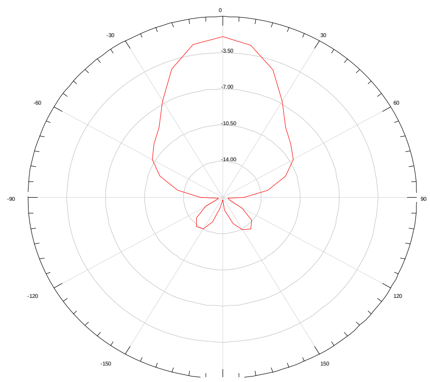

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Fig. 5 The radiation pattern of SIW antenna without slots

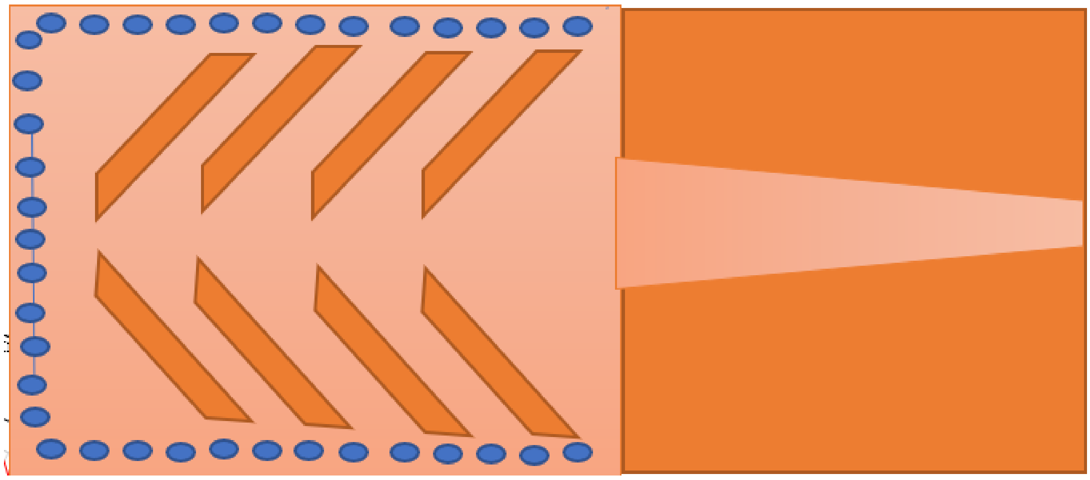

Fig. 6 Structure of SIW antenna with slots

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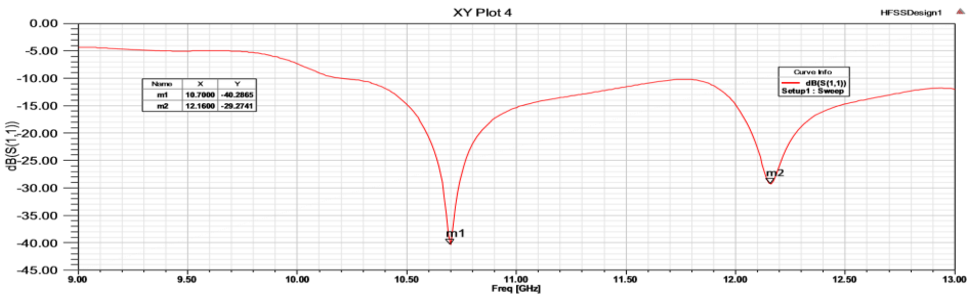

Fig. 7 The graph showing reflection coefficient and frequency in the circular polarisation

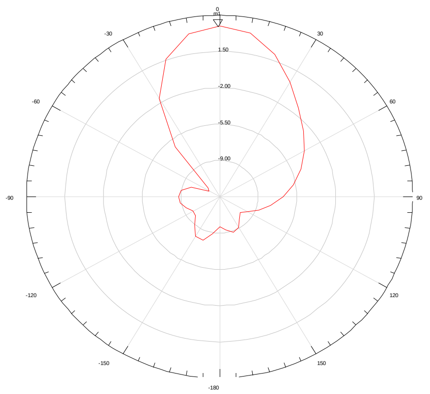

Fig.8 SIW antenna radiation pattern with slots in the circular polarisation

The SIW and its microstrip tapering is achieved in the X Band as above. From the results of simulation of SIW and its microstrip interconnect, the reflection coefficients are below -15 dB i.e., -38.58 at 10.24 GHz which is in X Band. resonating frequencies are 10.70 GHz and 12.16 GHz and reflection coefficient of -40.28 dB and -29.27 dB respectively ar achieved after making inclined slots in SIW. So, the gain value of 4.0025 is achieved after making slots in SIW structure.

V. HMSIW (HALF MODE SUBSTRATE INTEGRATED WAVEGUIDE) RESONANCE ANTENNAS DESIGN AND SIMULATION: BY MOHAMMAD SAEED MAJEDI. [2]

In this paper the antennas using an open-ended substrate integrated waveguide (SIW) resonator are designed and the open-ended SIW resonator is analysed using two different approaches waveguide theory and the transmission line (TL) based metamaterials theory. Two different antennas using the SIW resonator are designed and simulated. The first antenna operates at the first order resonance mode of the resonator. The operating frequency of this antenna is 8.33 GHz, bandwidth of this antenna is 1.9%, maximum gain of this antenna is 7.3 dBi and radiation efficiency of this antenna is 94%. The second antenna operates at the zeroth order resonance mode of the resonator which has a half mode substrate integrated waveguide (HMSIW) structure. Its operating frequency is 5.72 GHz, bandwidth is 1.2%, maximum gain is 4.2 dBi and radiation efficiency is 95%. The presented antennas have advantages of low profile, easy fabrication, easy integration with other circuits and high efficiency.

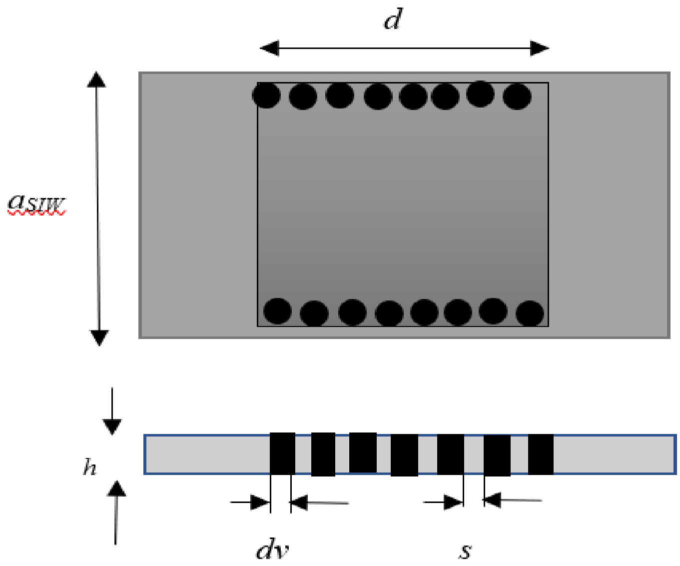

Fig. 9. top view and side view of an open-ended SIW resonator (a)

SIW structure is designed by drilling two rows of metallic posts in between two connected parallel conducting plates. SIW has planar structure and hence can be fabricated using planar processing techniques which is not possible in non-planar structure. Using this new structure slotted SIW antennas and leaky-wave SIW antennas are designed and fabricated. Structure is made compact by using Half-mode substrate-integrated waveguide (HMSIW) and 50 % size reduction is achieved. In this method it is assumed that the vertical cut of the waveguide acts as a virtual magnetic wall. Transmission line includes a series inductor and a parallel LC resonator. After simulation it is proved that at low frequencies the effective permeability of this Transmission Line is negative, at medium frequency it is zero and at high frequencies it is positive.

In this paper two open-ended SIW resonator antennas are demonstrated. This resonator is analysed using two methods. The first method results in electric and magnetic fields intensity relations in the resonator as well as the resonance frequencies of different modes. In the second method TL based metamaterials concept is used. In this method the SIW structure is considered as an ENG TL. Using this method in later part resonance modes and their frequencies are obtained. Two typical antennas are designed and simulated with the technique of an open-ended SIW resonator. The first antenna is designed at the first order resonance frequency of the resonator. The HMSIW antenna operates at the zeroth order resonance frequency. These antennas radiate from their open walls. Both antennas have high efficiency with broadside radiation patterns.

SIW open-ended resonator

The configuration of an open-ended SIW resonator in direction of *y*-axis is shown in Fig. 1. In the next two sections this resonator using two different methods are analysed.

A. Resonator analysis using Waveguides theory

In this section, relations of the electric and magnetic fields intensity in the resonator for different modes are studied. The SIW structure shown in Fig. .9 is equivalent to a waveguide structure with the same length (*d*), the same height (*h*) and the following width $a = a_{SIW} - (dv^2 / .95s)$.

In this way the structure is analysed as an open-ended waveguide structure with dimensions of $a \times d \times h$. Because of low thickness, the electric field is nearly normal to the surface of the patch and hence only TM^z modes with no variation

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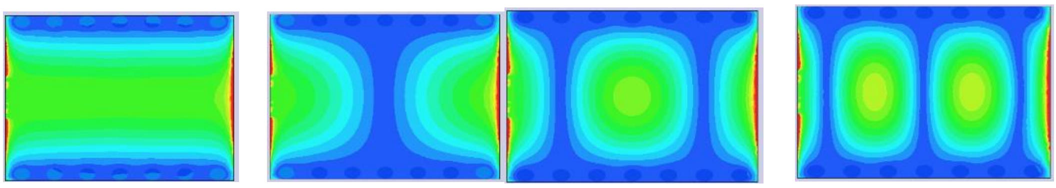
along the z axis will be considered. Similar to the microstrip structures, the open-ended walls of the waveguide resonator at $y = 0$ and $y = d$ can be modelled by perfect magnetic conducting (PMC) surfaces. The two other side walls of this resonator are considered as perfect electric conducting (PEC) surfaces.

For simulation an open-ended SIW resonator following sizes are taken.

a_{SIW} = 12.5 mm and d = 14 mm on a Taconic RF-35 substrate with dielectric constant of $\varepsilon_r = 3.5$ and height of h = 1.524. The via holes diameter is 1 mm and distance between them is s = 2 mm. This resonator is simulated using HFSS. The input impedance of the resonator is as shown in Fig. 2. In this Fig., the resonance frequency of different modes are shown. The resonance frequency is defined as the frequency where the input resistance reaches maximum. Magnitude of the electric field intensity in the resonator for the first four modes is shown in Fig. 10. Table I shows comparison between the resonance frequencies of the first four modes of the resonator obtained by HFSS simulation.



a b c d

Fig. 10. Magnitude of electric field intensity in the resonator for TM_{100}, TM_{110} ,TM_{120} and TM_{130} modes.

TABLE I. Theoretical and simulated resonance frequencies of the first four modes of the resonator

Mnl	**f_{mnl} (GHz) by eq. 4**	**f_{mnl} (GHz) HFSS simulation**
100	**6.70**	**6.68**
110	**8.81**	**8.44**
120	**13.27**	**12.12**
130	**18.44**	**16.38**

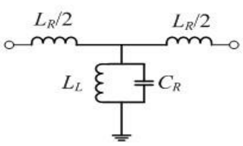


Fig. 11. Equivalent circuit model of an ENG TL unit cell

As can be seen, in this resonator contrary to the conventional waveguide resonators, there is a TM_{100}^z mode with no field variation along the y axis.

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Antenna design and simulation:

A. SIW first order resonator antenna

Configuration and dimensions of the presented antenna is shown in Fig. 6. A proximity coupling is used to match the antenna to a 50 Ω microstrip line. The open-ended walls of the antenna act as radiating elements. The equivalent magnetic currents at these radiating walls are

TABLE II. Theorical And Simulated Resonance Frequencies Of

The First Four Modes of The Resonator

Resonance mode	**f_r (GHz) Eq. (10)**	f_r (GHz) HFSS simulation
Zeroth order	6.73	6.68
First order	8.52	8.44
Second order	12.29	12.12
Third order	16.47	16.38

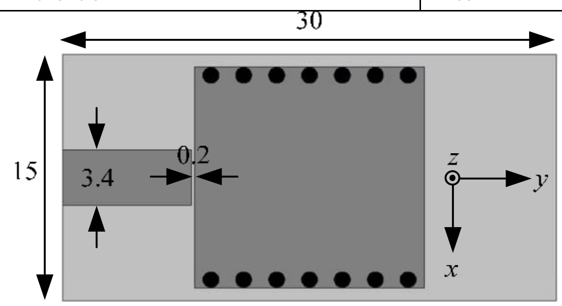

Fig. 12. Configuration of the presented antenna (dimensions are in mm)

The radiation pattern of this antenna is similar to the conventional microstrip antennas. For TM_{100} or zeroth order resonance mode, the equivalent magnetic currents are in opposite directions and the radiated fields cancel each other at *xz* plane.

In this antenna the TME_{110} or the first order resonance mode is used and the equivalent magnetic currents are in the same direction. This antenna produces a broadside radiation pattern with *y*-directed polarization.

SIW structure contain conducting walls in the form of vias due to which the ground plane size of the antenna can be reduced and hence the overall size of the antenna is smaller than the conventional microstrip antennas.

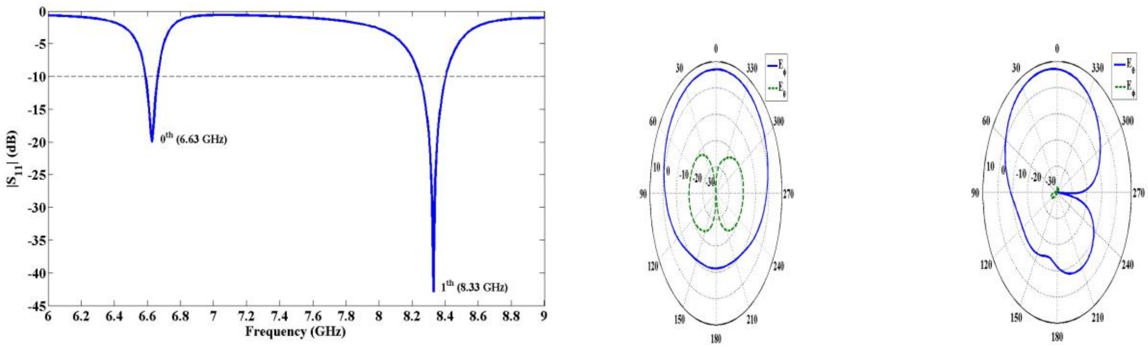

Fig. 13. Radiation patterns of the SIW first order resonator antenna (a) *xz* plane (b) *yz* plane

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The centre frequency and -10 dB bandwidth of this antenna are 8.33 GHz and 1.9% respectively. The radiation patterns of the antenna are shown in Fig. 13. The maximum antenna gain is 7.3 dBi and its radiation efficiency at the centre frequency is 94 %.

• VI. HMSIW ZEROTH ORDER RESONATOR ANTENNA

Configuration of the antenna is shown in Fig. 14 has a HMSIW (half mode substrate integrated waveguide) structure and operates in the TM_{100} or the zeroth order resonance mode. The antenna is fed through a proximity coupling.

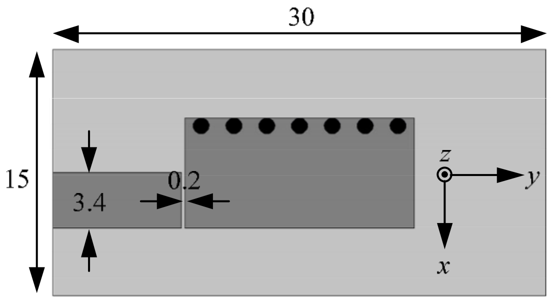
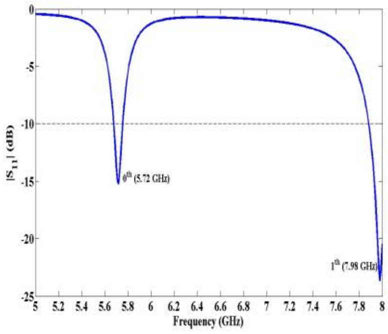
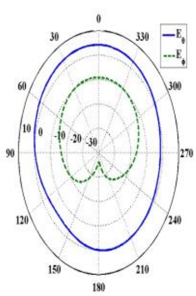


Fig. 14. Configuration of the presented antenna (dimensions are in mm)

The equivalent magnetic currents at the *x*-directed edges are in opposite directions and their radiated fields cancel each other at *xz* plane. Hence, the open *y*-directed edge acts as the main radiating element and produces a broadside radiation pattern with *x*-directed polarization.
Because of using HMSIW structure and also operating at zeroth order resonance mode, this antenna has more compact size compared to the previous one.
The S_{11} parameter of this antenna is shown in Fig. 10. The operating frequency and -10 dB bandwidth of this antenna are 5.72 GHz and 1.2%, respectively. Due to existence of the fringing field at the open sided wall, the resonance frequencies of this antenna are lower compared to the previous one. The radiation patterns of the antenna are shown in Fig. 11. The maximum antenna gain and its radiation efficiency at the centre frequency are 4.2 dBi and 95% respectively. As it is expected, the cross-polarization level of this antenna, which results from open *x*-directed edges, is higher than that of the previous antenna.
It should be noted that the structure of this antenna is similar to the shorted microstrip patch, however it was designed and analysed with a completely different approach.





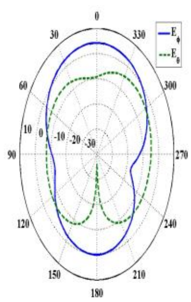


Fig. 15. S_{11} parameter of the HMSIW zeroth order resonator antenna

(a) (b)

Fig. 16. Radiation patterns of HMSIW zeroth order resonator antenna (a) *xz* plane (b) *yz* plane

In table III the simulated characteristics of the two presented antennas are summarized.

Antenna	f_0 (GHz)	Antenna size	-10 dB BW	Max Gain (dBi)	Efficiency (%)	Max X-Pol.
SIW first order resonance	8.33	13.5 mm × 14 mm	1.9%	7.3	94	-18.9
HMSIW 0^{th} order resonance	5.72	6.75 mm × 14 mm	1.2%	4.2	95	-3.5

TABLE III. **Characteristics of The Designed and Simulated** Antennas

VII CONCLUSION

The two new SIW resonance antennas are designed and analysed on the basis of an open ended SIW resonator. This resonator is analysed using the conventional waveguide theory as well as the TL based metamaterials theory. The first antenna operates at the first order resonance mode and its radiation pattern is broadside. In comparison to the conventional microstrip antenna that requires a large ground plane, the overall size of this antenna is smaller and also it provides lower cross polarization level. These results are due to the existence of conducting walls in the SIW structure. The second antenna which has HMSIW structure operates at zeroth order resonance mode. The footprint of this antenna is reduced about 56% compared to the first antenna. These antennas have low profile, high efficiency and they are easy to fabricate.

Table IV: Summary of slotted and unslotted SIW antennas.

Type of SIW antenna /Design methodology	**f_0 (GHz)**	**Antenna size**	**Reflection coeff. below -10 dB**
Unslotted antenna	**10.24 GHz (X Band)**	**Unslotted antenna**	**-15 dB**
SIW and its microstrip tapering	**resonates in 2 freq. of 10.70 GHz and 12.16GHz**	**Slotted antenna**	**-40.2865 dB and -29.2741 dB**

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Table V: SIW - Open-Ended Resonator

Type of SIW antenna /Design methodology	f_0 (GHz)	Antenna size	-10 dB BW	Max gain
SIW first order resonance antenna	8.33	13.5 mm × 14 mm	1.9%	7.3
HMSIW zeroth order resonance antenna	5.72	6.75 mm × 14 mm	1.2%	4.2

Thus, the SIW and its microstrip tapering is done in the X Band. From the results of simulation of SIW and its microstrip interconnect, the reflection coefficients is below -15 dB that is -38.58 from 10.24GHz which shows in X Band. After the introduction of inclined slots in SIW, the structure resonates in two frequencies of 10.70 GHz and 12.16GHz with a reflection coefficient of -40.2865 dB and -29.2741 dB respectively. From the radiation pattern for SIW having no slots the gain is comparatively less. But with the introduction of slots, the gain has increased to a reasonable value of 4.0025 as compared to the structure of SIW without slots.

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