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Analysis of Substrate Integrated Waveguide Antennas

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Abstract: *This study aim to provide the overview of substrate integrated waveguide antennas. Substrate integrated waveguide (SIW) technology acts as a bridge between planar and non-planar technology which is very favorable for the development of components operating at microwave and millimeter wave band. Nowadays SIW has very emerging technology because of high power handling capabilities, low radiation losses, low conductor loss and fabrication of SIW structure is very simple. The main reason we go to SIW, it offers simple and cheap to implement a waveguide to a printed circuit board.*
Keywords*: substrate integrated waveguide (SIW), microwave and millimeter wave band.*

I.Introduction

A transmission line is a pair of electrical conductors that transfer an electrical signal from one place to another place. For example, transmission line likes coaxial cable and twisted wire cable. This transmission line results in radiation loss, dielectric loss, conductor loss and skin effect. Integration of transmission line with planar circuit is very complex. So we go to the metallic waveguide is good compare to the transmission line. Substrate Integrated Waveguide is an alternate option of metallic waveguide [1]. Substrate Integrated Waveguide (SIW) is also one type of transmission line that has been used in past few years. Substrate Integrated Waveguide (SIW) is very hopeful applicant in present day of microwave and millimeter wave technology. Substrate Integrated Waveguide acts as bridge between non-planar to planar circuits [2]. It combines the both advantages of co-planar and conventional waveguide. It has low cost, low loss, small size, light weight, high power handling capabilities and simple fabrication. Nowadays most of microwave and millimeter wave components like filters, antennas, power divider, and phase shifter are fabricated by using SIW technology [3]. Substrate Integrated Waveguide (SIW) is a transition between micro-strip and dielectric-filled waveguide (DFW). Dielectric filled waveguide is converted to substrate integrated waveguide (SIW) by the help of vias (holes) for the side walls of the waveguide. Because there are vias (holes) at the sidewalls, transverse magnetic (TM) modes do not exist; transverse electric TE10 therefore is the dominant mode [4]. One major attraction to SIW is that the amount of metal that carries tha signal is far greater than it would be in micro-strip or strip-line. Therefore, conductor loss is very low.

To choose the SIW parameters are very important, because to avoid the radiation losses. The cut-off frequency of rectangular waveguide is followed by,

$$f_c = \frac{c}{2\pi}\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2}$$ …………….. (1)

Where c : speed of light , m and n: modes number(m=1,2,3 & n=1,2,3), a & b : dimension of rectangular waveguide. For TE10

mode the cut-off frequency is followed by,

fc=(c/2a) ………………. (2)

The width of dielectric waveguide is followed by,

$$w_d \quad \sqrt{a_r}$$

where $_r$ is dielectric constant. So the SIW has been calculated by the following formula

$$WSIW = Wd + (d^2/95p)$$

Here Wd is width of dielectric waveguide, d is diameter of via holes, p is spacing between two successive via.

$$P <= 2d$$

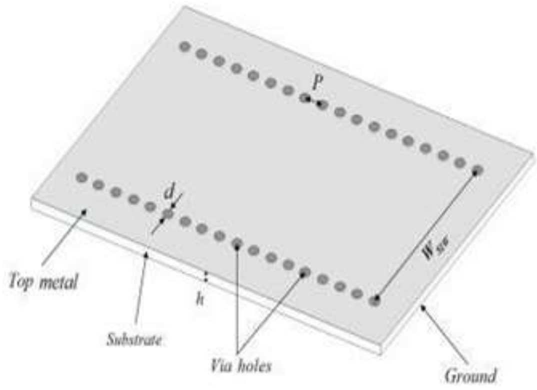

Fig. 1. Geometry of a SIW

II.SIW Antenna

A. Ka-Band Dual Frequency Single- Slot Antenna Based On Substrate Integrated Waveguide.

This paper proposed a dual-frequency single slot antenna. The slot length can be calculated by L= λ_o / 2($\sqrt{\varepsilon_r}$ 1) where λ_o is wavelength of the slot. The slot length L of the slot antenna should be chosen by the currents of both modes distributed at the same time. The length of the slot antenna should be calculated by the guided wavelength of f2. A tapered micro-strip line feed is used in this antenna. The dimension of the feed is Wfeed= 0.76 mm, Wt=1.32 mm and Lt=2.28 mm. the slot length L=5.66 mm, the SIW length *l*=11.2 mm and the slot location Le= 5.37. The substrate used in this antenna design as Rogers RT/Duroid 5880 with substrate thickness of 0.254 mm and permittivity of 2.2.

The resonant frequencies are 25.8 GHz and 31.5 GHz. The gain of antenna is 6.3 dBi for 25.8 GHz and 6.9 dBi for 31.5GHz. In this paper they use the frequency adjustable property. So to verify the frequency adjustable property two more antennas are designed. The dimension of two antennas is followed by the slot length L= 5.99 and 5.92 mm, the SIW length *l*=10.19 and 9.43 mm and the slot location Le= 5.27 and 5.2 mm. The same substrate thickness and feed dimension are used in these antennas. As the result of these antennas resonant frequencies as same. This antenna has been used in satellite communication [5].

B. Triple Band SIW Cavity Backed Slot Antenna

This paper proposed a triple band SIW cavity backed slot antenna. Generally, SIW cavity resonator has four electric walls at all sides and top and bottom metals. In this paper SIW cavity resonator has two magnetic walls that should be achieve by open circuited. So as the result SIW cavity resonator has two magnetic walls and two electric walls at the sides of the SIW. The resonant frequency of different modes is followed by

$$f_{mn0} \quad C / 2\sqrt{\varepsilon_r} X \left(\sqrt{(m/L_{eff})^2 + (n/W_{eff})^2} \right)$$

The first band of frequency is formed by combination TE210 and TE310. The second and third band of frequency is formed by TE030 and TE230. These modes can form the different resonant frequencies. The length of slot is calculated by the center frequency of the SIW cavity resonator. So to increase the length of slot the mode TE310 move to mode

TE030. Another slot will be placed, so the mode TE030 move to TE230.the dimension of the slot length L1= 40 mm and L2= 20 mm. The dimension of effective length and width Leff=53.2 mm and Weff=57.6 mm. The substrate used in this design is Rogers RO4003C with substrate thickness 1.524 and dielectric constant of 3.38.

The resonant frequencies are 3.3 GHz, 4 GHz and 4.9 GHz. The gain of each resonant frequency is 5.81 dBi for 3.3 GHz, 4 dBi for 4 GHz and 2.43 dBi for 4.9 GHz. The return losses are 24.6 dB for 3.3 GHz, 34.8 dB for 4 GHz and 31.6 dB for 4.9 GHz. This design antenna has covered the S band and C band of frequency [6].

C. A Novel Design of Dual Frequency SIW Slot Antenna.

This paper proposed a novel design of dua86 dBl frequency SIW slot antenna. This antenna design support only TEn0 (n=1, 2, 3,) and the dominant mode of this antenna is TE10 mode. They have used the trapper-via transition, because to compare the microstrip trapper transition it has well characteristics. The width of SIW has been calculated by the following formula,W=Wd + (d^2/95) where Wd is width of the dielectric filled waveguide, d is diameter of
via hole. Using the formula, they get the width of SIW is W=10.5 mm. They use the substrate as Rogers/RT Duroid 5880 (tm) with the dielectric constant $_r$ =2.2, and the height of the substrate is 0.787 mm. in this paper we use the collective iteration and optimization technique to found the size and location of the slot.

This antenna resonates at 12GHz and 13.8GHz. The VSWR and return losses are 12 GHz for 1.4093 & -15.4 dB and 13.8 GHz for 1.0843& -27.86 dB. The gain of the antenna is 12 GHz at 6.4357 dB and 13.8 GHz at 5.86 dB. It covers the Ku band application like satellite and remote sensing [7].

D. Design of Microstrip Patch Antenna using Half-Mode Substrate Integrated Waveguide Feeding Technique.

This paper proposed design of microstrip patch antenna using half-mode SIW feeding techniques. The main reason we so go half-mode SIW, because they reduce the size of antenna without affect any property of antenna. They use the half-mode substrate integrated waveguide, HMSIW can be achieve by top of the substrate one side is open circuited that acts like magnetic walls and another side is short circuited by the help of metallic vias (holes). At the open end of the HMSIW a microstrip patch is placed. The half wavelength of 10.5 GHz is length of patch (Lp). Coupling between the patch and HMSIW is controlled by adjusting the width of slot (Ws). They use the substrate as RT-Duroid with dielectric constant 2.2, and height of substrate as 1.57 mm.

The frequency response of the design we achieve 10.5 GHz. The return loss is -30 dB at the resonant frequency of 10.5 GHz. The gain of the propose structure is 6.8 dBi. This antenna is introduced for X- band applications like mobile communication and satellite communication system [8].

E. Microstrip SIW Patch Antenna Design for X Band Application.

This paper proposed a both circular and octagonal microstrip SIW patch antenna for X-band application. The main aimed of the antenna design a low cost, small size and achieve the high gain. The circular patch antenna design the SIW technology combines with grounded coplanar waveguide. They are negligible the coupling effect and give better matching. The vias are used to suppress the unwanted modes of the patch. The same dimension and technique are used in octagonal microstrip patch antenna. They use a substrate as Rogers 4350 with substrate thickness 1.52 mm and dielectric constant of 3.66.

The resonant frequency of both circular and octagonal microstrip patch antenna is 10 GHz. The return losses both design are at the resonant frequency 10 GHz for circular -17 dB and for octagonal -25 dB. The gain of circular patch has 7.9 dB and octagonal patch has 9.8 dB. This design covers the X-band application like radar and remote sensing [9].

F. Dual-Band and Dual-Polarized SIW-Fed Microstrip Patch Antenna.

This paper proposed a dual-band and dual-polarized SIW fed micro-strip patch antenna. This antenna contains three layers. The lower layer forms the SIW, using two longitudinal and transverse slots etched on it, which feeds by patches. The second layer contains the two patches, these are the radiating elements. The last layer is a frequency selective surface to the lower level of cross polarization. The implementation SIW uses the substrate as Rogers 4003 with dielectric constant 3.55 and the thickness of 1.32 mm. The radiating elements of patches are implemented by substrate Taconic TLY with dielectric constant 3.55 and substrate thickness of 1.5 mm. The patches' substrate and SIW are separated by the air gap. This gives the high cross polarization. So to overcome this problem to use the frequency selective surface on top of the patches. The FSS are implemented to Rogers 5880 with dielectric constant of 2.2 and thickness of 0.5 mm.

The resonance frequency of this antenna is 10.3 GHz and 12 GHz. The higher band is created by transverse slot in y- directed polarization and the lower band is created by longitudinal slot in x-directed polarization. A good cross polarization level is lower than 20 dB. The gain of the antenna can be achieved by 8.5 dB for the first and second band [10].

G. Compact SIW Microstrip Magnetic Yagi Antenna.

This paper designs a compact SIW microstrip magnetic Yagi antenna. In this antenna design the SIW acts as a driven element to generate a vertical polarization to the fundamental modes and the microstrip patches are connected to ground plane by plated through holes that work as magnetic dipole directors. The width of SIW

Ws can be determined by the centre frequency. The tapered microstrip line feed is used between microstrip line and SIW. They use the substrate as Rogers 5880 with dielectric constant 2.2 and substrate thickness of 1 mm.
In this design the operating frequency obtained is 9.5 GHz. The corresponding gain of antenna can be achieved by 7.26 dBi and 8.98dBi. The bandwidth is obtained as 16.84%. The total area of this antenna design is 1.58 $_1$ x 0.95 $_1$. This design mainly used in X-band application [11].

H. Design of Wheel Shaped SIW Antenna using Substrate Integrated Circuits for RADAR Applications.

This paper presents a design of Wheel Shaped SIW Antenna using Substrate Integrated Circuits for RADAR application. In this design we implement an ohm and wheel shaped slot. The first ohm shaped slot insert torus shape with inner radius 0.2 mm and outer radius 0.3 mm which fills as nickel material. The wheel shaped slot totally 5 circle, we use to design. The first circle radius as 1.2 mm filled with nickel material. The next circle radius as 1 mm with filled as copper. The next circle radius as 0.51 mm with filled as nickel. The next circle radius as 0.75 mm with filled as nickel. The last circle radius as 0.4 mm. The substrate used as RT duriod 5880 with dielectric constant as 2.2 and substrate thickness is 0.508 mm.

In this design the operating frequency obtained is 60 GHz. The return loss is -30.4 dB. The corresponding gain of the antenna design is 5.9 dBi. The bandwidth of antenna design is 9.04 %. This antenna mainly used in RADAR application [12].

I. SIW-tapered slot antenna for broadband MIMO applications.

This paper presents SIW-tapered slot antenna for broadband MIMO application. In this design two identical trapped slots are used and they are fed by port1 and port2 in the antenna. We have used four circular opening both sides of SIW that will improve antenna performance. The size of antenna is 1.28 * 1.46 *0.02 . The broadband antenna size is 55 × 46.8 × 0.79 mm^3. They use substrate as Arlon IsoClad 917 with dielectric constant as 2.17.

This design the operating frequency is obtained 8-15 GHz. The return loss is corresponding frequency as -22 to 35 dB. The gain of the antenna is varying from 2.2 to 8.7 dBi. This antenna is mainly used in X-band and lower Ku band application [13].

J. Small Size Rectangular Microstrip Patch Antenna with a Cross Slot Using SIW.

This paper design a small size rectangular Microstrip patch antenna with a cross slot using SIW. They have use two slots; they arrange cross to each other's. These slots are placed in the small rectangular microstrip patch. The dimension of the slots length is 12.2 x 0.3 mm. The substrate and ground plane dimension is 35 x 40 mm. we use substrate as FR4_epoxy with dielectric constant as 4.4 and the thickness of substrate as 1.52 mm.

The operating frequency of this design can obtain 8.1 GHz. The return loss value is -35 dB. The gain value is 9.1 GHz. The VSWR value is 0.3284dB at 8.1 GHz. This antenna is mainly used in satellite communications, military, weather monitoring and modern radar [14].

K. X-Band SIW Cavity-Backed Patch Antenna for Radar Applications.

This paper design a SIW Cavity-Backed Patch Antenna. This antenna can combine the both SIW cavity and patch antenna. In that the rectangular patch to apply 2 cuts on the lateral sides. The circular SIW cavity can be made of around the patch. The antenna allows a rough performance predication. Coaxial probe feed method uses to patch antenna. They use the substrate as a Taconic RF-35 with dielectric constant as 3.5 and substrate thickness is 1.52 mm.

The operating frequency of this design can be obtaining 9.4 GHz. The corresponding gain of antenna can be achieved by 6.7dBi. The return loss value is -15 dB. The beam width (-3dB) is 88.2^o [15].

L. Design of Planar High-Gain Antenna Using SIW Cavity Hybrid Mode.

This paper presents a design of planar High-Gain Antenna using SIW Cavity Hybrid mode. The slot antenna is placed above the metallic plate of SIW cavity. The current distribution of the cavity is hybrid mode surface that will change by adjusted the position of slot. The microstrip line feed is used in the SIW cavity. The substrate used as Rogers RT duriod 5880 with dielectric constant as 2.2 and substrate thickness is 0.787 mm.

In this design the operating frequency is obtained as 9.5GHz. The gain value is 9.62 dBi for corresponding operating frequency. The bandwidth is 670MHz. The return loss value is -46dB. This antenna mainly used in X-band application [16].

M. The Design of High Gain Substrate Integrated Waveguide Antennas.

This paper presents the design of high gain substrate integrated waveguide antennas. We have used slot at the centre of the SIW. The length of slot will be followed by

$L={}_{0}/\sqrt{2}\ \underline{\ \ r\ \ }\ 1$. This equation is used to find the length of slot for obtained in circular polarization. The Trapped microstrip line feed is used between the microstrip line and SIW structure. Here we have used a substrate as FR4-epoxy with dielectric constant as 4.4.

This design the operating frequency is obtained 10.70GHz and 12.16GHz. The return loss values are -40.286dB for 10.7GHz and -29.16dB for 12.16GHz. The gain value is 4.0025dBi. This antenna is mainly used in X-band application [17].

N. A K-Band Frequency Scanning Microstrip Array Using SIW.

This paper presents a design a K-band frequency scanning microstrip array using SIW. In this design, SIW acts as slow-wave transmission line. The slots on the design will be controlled the antenna distribution. A 50 ohm CBCPW with holes is used to ground layer. This is used as the direct input of antenna between CBCPW and SIW. The substrate use as Rogers 5880 with dielectric constant as 2.2 and the substrate thickness is 0.508 mm.

The operating frequency of this design can obtain 23.5GHz to 25.5 GHz. The gain value is above 16 dB in working frequency band. The return loss value is below -17 dB. This antenna has been used in the K-band application [18].

O. SIW Based Modified Slotted Array Antenna with Circular Polarization for X, Ku and K Band Communications.

This paper design a SIW based Modified slotted array antenna with circular polarization for X, Ku, & K band communication. In this design contains 3 transverse slots. These slots are inclined with 45^0 with respect to one longitudinal slot. The circular polarization can be achieving by increased the number of slots are inclined at 45^0. A tapered micro-strip line feed is used in this antenna. They use the substrate as FR4-epoxy with dielectric constant as 4.4 and the thickness of the substrate is 1.6 mm.

The operating frequency of the design can obtain 10.48 GHz, 17.85 GHz and 19.71 GHz. The return loss value is -27dB. This antenna mainly used in X-band, Ku-band and K-band application [19].

III. Comparision Of Various Antenna Design Using Substrate Integrated Waveguide

Various antennas are designed using Substrate Integrated Waveguide. In this table we compare operating frequency, gain, return loss value and which type of substrate used for design of antenna.

Table 1. Comparision Of Various Antenna Design Using Substrate Integrated Waveguide

Ref No	Operating Frequency (GHZ)	Gain (dBi)	Return loss (dB)	Material used for design
14	23.5GHZ to 25.5GHz	Above 16 dBi	-17dB	Rogers 5880
5	Circular & octagonal patch 10GHz	7.9dBi& 9.8dBi	-17dB -25dB	Rogers 4350
12	9.5GHZ	9.6dBi	-46dB	Rogers RT/Duriod 5880
10	8.1 GHz	9.1dBi	-35dB	FR4_epoxy
7	9.5 GHz	7.26dBi 8.98dBi	-33dB	Rogers 5880
6	10.3GHz & 12 GHz	8.5dBi	-32 dB -30dB	Rogers 5880
9	8GHz to 15GHz	2.2dBi to 8.7dBi	-22dB to -35dB	ArlonIsoclad 917
1	25.8GHz 31.5GHz	6.3dBi 6.9dBi	-23dB -28dB	Rogers RT/Duriod 5880

4	10.5GHz	6.8dBi	-30dB	RT-Duriod
11	9.4GHz	6.7dBi	-15dB	Taconic RF-35
3	12GHz 13.8GHz	6.44dBi 5.86dBi	-15.4dB -27.9dB	Rogers RT/Duriod 5880(tm)
8	60GHz	5.9dBi	-30dB	RT-Duriod 5880
2	3.3GHz 4GHz 4.9GHz	5.81dBi 4dBi 2.43dBi	-24.6dB -34.8dB -31.6dB	Rogers RO4003C
13	10.7 & 25.5 GHz	4dBi	-40.29dB -29.16dB	FR4_epoxy

IV. Conclusion

In this analysis, we discussed the various antenna designs using Substrate Integrated Waveguide. These antennas are mainly used in the satellite communication, radar communication, remote sensing, military, mobile communication and weather monitoring. In future, we have design a SIW based for millimetre wave application also. These antennas are simulated by using HFSS and ADS software.

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