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Research paper

Investigation of SIW directional coupler for 60ghz mm-wave applications

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Abstract

In this article, 60 GHz directional coupler is designed by using Substrate Integrated Waveguide (SIW) technology using Coplanar waveguide as a transmission path. To design directional coupler RT duriod 5880 substrate material is used. Here directional coupler is analyzed by changing the thickness of copper coating and height of the substrate. By changing the thickness of copper coating and height of substrate examining the directional coupler results like reflection coefficient, insertion loss, coupling factor, isolation loss, VSWR, surface current, Electric field and magnetic field variations. Verifying the thickness and height of substrate is suitable for RADAR application in millimeter frequency range. RT duriod 5880 substrate material height is 0.508mm and thickness of 0.035mm are chosen to design directional coupler. At 60 GHz directional coupler gives reflection coefficient as -36.03 dB, insertion loss as -1.3 dB, coupling factor of -6.3 dB and isolation loss of -36 dB.

Keywords: *Directional Coupler; GCPW; mm-wave ; SIW; SIP; SOS; Surface Current; RADAR; Wireless Communication*.

1. Introduction

Due to the incorporation of a wireless communication system in many applications high bandwidth is required. Not only bandwidth require but also less delay, low loss, compact size and high packing density is required. Less delay and high data rate transmission are possible when the carrier frequency is high. At higher frequencies availability of high free spectrum is required. All these requirements are fulfilled by millimeter frequency range (30 GHz – 300 GHz) [5], [6]. According to federal communication commission (FCC) 57GHz to 64GHz [6] is an unlicensed frequency band i.e. 7GHz band of frequency access any device anywhere. Mainly FCC announces 59GHz to 64GHz is used for RADAR application. In this frequency range 60 GHz plays a much-dominated role. By using this frequency range all the component size is reduced. Due to compact size all the components are placed in a single package which is called System in Package (SIP) [5]. Single packing components are placed on a substrate which is called System on Substrate (SOS). Due to SIP and SOS packing density is increased. To design SIP and SOS a new technology is required. This new technology must satisfy the requirements of SIP and SOS at millimeter wave frequency range [5]. To design millimeter wave frequency components Substrate Integrated Waveguide (SIW) technology most suitable one. But to connect the all the SIW components either in series or shunt manner coplanar waveguide transmission is most suitable transmission path. In wireless communication RADAR and 5G domains have dominated developments. Fig .1 shows a basic block diagram of the basic RADAR system [7].

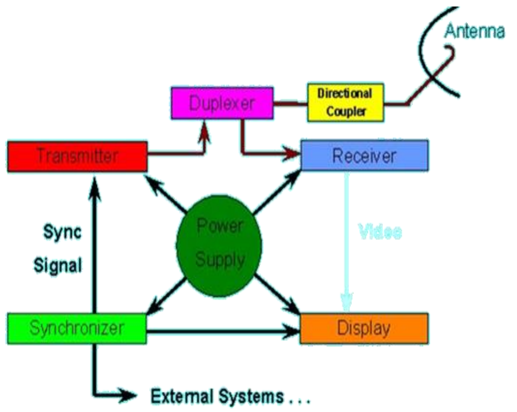

Fig. 1: Basic RADAR Block Diagram.

In the wireless communication coupler plays an important role in dividing, routing and combining the signal in microwave systems. The coupler is most important components in power dividing or combining networks. A coupler having many applications like cable distributed systems, antenna beam forming, separating receiving and transmitting signal on telephone lines, feedback networks and providing a single sample for measuring or monitoring. The essential feature of the coupler is power flow one direction.
In Coming next section explains the design of SIW, coplanar wave structures and coupler concept. The third section results are discussed in a detailed manner. In fourth section results are compared with references and finally explained the conclusion of the proposed design.

2. Design of SIW, CPW and coupler structure

2.1. SIW design

In Substrate Integrated Waveguide (SIW), top and bottom of the substrate coated with a copper conductor and these two layers are connected by using array vias. This is shown in fig.2. Here diameter of via (d), the spacing between two vias (p) and width between two rows of via (Wsiw) are the important parameters. Which are calculated using below formulas [5-6].

$$W_{eff} = W_{siw} - d^2/ (0.95\ p) \qquad (1)$$

$$Weff = a/ (\sqrt{\varepsilon r}\ ) \qquad (2)$$

$$P \leq 4d \qquad (3)$$

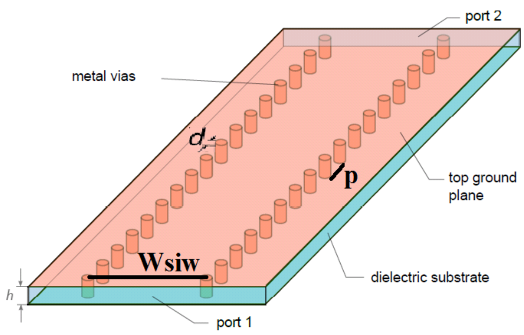

Fig. 2: SIW Structure.

Here a number of vias are maintained less than 20 per unit of wavelength. "a" is the standard value of the rectangular waveguide width, substrate relative permittivity ε_r is 2.2. RT duriode 5880 substrate height is 0.508mm and above and below copper layer thickness of the substrate is 0.035mm.

2.2. GCPW design

Grounded Coplanar Waveguide (GCPW) provides good impedance matching to implement transmission path for millimeter wave components. To design SIP, SOC and SOS all the components are placed very near to each other. In place GCPW provide good impedance matching transmission path between the components. Below fig.3 shows the CPW structure. To design GCPW, the width of the center feed (W) and spacing between center feed to beside ground conductor (S). For GCPW W and S is calculated using equa.4. [1], [3]

$$0.2 \leq w/ (w+2s) \leq 0.8 \qquad (4)$$

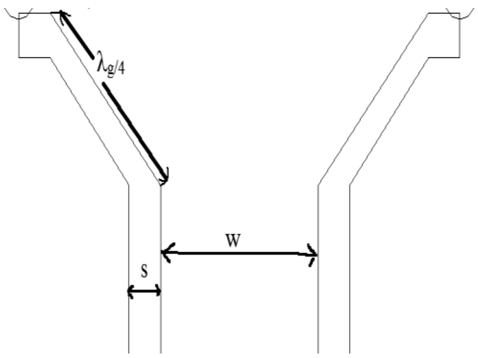

Fig. 3: GCPW Structure.

Here tapering is used to connect CPW to SIW. The tapering provides good impedance matching. The length of tapering is λg/4 shown in the figure. This tapering provides perfect impedance matching.

$$\lambda g = \lambda o /(\sqrt{\varepsilon r}\ ) \qquad (5)$$

2.3. Directional coupler design

The basic coupler structure is shown in fig.4. This Coupler is four port passive components. Port1 designed as an input port, port2 is designed as an output port, port3 designed as coupling port and port4 designed as an isolated port. The tapped transmission between SIW to CPW is 50Ω. The coupler geometry is based on even or odd mode analysis. When TE_{10} is even mode and TE_{20} is odd mode. [1]- [3]

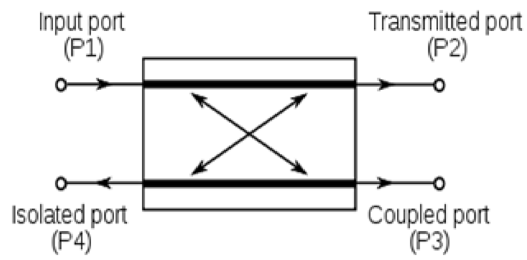

Fig. 4: Basic Hybrid Coupler Structure.

The phase difference between two modes is

$$\Delta\varphi= (\beta_1-\beta_2)\ Wap \qquad (6)$$

Where β_1 and β_2 are the propagation constant of TE_{10} and TE_{20} mode. Δφ Value is π/2 in operation band. All the coupler provides good impedance matching, high directivity and wide bandwidth when other ports are terminated with matched impedance. General characteristics of the coupler are coupling factor, loss and isolation. The primary property of coupling is coupling factor which does not exceed 0dB as a passive device. Coupling is varied with frequency; a perfect couple theory cannot be built.
The below fig.5 is the proposed directional coupler. The design parameters are given in table.1. Here RT 5880 substrate is used. Here diameter of via (d) and spacing between via arrays (P) given in the table.

Table 1: Proposed Directional Coupler Design Structure Parameters

Parameter	Value(mm)
L	8
W	6
D	0.2
P	0.25
W_{siw}	2.725
λ_g	3.371
W_c	1.008
S	0.1
L_p	5.1

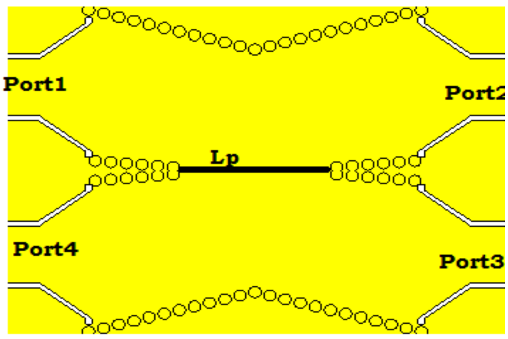

Fig. 5: Proposed SIW Directional Coupler Design Structure.

3. Results and discussions

By simulating the proposed directional coupler getting results are shown in fig.6. Consider RT duriod 5880 substrate material height as 0.508mm and copper coating thickness as 0.035mm.

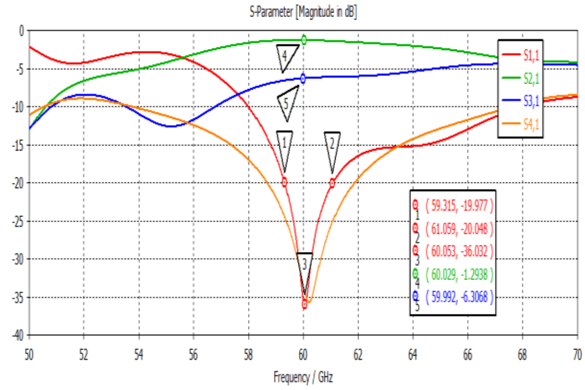

Fig. 6: Simulation Results of Proposed Hybrid Coupler.

In this simulation result graph reflection coefficient (S_{11}) indicates with a red line, transmission coefficient (S_{21}) indicates with a green line, coupling coefficient (S_{31}) indicates with the blue line and finally isolation coefficient (S_{41}) indicates with an orange line. To calculate the bandwidth of the device -20dB line is taken as a reference on S_{11}. Which is touches the S_{11} at 59.315GHz and 61.1GHz. Due to these points getting bandwidth is 1.78GHz. Maximum resonance peak occurs at 60GHz with reflection coefficient (S_{11}) is -36.03dB. From the results transmission coefficient (S_{21}) at 60GHz is -1.3dB. Thought out the band transmission coefficient value is less than -2dB shown in results. Coupling coefficient value varies with frequency. In these results coupling coefficient at 60GHz is -6.3dB.

Generally different height and thickness of RT duriod substrate material are available. RT duriod substrate material copper thickness is chosen as five times of skin depth. The skin depth of copper material at 60GHz is 0.0105mm. The copper thickness of substrate material is less than 0.0525mm.Substrate height is chosen below of Wsiw/2. In market substrate height are 0.127mm, 0.254mm, 0.381mm, 0.787mm are available. Similarly copper coated thickness of substrate 0.009mm, 0.017mm, 0.035mm and 0.07mm are available. First vary the height of substrate and analyzed all the parameters of the directional coupler. Fig.7 shows the variation of S11 with a height of the substrate. These all parameters are calculated at 60 GHz.

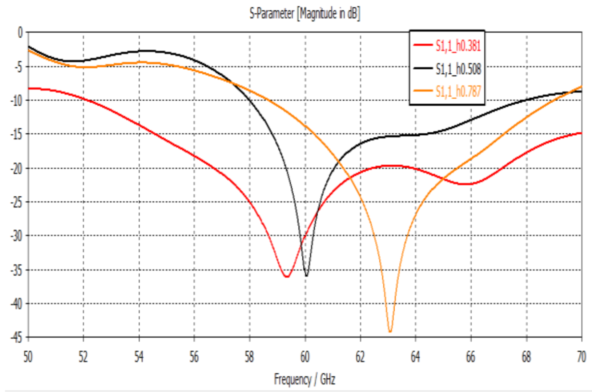

Fig. 7: Variation of S_{11} with A Height of the Substrate.

From above graph substrate height 0.381mm gives more bandwidth but reflections coefficients value same as 0.508mm. But 0.508mm height gives less bandwidth compared with 0.381mm. 0.787mm height gives more reflection coefficient but bandwidth middle of 0.381mm and 0.508mm.

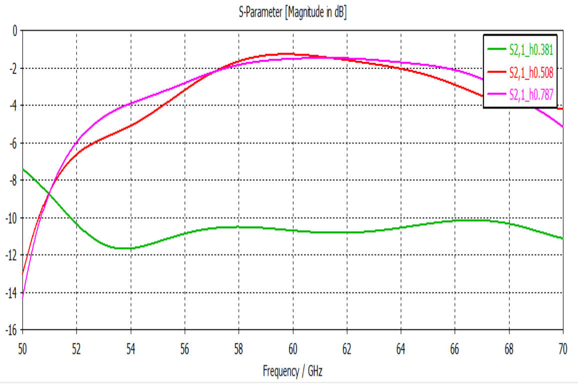

Fig. 8: Variation of S_{21} with A Height of the Substrate.

Fig.8 gives a variation of S_{21} with a height of substrate material. Here 0.787 mm and 0.508 mm heights are maintained less S_{21} but 0.381mm gives more S_{21}. In practical applications S_{21} is maintained very less value approximately 0dB. In this case 0.787 mm and 0.508 mm gives a good result.

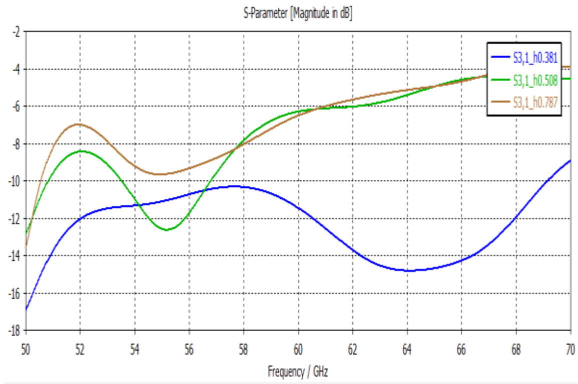

Fig. 9: Variation of S_{31} with A Height of the Substrate.

For practical applications S_{31} value requires very low similar S_{21}. But in this structure 0.787 mm and 0.508mm are maintained similar values. 0.381 mm gives a very high value which is shown in fig.9.

In practical application S_{41} require a very high value. 0.787 mm height provides high value compared with 0.381mm and 0.508 mm. But 0.381 mm provides high bandwidth. This is shown in fig.10.

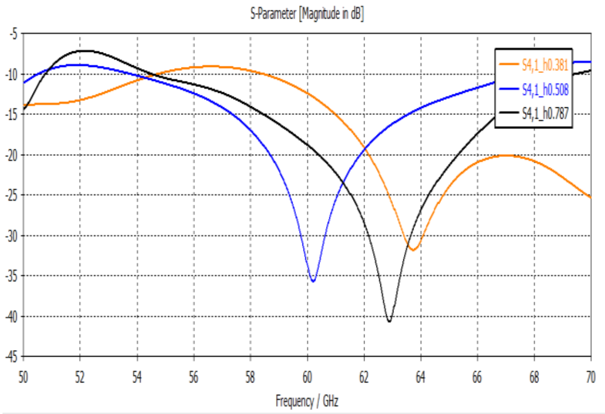

Fig. 10: Variation of S_{41} with A Height of the Substrate.

Due to the change in copper thickness all the parameters are not affected at 60 GHz. This is shown in fig.11. But the minimum thickness of copper is maintained approximately five times of skin depth that is 0.035mm.

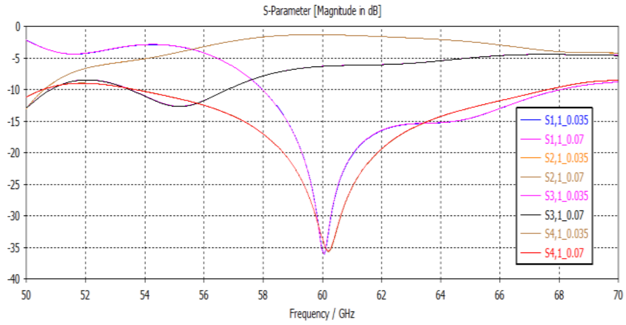

Fig. 11: Variation of Directional Coupler Parameters with A Thickness of the Copper Substrate.

The height of substrate changes voltage standing wave ratio (VSWR) is also changed. This is shown in fig.12. When the height of substrate decreases VSWR is also maintaining in between 1 to 2. But all the heights are the main VSWR as 1 to 2 throughout bandwidth.

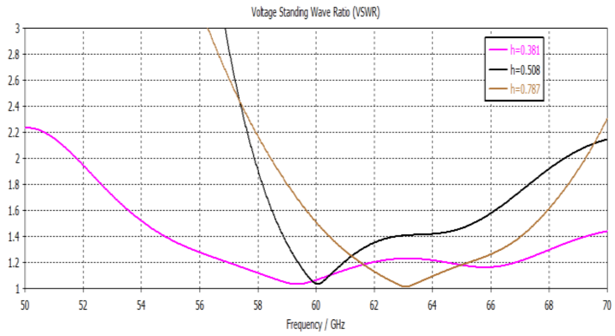

Fig. 12: Variation of VSWR with A Height of the Substrate.

The electric field distribution of a directional coupler is shown in fig.13. These E-fields occurs at 60GHz.

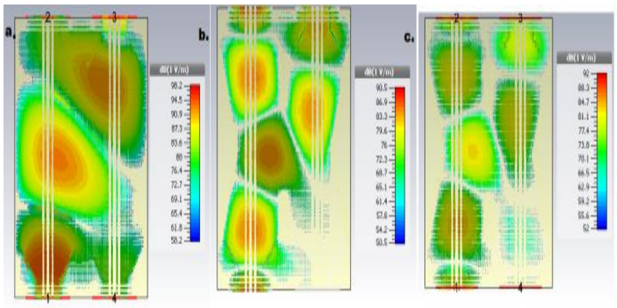

Fig. 13: E-Field Distribution of the Directional Coupler A) 0.381 B) 0.508 C) 0.787.

The Magnetic field distribution of a directional coupler is shown in fig.14. This H-field occurs at 60GHz.

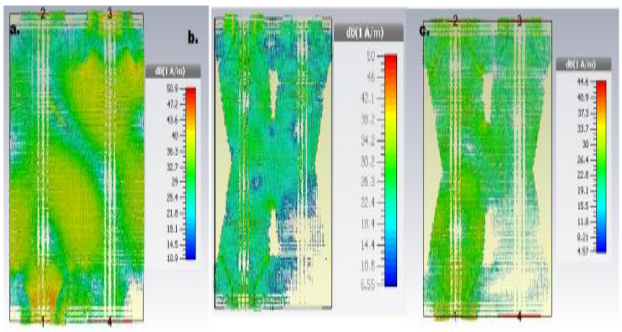

Fig. 14: H-Field Distribution of the Directional Coupler A) 0.381 B) 0.508 C) 0.787.

The surface current distribution of a directional coupler is shown in fig.15. This surface current occurs at 60GHz.

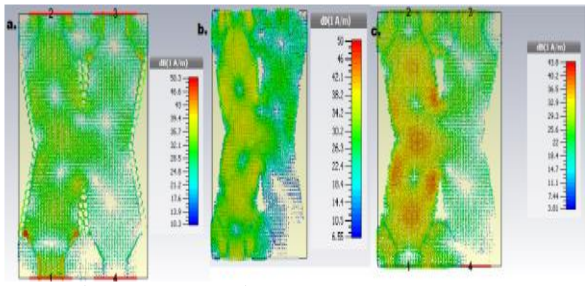

Fig. 15: Surface Distribution of the Directional Coupler A).0.381 B).0.508 C).0.787.

Below table gives the comparisons of fields, surface current and VSWR changes according to the height of substrate materials at 60 GHz.

Table 2: Comparisons of Surface Current and Field According to Heights

Parameters	Height of Substrate(h) (mm) h=0.381	h=0.508	h=0.787
E-Field dB(1V/m)	98.2	90.5	92
H-Field dB(1A/m)	50.9	50	44.6
Surface Current (1A/m)	50.3	50	43.8
VSWR	1.06	1.03	1.5

From above table height of substrate 0.381 mm gives more power but the loss is also increases compared with 0.508mm and 0.787mm. Because height decreases losses increased. The height of substrate0.787 mm gives good power with the low loss but the surface current is less which also provides VSWR is the height at 60 GHz. To design directional coupler at 60GHz RT duriod 5880 height of 0.508mm and copper thickness of 0.035mm is more suitable for RADAR application in the millimeter wave frequency range.

4. Comparisons

Parameters	Ref [6]	Ref[7]	Ref[8]	Proposed Design
Type of Coupler	SIW Directional Coupler	RSIW Directional Coupler	Cross SIW Hybrid Coupler	SIW Directional Coupler
F (GHz)	60	60	60	60
B.W (-15dB)	30%	26.43%	30%	30%
ε_r	2.2	3.15	2.2	2.2
S_{11}(-dB)	36.4	57	29.5	36.03
S_{21} (-dB)	0.7	3.89	2.17	1.3
S_{31} (-dB)	11	3.89	4.63	6.3
S_{41}(-dB)	21	60	31	36
Size (all in mm)	8*6* 0.508	12.3*3*0.15	8*8*0.508	8*6*0.508

5. Conclusion

In this paper passive v-band directional coupler is designed for 60 GHz by using SIW technology. This directional coupler serves as a basic building block in a RADAR application. Directional coupler analyzed by changing height and copper thickness of RT duriod 5880 substrate material. For 60GHz RADAR applications height 0.508 mm and copper thickness 0.035mm is more suitable. This gives less VSWR, good power and moderate losses. This directional coupler gives 30 dB as directivity. Due to its compact size, bandwidth and directivity this directional coupler is more suitable for RADAR and 5G application in millimeter frequency range.

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