International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-10, August 2019

Intra-Chip and Inter-Chip Wireless Communication Analysis for Millimeter Wave using Miniaturized On-Chip Antenna

Deepa N P, K L Sudha

Abstract: System on Chip (SoC) is an emerging technology for semiconductor devices that aims for better compaction with reduced interconnects, RC delay, noise, and power consumption. Wired connections between chips, ICs or SoC's lead to increased heat dissipation, which is undesirable. Hence, mechanisms have been developed for making communication between the chips wireless and use of miniaturized RF antenna is inevitable. In this paper, to analyse the performance of wireless communication over millimeter range, millimeter scale RF antennas operating at frequencies of 20 GHz to 70 GHz are considered. Using ANSYS HFSS software, the scenario for intra and inter chip wireless communication is established using the bowtie antenna operating around 50 GHz and their performance evaluation is done considering the various parameters. An intrachip system of four bowtie antennas is simulated around 50GHz and the S-parameters are plotted and analysed.

Index Terms: Channel Model, On-Chip Antenna, System-on-Chip, Wireless Channel.

I. INTRODUCTION

Communication between chips can occur through conventional, RF, optical and 3D interconnects. Metal wires are used to interconnect blocks in SoC's and other chips which not only increase heat dissipation but also create restriction for signals, noise and interference. Wireless communication between two blocks having same substrate requires on chip antenna. Usage of Giga Hertz frequency results in millimeter antenna of very small size. Transceivers use electromagnetic waves at radio frequencies. Various types of antennas are used for different purposes and antenna on-chip is one configuration among them [1]-[4].

Due to fast growth in short range high speed wireless communications, the spectrum at 60 GHz frequency region has gained much more attention in last few years. The implementation of compact, low cost 60-GHz system in SoC is to integrate antennas on the chip with necessary additional circuits so that the complete system can be made in one step with foundry fabrication. For compact RF system, the miniaturization of antenna is also necessary with their effective performance [4]. On- chip antennas are the one which are fabricated on Silicon wafer by CMOS processes [5]. On-chip antennas are mainly used as wireless interconnects for the purpose of inter-chip/intra-chip communications. Generally, interconnect is a physical or logical connection between two electronic devices or networks. Connections between chips are mainly categorised as conventional, RF, Optical and 3D interconnects. Conventional interconnects are the low frequency metal wired connections. Since these ICs require high signal speed requirements, the wired interconnect structures are becoming the bottleneck for delay and noise in chips, making them an obstacle for increasing IC speed and performance. This is because resistance-capacitance (RC) delay is a characteristic of interconnects that increases sharply with increase in resistance. Hence, there is a need for better compaction using microwave and millimetre components. To make these antennas feasible with other components, they are usually designed on a millimetre scale at higher frequencies of around 10GHz (up to 60 GHz). However, communication range is limited. For frequencies lower than 10GHz, near field or inductive coupling is being used [6]-[8].

Manuscript published on 30 August 2019.
***Correspondence Author(s)**
Deepa N P, Electronics and Communication Engineering, Visvesvaraya Technological University, Dayananda Sagar College of Engineering, Bengaluru, India.
K.L Sudha, Electronics and Communication Engineering, Visvesvaraya Technological University, Dayananda Sagar College of Engineering, Bengaluru, India.

II. OVERVIEW OF RELATED WORK

On-chip antennas are fabricated on a Silicon wafer by CMOS processes to operate at high frequencies of around 10 GHz to 70 GHz. They are mainly used as wireless interconnects for inter-chip/intra-chip communications. Latest research in the field mainly focuses on shapes, usages of antenna for interconnect applications and the propagation of radio waves through different material layers, mainly Silicon. On-chip antennas are mainly used for faster communications and RF sensor applications. Congestion related to signal transmission between ICs can be decreased [1]. Bow-tie antennas are widely used for Ground Penetrating Radar System applications, as they possess a set of stringent antenna performances such as a low frequency of operation, ultra-wideband performances, minimal ringing, compaction, planar structure and light weight [12],[13]. Planar log periodic antenna was first introduced in wideband antenna design. It is used in radio signal detection application as it can achieve high directivity [5], [6]. On-chip wireless interconnects have emerged as a promising alternative to conventional wired interconnects in on-chip fabrics for multicore systems. They reduce network congestions and enhance bandwidth and energy efficiency but have very low per bit energy [14].

Bow-tie antenna has moderate gain and a wide bandwidth. [9]. Main advantage of planar log periodic antenna is that it exhibits constant characteristics over a desired frequency range of operation [5]. Wireless interconnects are noisy wireless channels as interferences will be there in the channel. It has higher probability of link failures when compared to optical and the 3D interconnects [1]. Bow-tie is not sensitive to small parameter variations; that is whenever there is a small change in parametric analysis, it will not give accurate results. It also uses a limited bandwidth. Planar log periodic antenna [PLPA] has lesser gain than the Yagi antenna of the same size and VSWR performance is not very good. [5], [6]. Table-I shows the performance comparison of different antennas designed by different researchers for mm range applications.

III. WORKDONE AND RESULTS

Work considered in this paper is to construct an antenna and establish communication for mm range communication. ANSYS HFSS [10] simulation tool is used to develop the antennas and the frequency of operation considered up to 70GHz. To accommodate this frequency range, the following dimensions are used to construct Bow tie antenna in HFSS.

The silicon layer has 0.832 mm x 0.72 mm x 0.35 mm dimensions. The SiO_2 layer has 0.832 mm x 0.72 mm x 0.15 mm dimensions. The bow has a length of 0.275 mm and width of 0.35 mm. The Microstrip feedline is 0.637 mm long. The lumped ports are assigned a 50 Ohm impedance by default for antenna design. Fig. 1 shows the bow-tie antenna with the above specifications.Fig. 2(a) shows Bow tie antenna structure enclosed in SiO2 layer of 0.1mm thickness and Fig. 2(b) shows its radiation pattern. The bowtie simulation results showed that the SiO_2 layer shifts the resonant frequency to the right. The far field parameters have an increase of 3 dB in both gain and efficiency. When an additional SiO_2 layer is added on top of the existing SiO_2 layer for the bowtie, the resonance frequency shifts to the left, due to inhibition of the antenna's radiating capacity. Matching circuit [11] for Bow tie antenna structure enclosed in SiO2 layer of 0.1mm thickness is shown in Fig. 3.

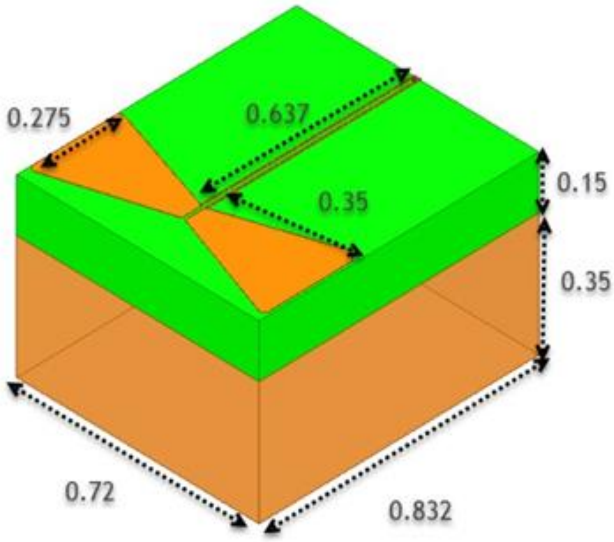

Fig. 1. Specifications For Bowtie Antenna

Table-I. Performance Comparison Of Different Mm Range Antennas Reported In Literature

Year	Antenna Type	Frequency (GHz)	Gain (dB)	VSWR	Efficiency (%)	Return Loss (dB)
2005	Quasi Yagi	55-65	-10.6	< 2.0	10	-
2008	Meander Line Inverted F antenna	60	-15.7	< 2.0	10.2	-10
2012	Tab Monopole	60	0.11	< 1.5	39	-
2014	PLPA	60	-	-	-	-
2017	Bow-Tie	60	-6	-	10	-40
2017	On chip antenna with InP substrate	140	-5.3	-	-	-10

Retrieval Number: J92230881019/19©BEIESP
DOI: 10.35940/ijitee.J9223.0881019
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

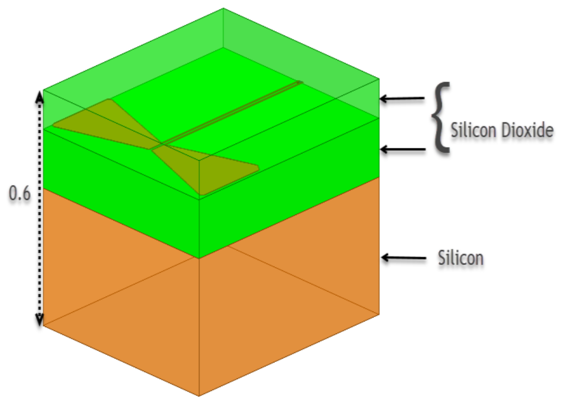

Fig. 2(a)

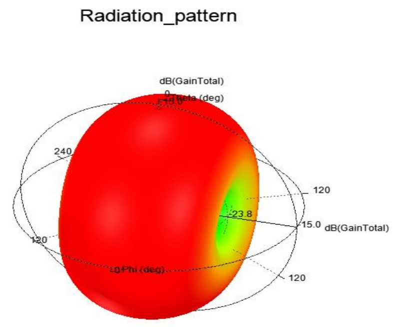

Fig. 2(b)

Fig. 2(A). Bow Tie Antenna Structure Enclosed In Sio2 Layer (0.1mm Thickness) And Fig. 2(B) Its Radiation Pattern

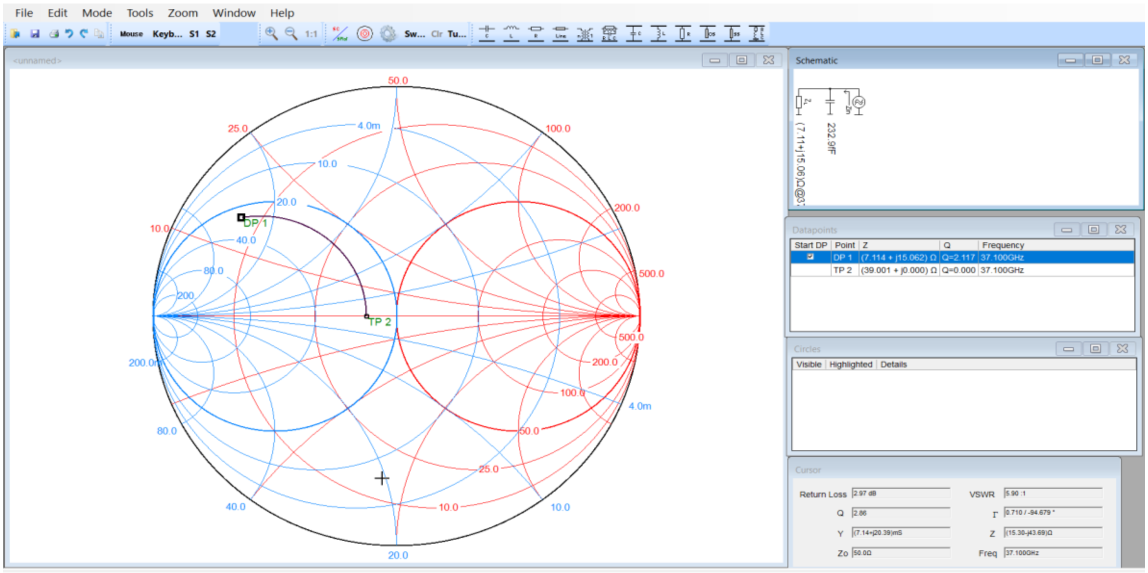

Fig. 3. Mactching Circuit For Bow Tie Antenna Structure Enclosed In Sio2 Layer (0.1mm Thickness)

As we know S- parameters are the most commonly used measuring parameters for high frequency. In this section, the obtained results of simulated bow tie antenna transmitter-receiver system, followed by mixed Transmitter-Receiver of Bowtie and PLPA system's s-parameters are tabulated and analysed.

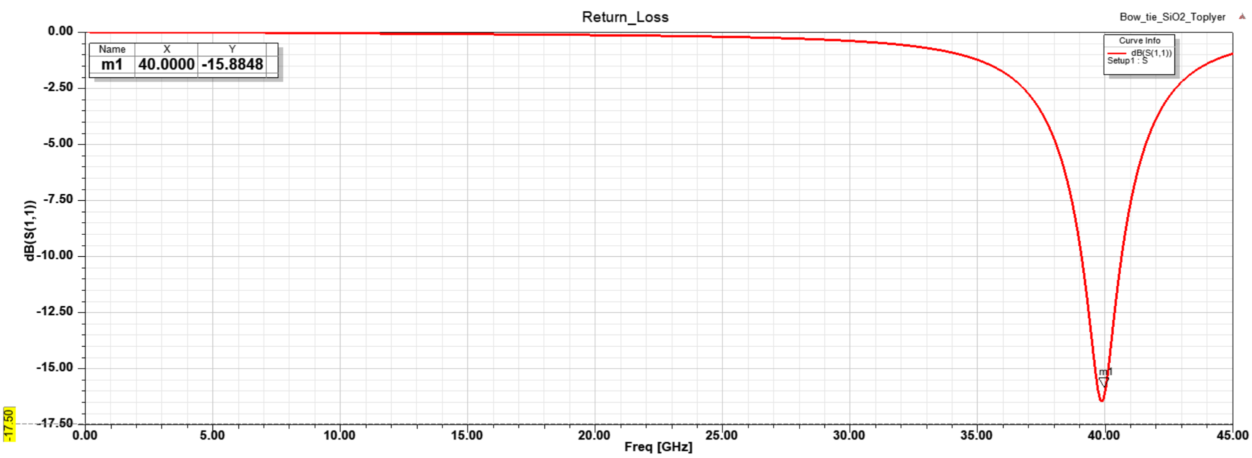

Fig. 4. S11 Bow-Tie Antenna

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

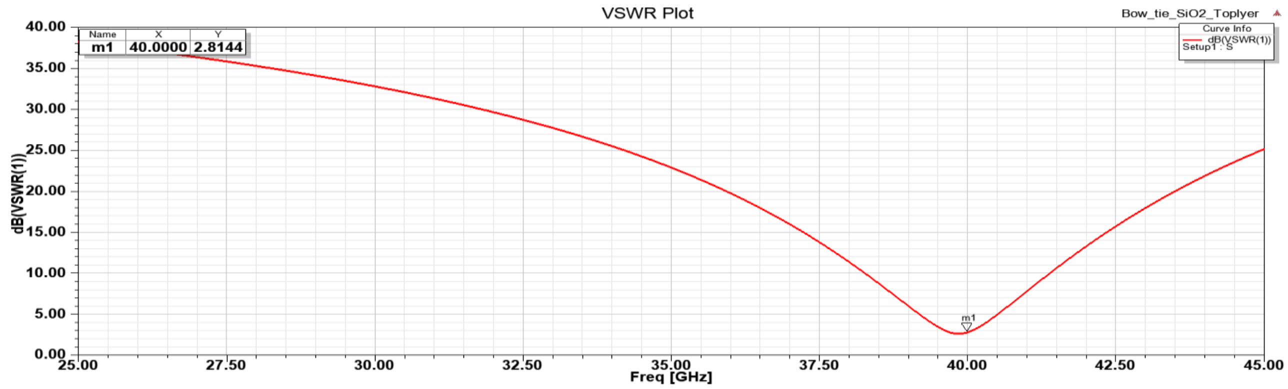

Fig. 5. VSWR For Bow-Tie Antenna

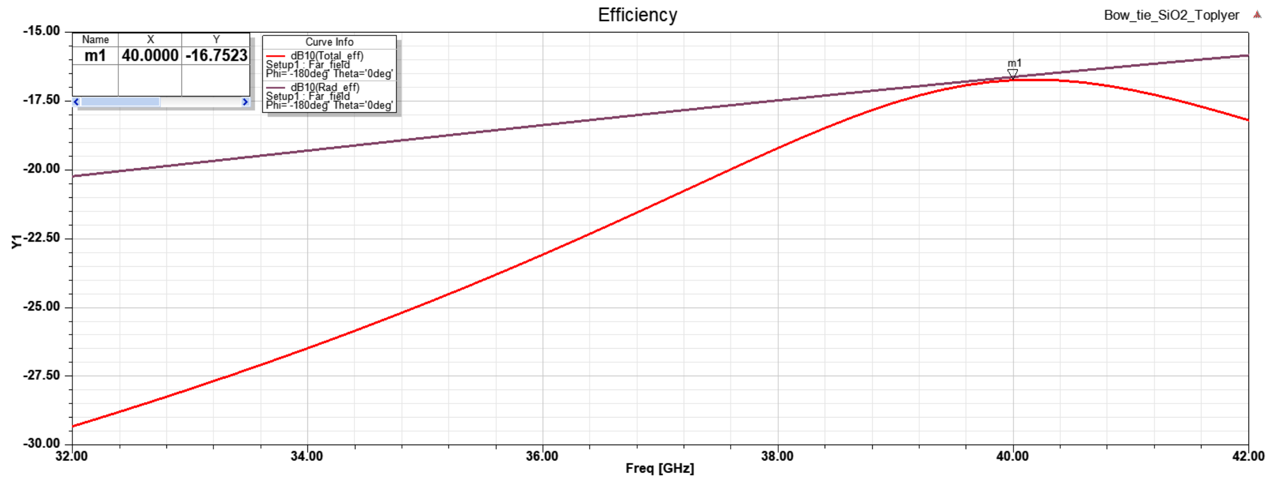

Fig. 6. Gain For Bow-Tie Antenna

Fig. 4, Fig. 5 and Fig. 6 shows plots for S11, VSWR and gain Vs frequency for the Bow tie antenna developed using HFSS and it is evident that all three parameters fall within the specified range considered.

Another antenna into consideration is PLPA antenna which is frequency independent and the resonant frequency depends on the size of the antenna. The PLPA antenna with matching elements, originally designed to operate at around 60 GHz and simulated. As shown in Fig. 7, a 0.1 mm layer of SiO_2 is added below the antenna structure. This reduces the effective dielectric permittivity value of the substrate. Hence, the dielectric losses are reduced. There is an increase in the far field simulation values by almost 75% (7dB). The variations of S11 and gain of the antenna are shown in Fig. 8 and Fig. 9.

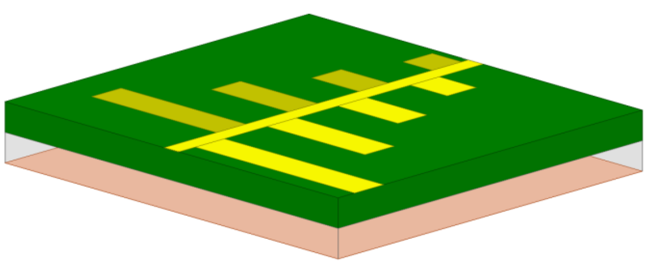

Fig. 7. PLPA with SiO2 (0.1mm thickness)

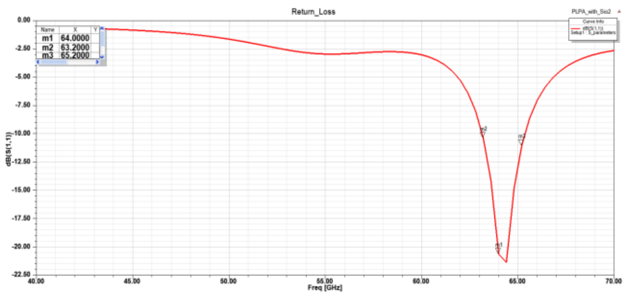

Fig. 8. S11 for PLPA

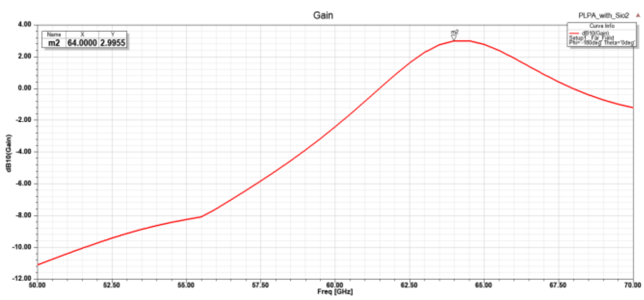

Fig. 9. Gain for PLPA

Retrieval Number: J92230881019/19©BEIESP
DOI: 10.35940/ijitee.J9223.0881019
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

Next work is to analyze the propagation mechanism of radio waves over inter-chip using bow tie transceiver antennas. The propagation of radio waves considered in frequency domain is from 30 GHz to 70GHz. Here the expectation is to get transmission coefficient S21 of at least -30dB for 1mm transmission distance. Fig. 10 shows transceiver antenna system and obtained S21 between the transceivers is tabulated in Table-II.

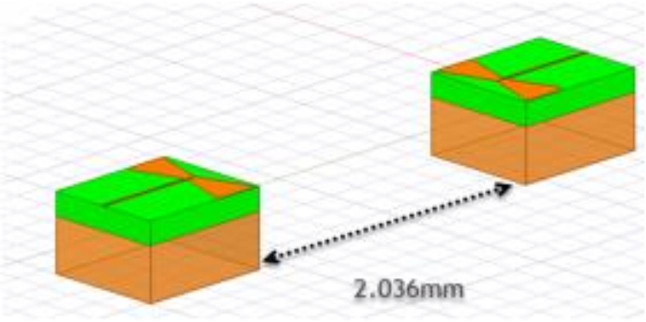

Fig. 10. Bowtie Antenna Transmitter-Receiver System with Matching

Table-II: S(2,1) Between Transceivers Of Fig. 10

Distance(mm)	S(2,1) in dB
0.2	-9.6
1.2	-32
2.2	-34
3.2	-35
4.2	-39.2

For the Bow-tie antenna transmitter-receiver system, it is seen from the Table-II that the received signal strength decreases with increase in distance. The received signal strength is maximum when the separation between transmitter and receiver antennas is 0.2 mm. Fig. 11 shows variation of S21 with frequency for various distances. The received signal is maximum at the resonant frequency of the antenna that is 49 GHz. When two antennas are placed inside a same radiation box for perfect isolation, the forward transmission coefficient, S21 has a value of -30dB which can be considered as the acceptable value for the proper reception. Hence, it can be assumed that the received signal power is low when the S21 value is below -30dB. The antennas can radiate effectively when the separations are less than 1 mm.

If we consider two different antenna types for the transmitter and receiver system i.e., PLPA and Bow-tie antenna, the performance variations of S12 and S21 is tabulated in Table-III. Fig. 12 shows Mixed Bowtie and PLPA Transmitter-Receiver system. Fig. 13 and Fig. 14 shows S11 of PLPA and S22 of Bow-tie antenna. S21 for mixed Transmitter-Receiver System at various distances can be seen in Fig. 15.

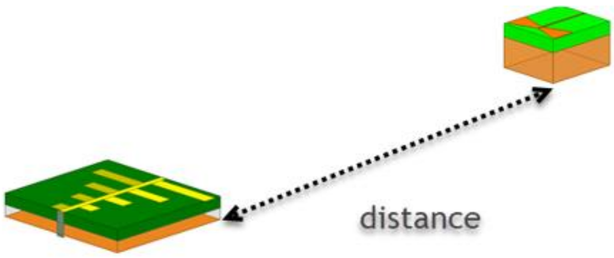

Fig. 12. Mixed Transmitter-Receiver System: Bowtie And PLPA Transmitter-Receiver System

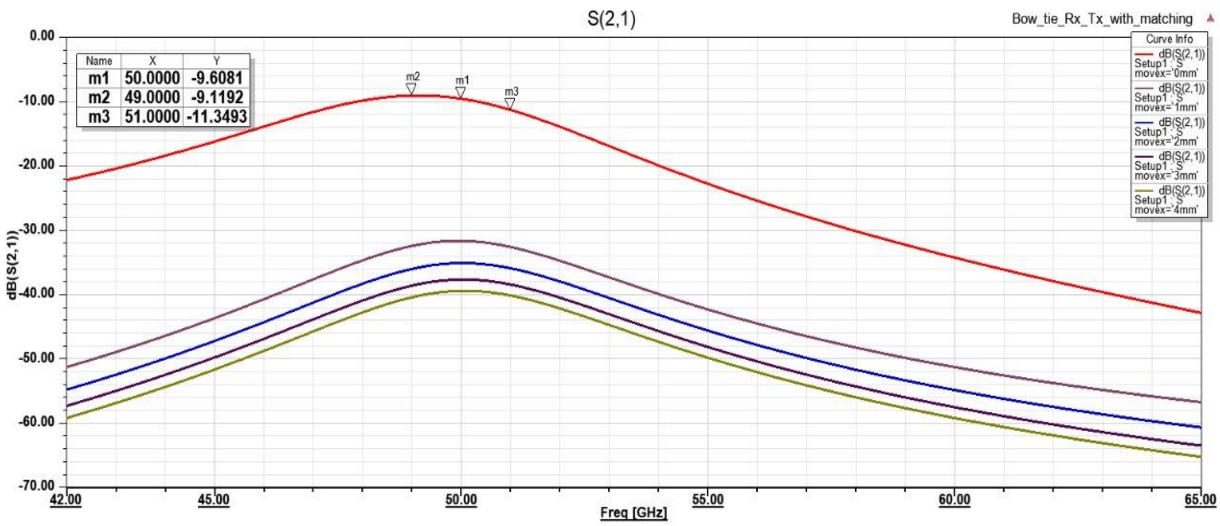

Fig. 11. S21 for Bowtie Antenna Transmitter-Receiver System at various distances

Retrieval Number: J92230881019/19©BEIESP
DOI: 10.35940/ijitee.J9223.0881019
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

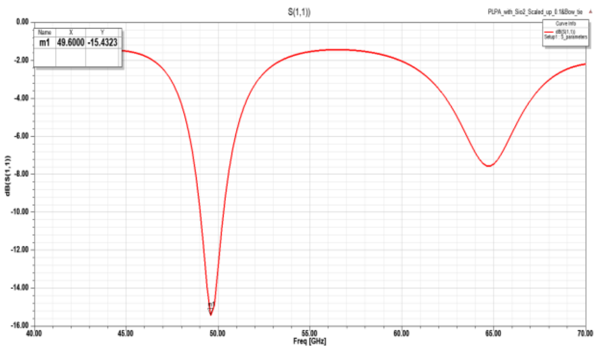

Fig. 13. S11 For Mixed Transmitter-Receiver System (PLPA Antenna)

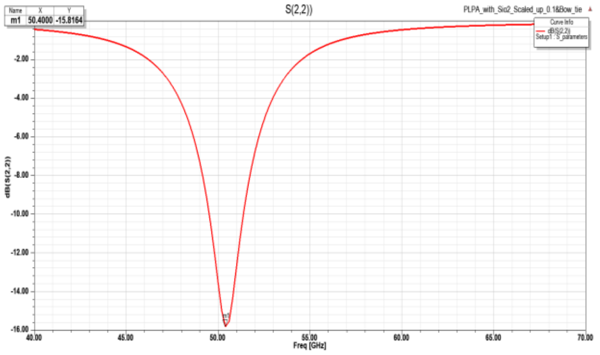

Fig. 14. S22 For Mixed Transmitter-Receiver System (Bow Tie Antenna)

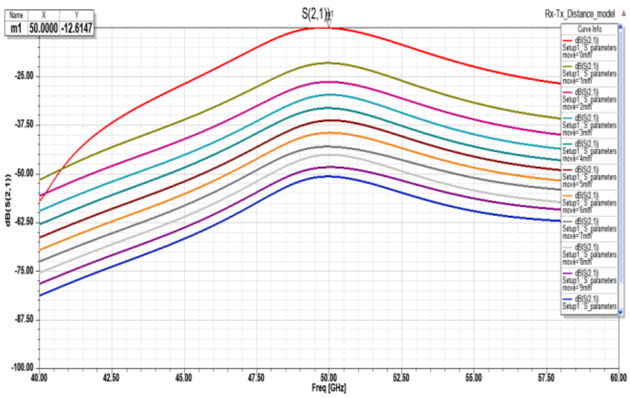

Fig. 15. S21 For Mixed Transmitter-Receiver System At Various Distances

The PLPA operating at a resonant frequency of 64 GHz is scaled by 110% of its original size. This aids the design of a transmitter receiver system, where the PLPA resonates at the same resonance of Bow Tie antenna, 50 GHz. It can be assumed that the received signal power is low when the S21 value is below -30dB. The antennas can radiate effectively when the separations are less than 3.5 mm. It can also be seen that the two antennas radiate at 49.4 GHz and 50 GHz respectively.

Table-III. Parametric Analysis of Bow-Tie & PLPA Transmitter Receiver System

Distance (mm)	S(2,1) in dB	S(1,2) in dB
0.5	-12	-11
1.5	-22	-23
2.5	-27	-26
3.5	-31.25	-28
4.5	-34	-32
5.5	-37	-36
6.5	-39	-38
7.5	-41.25	-41.5
8.5	-45	-43
9.5	-47	-46
10.5	-51	-50.5

A. Intra-chip Bowtie Antenna Transmitter-Receiver System

To analyse the performance of intra chip, a setup of four bow-tie antenna are placed in four corners with the distances as shown in the Fig. 16. The reception of the signal and S-parameter analysis is shown in Table-IV. Fig. 17, Fig. 18, Fig.19 and Fig. 20 shows the received signal strengths of the intra-chip antenna. During simulation, one antenna acts as the transmitter, while three other antennas behave as receivers.

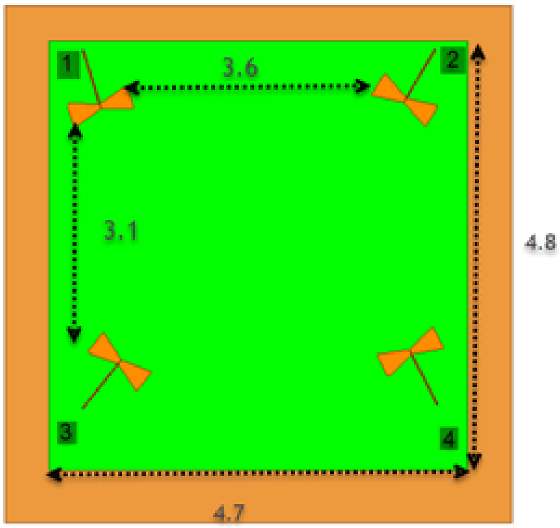

Fig. 16. Intra-Chip Arrangement For Bowtie Antennas On Sio2 Substrate

Retrieval Number: J92230881019/19©BEIESP
DOI: 10.35940/ijitee.J9223.0881019
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

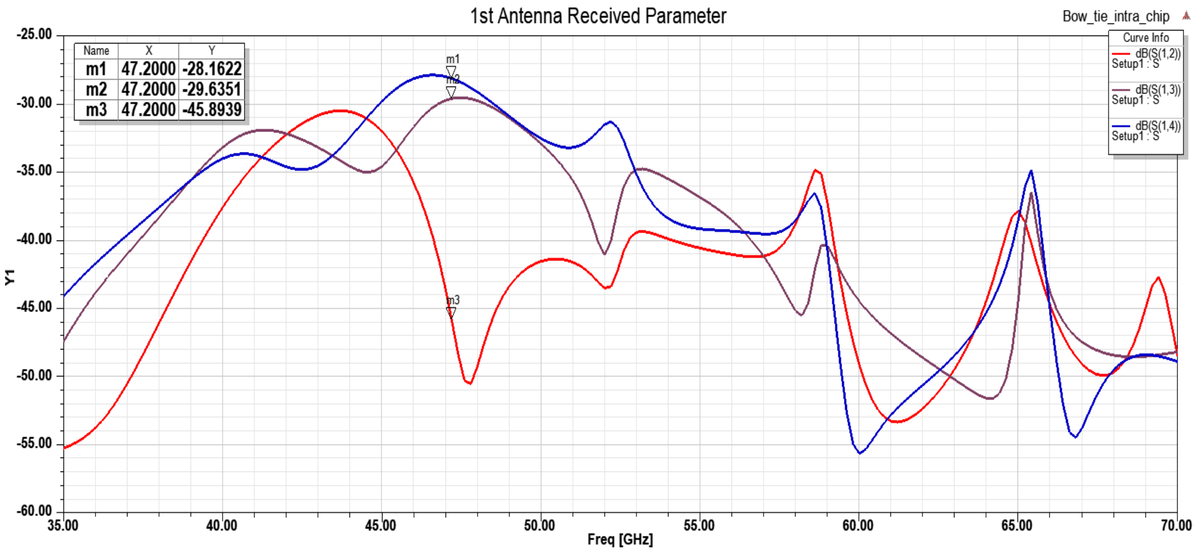

Fig. 17. S Parameters For Intra-Chip System With 1st Antenna As Receiver

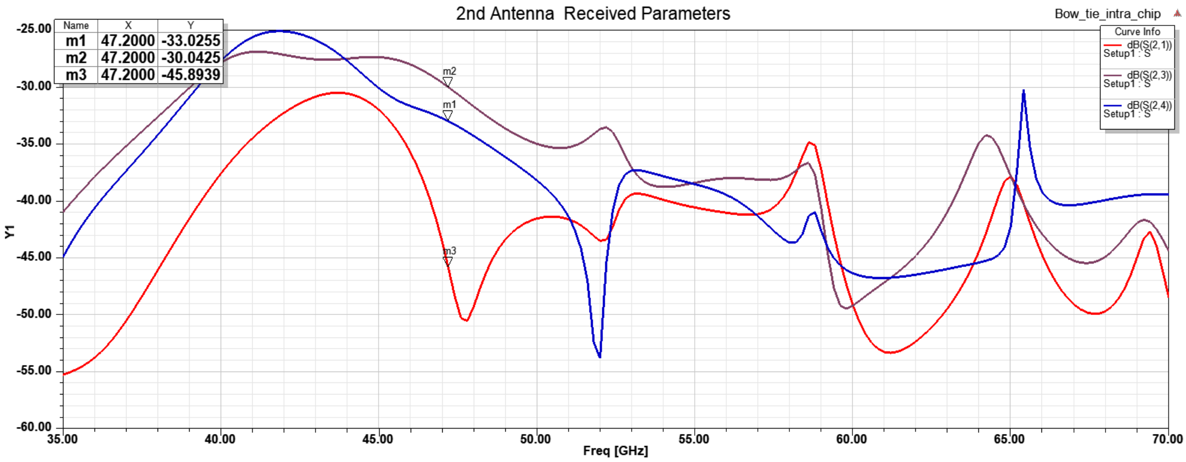

Fig. 18. S Parameters For Intra-Chip System With 2nd Antenna As Receiver

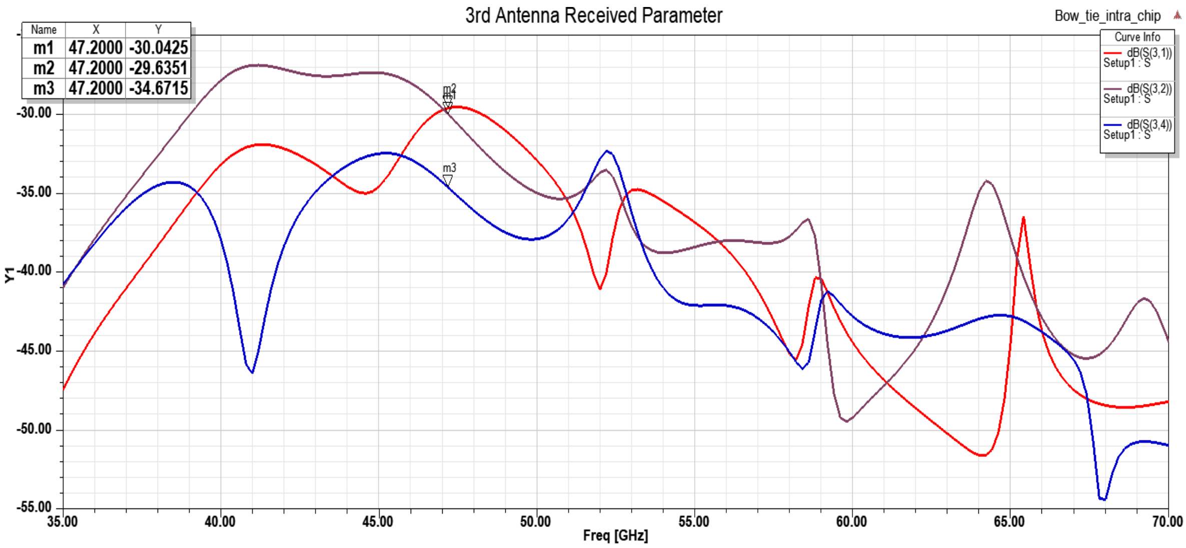

Fig. 19. S Parameters For Intra-Chip System With 3rd Antenna As Receiver

Retrieval Number: J92230881019/19©BEIESP
DOI: 10.35940/ijitee.J9223.0881019
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

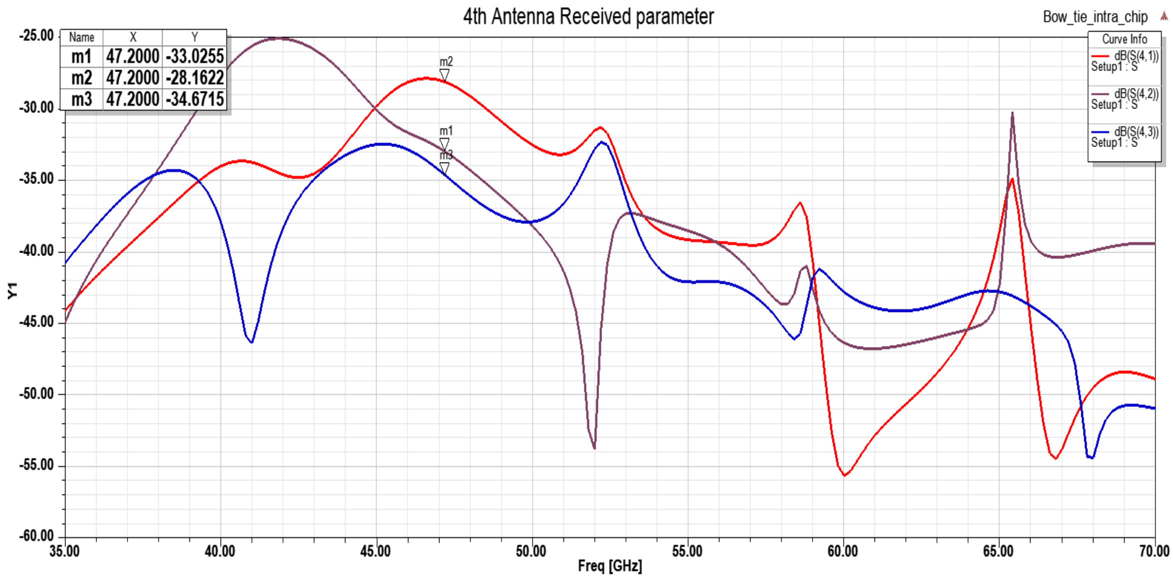

Fig. 20. S Parameters For Intra-Chip System With 4th Antenna As Receiver

Due to the doughnut shaped radiation pattern of bowtie, the received signal strength obtained by the receivers vary. The received signals along the sides of the bowtie are relatively low when compared to the receiver placed right opposite the transmitter. As observed in Table-IV, the strength of the received signal varies for each antenna based on orientation and placement of antenna. Antenna 1 to/from antenna 3 and antenna 4 have better reception compared to antenna 2 from antenna 1 or vice versa.

Table-IV. S Parameters Of Bow-Tie Intra-Chip Structure

Received signal strength in dB	Antenna 1	Antenna 2	Antenna 3	Antenna 4
Antenna 1	-	-45.89	-29.63	-29.63
Antenna 2	-45.89	-	-30.04	-33.02
Antenna 3	-29.63	-30.04	-	-34.67
Antenna 4	-29.63	-33.02	-34.67	-

IV. CONCLUSION

The analysis of intra/inter chip communication is done in this work, using various scenarios considering the bowtie antenna, log periodic antenna simulations based on their return loss, gain, efficiency and radiation pattern. The frequency independent PLPA antenna has a resonant frequency that depends on the size of the antenna. The PLPA scaled down by 20% shows results with increased losses and lower efficiency. Therefore, antennas at higher frequencies should not be scaled down. The addition of SiO_2 layer reduces dielectric losses and increases frequency and gain. For interchip communication systems, the received signal strength decreases with increase in the distance. In intrachip communication with one antenna as transmitter and other three antennas as receivers, one of the receiving antenna receives more signal strength compared to other two due to the configuration and structure of antennas. To improve the results further, active layers of metals like Silver and Gold can be added and substrates of semiconductor materials like GaAs, GaN, InP, InAs and Graphene can be used. The overall analysis is done using S-Parameters.

ACKNOWLEDGMENT

Authors would like to thank Manu S and Sahana Rao for their assistance in construction of Antenna.

REFERENCES

1. Jau-Jr Lin, Hsin-Ta Wu, Yu Su, Li Gao, Aravind Sugavanam, Joe E. Brewer and Kenneth K. O, “Communication using antennas fabricated in silicon integrated circuits”, IEEE Journal of Solid-State Circuits, Vol. 42, Issue: 8, 2007, pp 1678 – 1687.
2. P.J. Guo, and H.-R. Chuang, “A 60-ghz millimeter-wave CMOS RFIC-on-chip meander-line planar inverted-F Antenna for WPAN applications”, 2008 IEEE Antennas and Propagation Society International Symposium, IEEE, 2008, DOI: 10.1109/APS.2008.4619464
3. Shun-Sheng Hsu, Kuo-Chih Wei, Cheng-Ying Hsu, and Huey Ru-Chuang, “A 60-GHz millimeter-wave CPW-fed Yagi antenna fabricated by using 0.18-µm CMOS technology”, IEEE Electron Device Letters, vol. 29, no. 6, June 2008, pp. 625-627. DOI: 10.1109/LED.2008.920852
4. W. Yang, K. Ma, K. S. Yeo and W. M. Lim, "A 60GHz on-chip antenna in standard CMOS silicon technology," 2012 IEEE Asia Pacific Conference on Circuits and Systems, Kaohsiung, 2012, pp. 252-255. DOI: 10.1109/APCCAS.2012.6419019
5. S. Pan and F. Capolino, "Design of a CMOS on-chip slot antenna with extremely flat cavity at 140 GHz," in IEEE Antennas and Wireless Propagation Letters, vol. 10, 2011, pp. 827-830, DOI: 10.1109/LAWP.2011.2163291
6. Adel Barakat, Ramesh Pokharel and Hala Elsadek, “Innovative techniques for 60-GHz on-chip antennas on CMOS substrate”, Microwave Systems and Applications, Sotirios K. Goudos, IntechOpen, 2017, DOI: 10.5772/66238.

7. Y. Dong, T. K. Johansen and V. Zhurbenko, "On-chip patch antenna on InP substrate for short-range wireless communication at 140 GHz," 2017 SBMO/ IEEE MTT-S International Microwave and Optoelectronics Conference (IMOC), 2017, pp. 1-5. DOI: 10.1109/IMOC.2017.8121032
8. http://www.antenna-theory.com/antennas/patches/antenna.php
9. X. Timoneda et al., "Millimeter-wave propagation within a Computer chip package, "2018 IEEE International Symposium on Circuits and Systems (ISCAS), Florence, 2018, pp. 1-5. DOI: 10.1109/ISCAS.2018.8351875.
10. https://www.ansys.com/en-in/products/electronics/antennas
11. https://www.optenni.com/
12. Saeid Karamzadeh, Oğuz Furkan Kilic, Ahmet Said Hepbicer and Fatih Demirbas, “Bow-Tie antenna design for GPR applications”, International Journal of Electronics, Mechanical and Mechatronics Engineering, Vol.6, No.2, 2016, pp.1187-1194.
13. Md Shahriar Shamim, Naseef Mansoor, Aman Samaiyar and Shobha Sundar Ram, “Energy-efficient wireless network-on-chip architecture with log-periodic on-chip antenna” GLSVLSI 14 Proceedings of the 24th edition of the great lakes symposium on VLSI, 2014, pp. 85-86. DOI: 10.1145/2591513.2591566
14. N. H. Noordin, Y. C. Wong, A. T. Erdogan, B. Flynn and T. Arslan, "Meandered inverted-F antenna for MIMO mobile devices," 2012 Loughborough Antennas & Propagation Conference (LAPC), Loughborough, 2012, pp. 1-4, DOI: 10.1109/LAPC.2012.6402948.

AUTHORS PROFILE

Deepa N P, obtained her Bachelor’s degree in Electronics and Communication Engineering from Kuvempu University, Karnataka, India and Masters in Digital Communication Engineering from Visvesvaraya Technological University, Belagavi, Karnataka, India. She is a part time research scholar in the field of short range wireless communication and has 15 years of teaching experience in various engineering colleges. She has guided many post graduate and undergraduate students for their final year projects. She has published research papers in various journals and national / international conferences. Her area of interest includes Wireless communication, Network on Chip, RF and Microwave, Signal Processing and Image processing.

Dr. K. L. Sudha, obtained her Bachelor’s degree in Electronics and Communication engineering from Mysore University and Masters from Bangalore University. She got Ph.D for her work on “Detection of FH CDMA signals in time varying channel” from Osmania University, Hyderabad. She has 20 years of teaching experience in Engineering Colleges. She has executed two ISRO funded research projects successfully as principal investigator. She is supervising seven PhD scholars and has guided many post graduate and undergraduate students for their projects. She has published more than 60 research papers in national / International journals and conferences. Her research interests are Wireless communication, coding theory, image processing and chaotic theory.