DESIGN, SIMULATION AND ANALYSIS OF 5G mm WAVE BEAMFORMING

Report submitted to the SASTRA Deemed to be University

as the requirement for the course

ECE300: MINI PROJECT

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May 2023

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BONAFIDE CERTIFICATE

This is to certify that the project work entitled "**Design , Simulation and Analysis of 5G mm Wave Beamforming**" is a bonafide record of the work carried out by Padmanabhan G(124004430), Sabarish P(124004257), Naveen S (124004404) students of third year B.Tech. Electronics and Communication Engineering, in partial fulfillment of the requirements for the award of the degree of B.Tech. in Electronics & Communication Engineering of the **SASTRA DEEMED TO BE UNIVERSITY, Thirumalaisamudram, Thanjavur - 613401**, during the year 2022 -23.

Name of the Internal Guide :

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Examiner -I **Examiner-II**

SCHOOL OF ELECTRICAL AND ELECTRONICS ENGINEERING

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Declaration

I declare that the report titled "**Design, Simulation and Analysis of 5G mm Wave Beamforming**" submitted as an original work done by me under the guidance of **Dr. Yogeshwari P (AP-Research/ECE/SEEE), SCHOOL OF ELECTRICAL AND ELECTRONICS ENGINEERING,** SASTRA Deemed to be University during the sixth semester of the academic year 2022-23, in the **SCHOOL OF ELECTRICAL AND ELECTRONICS ENGINEERING**. The work is original and wherever we have used materials from other sources, we have given due credit and cited them in the text of the report. This report has not formed the basis for the award of any degree, diploma, associate-ship, fellowship or other similar title to any candidate of any University.

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ACKNOWLEDGEMENTS

First and foremost, we are thankful to God Almighty for giving us the potential and strength to work on this project fruitfully. I express our gratitude to **Dr. S. VAIDHYASUBRAMANIAM**, Vice- Chancellor, SASTRA Deemed to be University for providing us with an encouraging platform for the course of study. We also thank **Dr. R. CHANDRAMOULI**, Registrar, SASTRA Deemed to be University for providing us the opportunity to work in the SEEE, SASTRA Deemed to be University for the course of the work. We render our solicit thanks to **Dr. K. THENMOZHI**, Dean, SEEE and **Dr. K. SRIDHAR**, Associate Dean, ECE, SASTRA Deemed to be University for introducing this Project Based paper in our curriculum.

We owe a debt of earnest gratitude towards our guide **Dr. P. YOGESHWARI** (AP-Research/ECE/SEEE) and **Smt.Sumathi R** (Assistant Professor-III-ECE) for their continued support and guidance throughout the duration of our project on the topic "**Design, Simulation and Analysis of 5G mm Wave Beamforming**". The intriguing questions raised by our panel members **Dr. NARASIMHAN K** and **Dr. RAJKUMAR G** from the department of ECE helped us in shaping this project to its worth. We take this opportunity to thank all our lecturers who have directly or indirectly helped our project. We also extend our sincere thanks to our parents for their continuous moral support and friends without whose thought-provoking suggestion and encouragement, along with our guide, this work would not have been what it is today.

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ABBREVIATIONS

1. RFIC – Radio Frequency Integrated Chips
2. IoT – Internet of Things
3. SNR – Signal to Noise Ratio
4. MIMO – Multiple Input and Multiple Output
5. SISO – Single Input and Single Output
6. RF – Radio Frequency
7. UE – User Equipment
8. BS – Base Station
9. CDL – Clustered Delay Line
10. OFDM - Orthogonal Frequency Division Multiplexing
11. HARQ - Hybrid Automatic Repeat Request

ABSTRACT

In 5G networks, beamforming is important because it helps to reduce interference, increase network capacity, and improve overall signal quality. By focusing the signal in a specific direction towards the intended receiver, beamforming can reduce the likelihood of interference from other devices and increase the signal-to-noise ratio, resulting in a clearer and more reliable signal. This project focuses on the design, simulation, and analysis of 5G mm Wave beamforming using System Vue software. To achieve this, a comprehensive literature review will be conducted to understand the relevant concepts and technologies, including beamforming, mm Wave, and System Vue. The project will identify the requirements and specifications for the beamforming system, evaluate the appropriate antenna array and RF front-end components, and implement the entire beamforming system using the signal processing algorithms available as DSP modules in System Vue. The simulation of the beamforming system, which will include both the transmitter and receiver components, will be conducted to analyze the system performance under different conditions. Metrics pertaining to the beamforming and system, such as Beam Pattern and SNR v/s Throughput, will be evaluated and presented using various plotting tools in SystemVue Software. Furthermore, this project is anticipated to contribute to the growing body of knowledge on 5G mm Wave beamforming and provide insights into enhancing network performance and user experience.

Specific Contribution:

- Padmanabhan G:
    1. Implemented various systems and block diagrams in SystemVue that provides analysis on various parameters of the established system. Also worked on designing tools required for the downlink wave system.
    2. The concept of beamforming and its impacts on 5G mm Wave Wireless Communication. Also, learnt using SystemVue software to create and model different subnets required for 5G beamforming and to implement the same in the main design.

- Sabarish P:
    1. Implemented the downlink 5G mm wave system consisting of transmitter, receiver and channel by using appropriate modules and parameters from SystemVue
    2. The key components of 5G beamforming for downlink network and its working were learnt. Also, Learnt the using of SystemVue software for applying the concepts for analysis.
- Naveen S:
    1. Implemented the Radio Frequency Integrated Chips (RFIC) phased antenna array using appropriate blocks to analyze beam patterns and other parameters in SystemVue
    2. Learnt to use SystemVue software to implement RFIC array and to analyze and interpret the array using the data flow analysis.

CHAPTER 1

LITERATURE REVIEW

Beamforming is a technique used in wireless communication and signal processing that focuses a wireless signal in a specific direction to improve the quality of a transmission. Beamforming works by manipulating the phase and amplitude of the signal to create constructive interference in the direction of the intended receiver and destructive interference in other directions.

Beamforming is a key technology in 5G mm Wave networks that is used to focus the transmitted signal towards the intended receiver in a specific direction, resulting in reduced interference, increased network capacity, and improved overall signal quality. By directing the signal towards the receiver, beamforming can enhance the signal-to-noise ratio, resulting in a more reliable and clearer signal. This is especially important for 5G mm Wave networks, which offer high bandwidths and data rates but suffer from shorter propagation ranges and attenuation

In the absence of beamforming technology, 5G mm Wave networks would face multitudinous challenges that could negatively impact the network's performance and degrade the user experience. Due to the highly directional nature of mm Wave signals, the signal suffers from lesser attenuation and has shorter propagation ranges. This would limit the content and capacity of the network and result in a poor signal quality, causing frequent disconnections and drops. Additionally, the directional signal could lead to significant interference from other devices, reducing the signal- to-noise ratio and further degrading the network's performance. Conversely, beamforming can overcome these challenges by directing the signal towards the intended receiver, resulting in a more dependable and clearer signal. By optimizing the beamforming algorithm and antenna array, the network's coverage and capacity can be enhanced, and hindrance from other devices can be minimized. likewise, beamforming can enhance the signal- to- noise ratio, leading to better spectral efficacy and refined data rates.

The proposed design aims to contribute to the growing body of knowledge on 5G mm Wave beamforming by designing and simulating a beamforming system using System Vue software. The design will identify the requirements and specifications for the system, select applicable antenna arrays and RF front- end constituents, and implement the beamforming system using signal processing algorithms available in System Vue. The simulation will be conducted to analyze the system performance under different conditions, assessing metrics such as Beam Pattern and SNR v/s Throughput. The results of this design will give perceptivity into enhancing network performance and user experience, which is pivotal for the successful deployment of 5G mm Wave networks.

CHAPTER 2

INTRODUCTION

Ever since the dawn of humanity, communication has been an indispensable part of history. May it be the sounds made by the cavemen or the binary language used to talk with robots, humans always want to communicate with each other. From using pigeons to deliver letters to talking with a person who is thousands of kilometers away in a blink of an eye, the modes of communication have grown along with humans. Modern communication has greatly improved the ways of exchanging information and has impacted our lives drastically. The antenna is a crucial component in modern communication systems. Antennas are the gates by which information is transmitted or received.

Antennas can be tuned to receive the specified frequencies, by which we filter them and use them for specific purposes. Antennas have a special property called **Directivity**. Directivity is a property of an antenna that measures the degree to which radiation is concentrated in a single direction.

Beamforming is a technique by which the antenna array can be steered to a specific direction to increase intensity of the beam in that particular direction. Basically, beamforming uses the property of directivity to focus the signals toward a specified region.

5G is the **fifth generation of mobile networks** that provides **faster internet speeds, lower latency, and higher bandwidth** compared to previous generations. It uses advanced technologies such as **millimeter waves, massive MIMO, and beamforming** to achieve higher data rates and better network performance.5G is expected to revolutionize industries such as healthcare, transportation, and manufacturing by enabling new applications and services that require high-speed connectivity and low latency. It is also expected to pave the way for the widespread adoption of technologies such as **augmented reality, virtual reality, and the Internet of Things (IoT)**. However, the deployment of 5G has raised concerns about its potential impact on public health and privacy, as well as its potential to exacerbate existing inequalities in access to digital technologies. As such, it is important to ensure that the **deployment of 5G is done in a responsible and equitable manner**, taking into account the concerns and needs of all stakeholders.

CHAPTER 3

BEAMFORMING

Wireless signals are steered to a specific receiving device via beamforming, a sort of radio frequency (RF) management. It sends out and directs powerful concentrated signals to a specific device via many antennas. These signals will have more direct connection and it is faster and reliable than it would be without beamforming. It can improve wireless bandwidth utilization and it can increase a wireless network range.

The beamforming approach involves transmitting pulses from each monitor at subtly different timings, giving the appearance of a single powerful pulse from a particular dominating projector hitting the target at about the same time.

Depending on the type or technique of beamforming, it functions differently. A beam producing antenna, and from the other hand, may change the signals it transmits out by combining many antennas that send out different data at different times. This change determines the optimum path for the signal to reach the client device. Beamforming, in a sense, moulds the Radiofrequency beam as it moves across physical space.

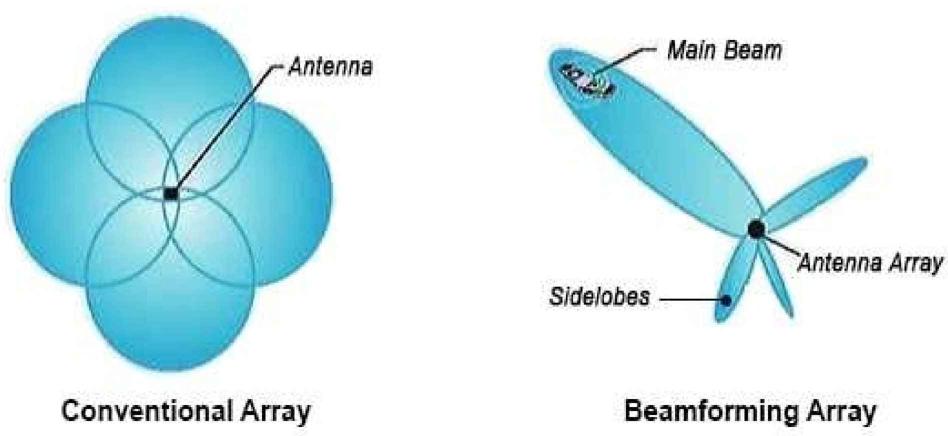

Fig 3.1 Types of Beamforming

CHAPTER 4
BEAMFORMING IN RFIC PHASED ANTENNA ARRAYS

Radio Frequency Integrated Chips transmits and receives radio waves. RF chips are found in portable telephones, cellphones, Wi-Fi devices, wireless routers, wireless base stations, satellite transceivers and microwave equipment.

A phased array is an array of antennas in which the relative phases of the signals feeding the antennas are varied in such a way that the signal is reinforced in a desired direction and suppressed in unwanted directions. RFIC phased arrays are arrays of antennas that are integrated with RFICs (Radio Frequency Integrated Circuits), which are highly integrated circuits that process and amplify radio frequency signals.

Phased array technology has many applications, including in radar systems, satellite communications, and wireless communication systems such as 5G. RFIC phased arrays are particularly useful in wireless communication systems as they allow for beamforming, which is the process of directing the signal in a specific direction to improve signal strength and reduce interference.

RFIC phased arrays are highly complex systems that require careful design and optimization to achieve the desired performance. They require high levels of integration and miniaturization to achieve the required functionality while minimizing size, weight, and power consumption. As such, they are typically designed using advanced software tools and simulation techniques to optimize performance and reduce development time.

Overall, RFIC phased arrays are a key technology in the development of advanced wireless communication systems, and their continued development is likely to drive further improvements in the performance and capabilities of wireless networks.

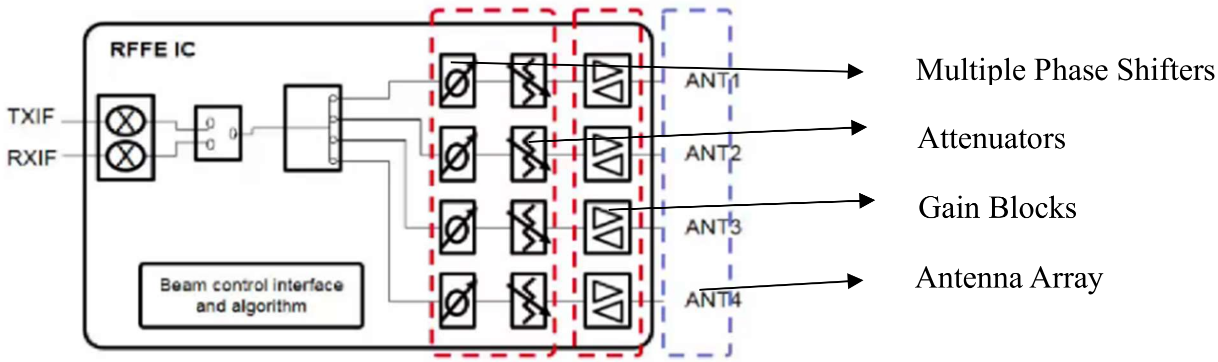

Fig 4.1. RFIC Phased Antenna Array

4.1 Block Diagram and working of RFIC phased array in SystemVue

The phased array TX/RX module is simulated using Keysight SystemVue design software. **Fig (3)** Shows the Tx/Rx module of RFIC phased array. The Tx/Rx module consists of antenna array, a switch to enable the transmit or receive path, Phase Array Combiner/Splitter, phase shifter arrays, array of attenuators and amplifier circuits.

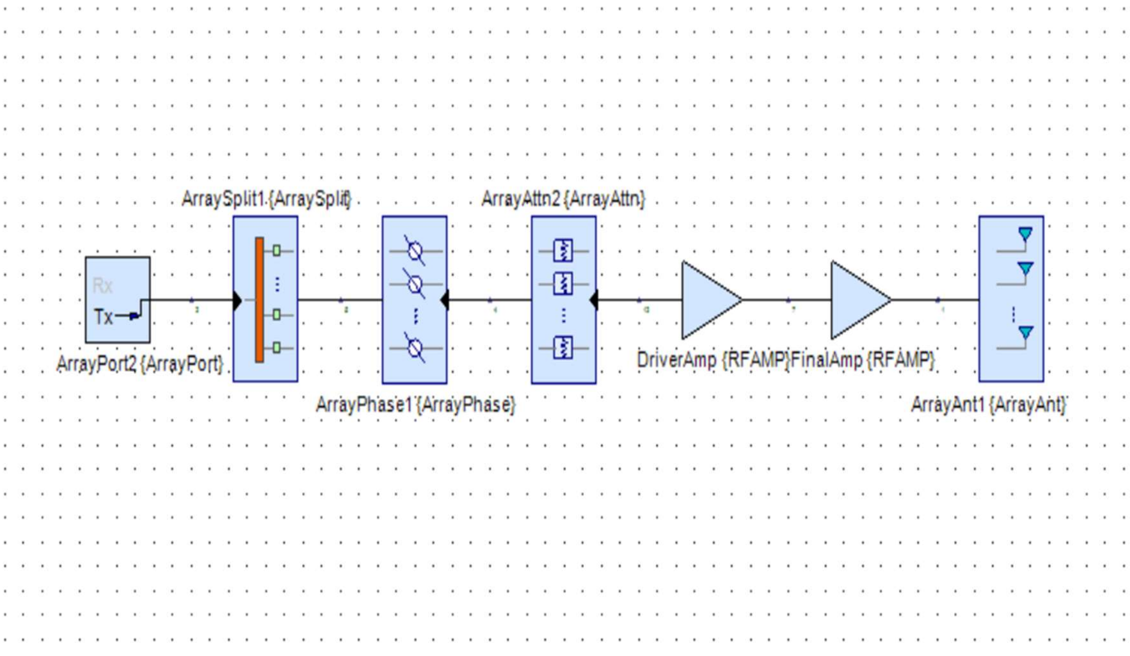

Fig 4.2. SystemVue Block Diagram of RFIC Phased Array

4.2 WORKING:

The Tx/Rx module of RFIC Phased Array starts with the Array Port Block as in fig (3), This block is used to group a set of signals or data values together into an array, simplifying the design process and improving system performance and it works in two modes Transmitter and Receiver respectively based on the direction of signal transmission. The space between the elements in the array is 0.5 times the wavelength.

In this particular mode we have attempted to simulate an 8x8 phased array, The signal that is received from the array port block is now passed on to the array splitter/combiner block that receives the signals from different elements and combines it or splits the signal into smaller chunks as per the mode of operation that is been taking place.

The signal after passing through the array splitter/combiner block reaches the vital Phase Array Shifter Module where in the phase of each signal is adjusted by using the desired beamTheta and beamPhi values, this adjustment is done so that the phased array system can steer the desired direction of the Transmitted or Received radio signals that has been fed.

After which the signal is fed on to the Phase Array Attenuator Model to adjust the amplitude of the signals going to each individual antenna element in the array. By adjusting the amplitude of the signals, the phased array system can control the power of the transmitted or received radio signals. We use Taylor window, which is a type of window function that is similar to Chebyshev window rather here it reduces the magnitude of the sidelobes and helps in improving the overall signal-to-noise ratio and reduces interference by providing the desired frequency of the main lobe by minimizing the side lobes.

The signals are fed into a series of amplifiers that is necessary to ensure whether the signals are strong enough to transmitted or received over long distances.

The antenna array, which receives or transmits the radio signal, often initiates the signal flow in the Tx/Rx module of an RFIC phased array. Depending on the operational mode, the switch then selects either the transmit or receive path to be operational. The Phase Array Combiner/Splitter combines or divides signals coming from each antenna element in the array into a single signal that is then supplied to each individual antenna element.

The phase, amplitude, and strength of the signals are then adjusted as necessary by the Phase Shifter Arrays, Array of Attenuators, and Amplifier Circuits. A signal that has been shaped to move in a particular direction or to be received from a specific direction depending on the operational mode of the system.

4.3 SIMULATION PARAMETERS:

SL NO.	PARAMETERS	VALUE
1	Distance between the Array elements	0.5mm
2	Frequency	28Ghz
3	Array State	1-Rx &2-Tx
4	Receiver Power Density	-50dbm
5	Number of elements	8
6	beamTheta	0^{o}to360^{o}
7	beamPhi	0^{o}to360^{o}
8	Insertion Loss	1db for combiner/splitter and attenuator
9	Array Type	Uniform Rectangular Array
10	Driver Amplifier and Final Amplifier Gain	15db and 20db

Table 4.1. Simulation Parameters

4.4 RESULT AND OUTPUT:

The simulation of the 8x8 RFIC is done by varying the angle of theta and Phi. The **Beam Shape Pattern** containing the desired signal direction as the main lobe and other minimized side lobes are obtained as in **figure (4.3,4.4,4.5)** respectively .and the **Directivity Cut** of the signals are also depicted in **figure (4.6)** where the maximum directivity is obtained at the specified angle as given during the simulation.

Beam Pattern:

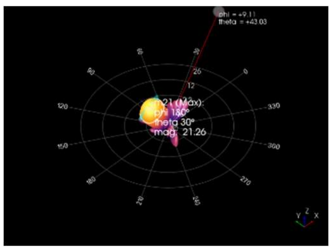

Fig 4.3

Isometric view

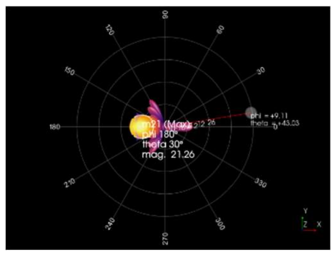

Fig 4.4

Top view

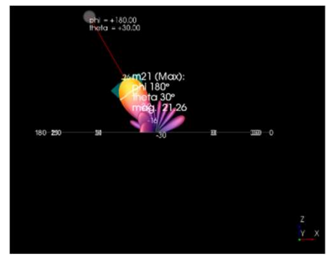

Fig 4.5

Front view

Directivity Cut:

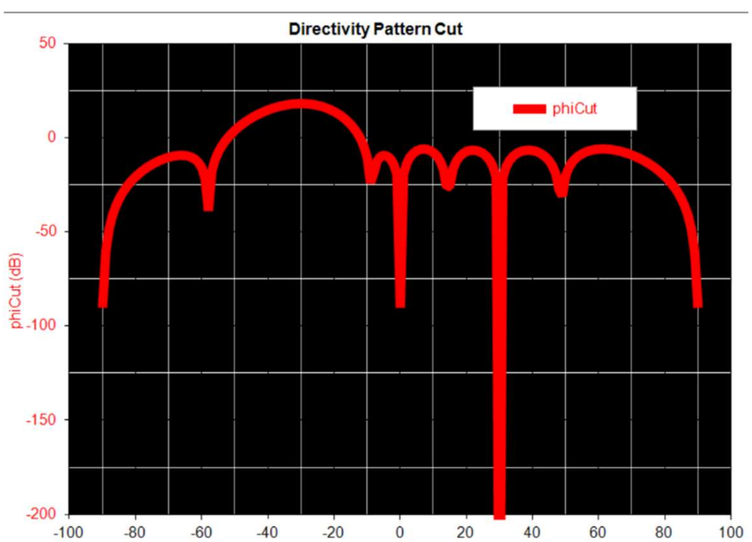

Fig 4.6. Directivity Cut of RFIC Phased Array

CHAPTER 5

5G mm WAVE BEAMFORMING

In this project, we simulate beamforming in a 5G downlink network using Keysight SystemVue software. We utilize the advanced modem library to import all the 5G components used in this simulation. The simulation is divided into different models, each performing a specific task. The different models involved in this simulation are shown below.

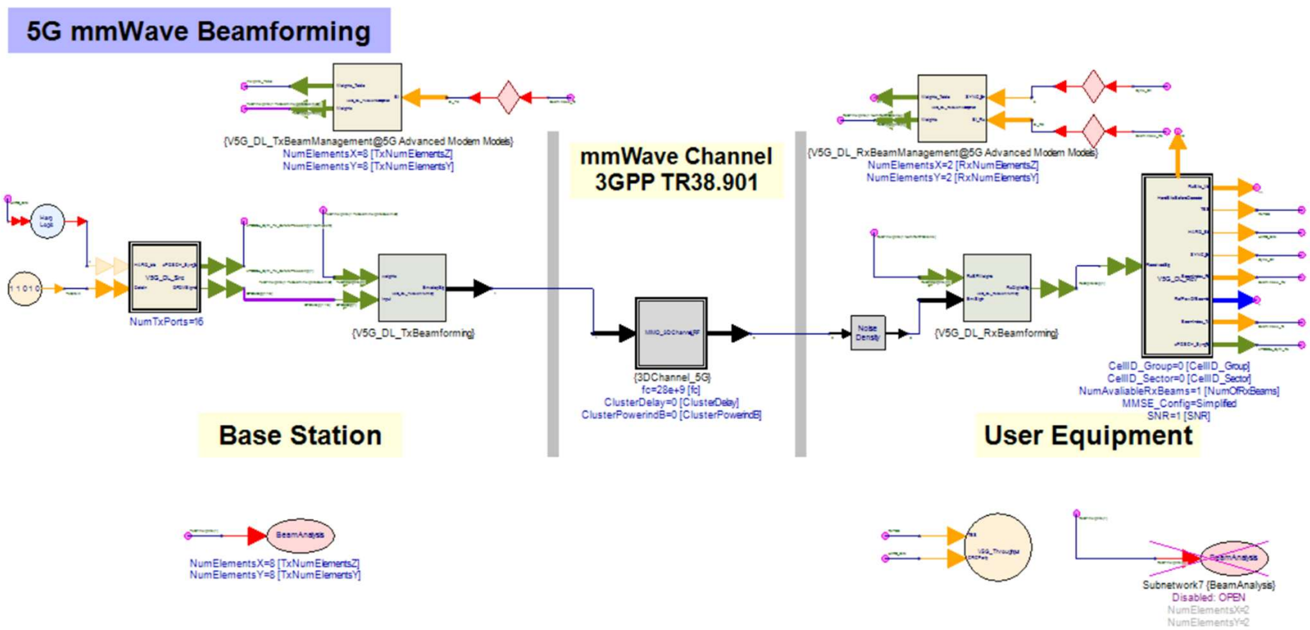

Fig 5.1. SystemVue Design of 5G mm Wave Beamforming

The image shows the overall design of the 5G mm wave beamforming setup. In a 5G downlink setup, there are three key components: the base station, the channel, and the User Equipment (UE).

1. Base Station: The base station is the central hub that communicates with the UE. It is responsible for transmitting data to the UE and receiving data from the UE. It is connected to the core network, which provides services such as billing, authentication, and routing.

2. Channel: The channel is the medium through which the base station communicates with the UE. In 5G, there are two types of channels: Control Channel and Data Channel. The Control Channel

is used for signaling between the base station and the UE, while the Data Channel is used for transmitting user data.

3. User Equipment (UE): The UE, also known as the mobile device, is the endpoint that communicates with the base station. It can be a smartphone, tablet, or any other device that is capable of connecting to a cellular network. The UE receives data from the base station through the downlink channel and sends data to the base station through the uplink channel.

5.1 Base Station parts involved and working:

- V5G_DL_Src@5G Advanced Modem Model
- V5G_DL_TxBeamforming

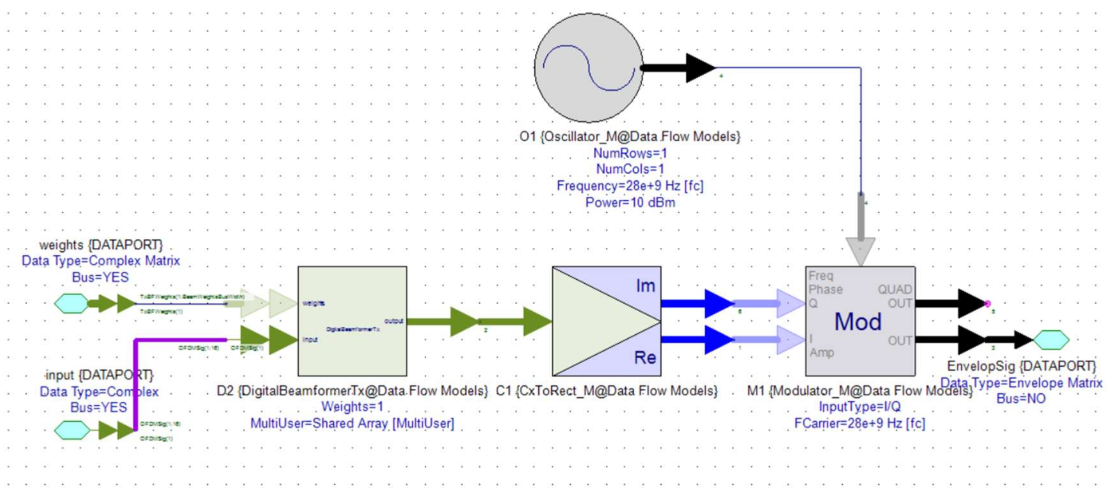

Fig 5.2. V5G_DL_TxBeamforming model

- V5G_DL_TxBeamManagement@5G Advanced Modem Models

- Harq logic

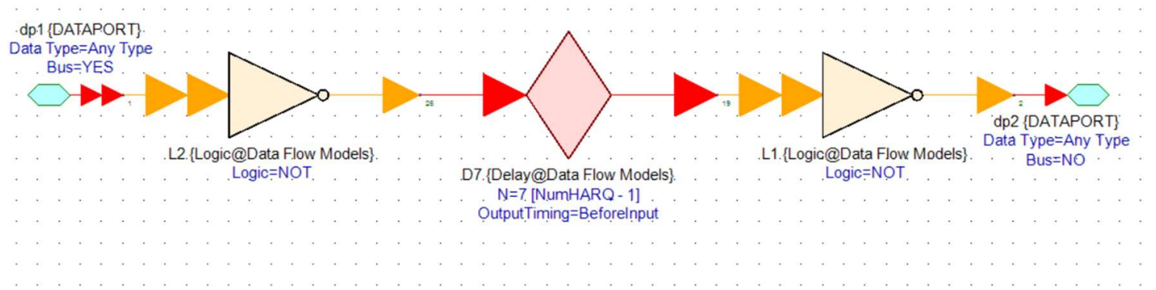

Fig 5.3. Harq Logic Model

- Data Pattern

The transmitter end consists of a 5G downlink source with two inputs, i.e., the bits to be transmitted provided by the data pattern model configured at PN9 pattern. The Harq logic is provided as input to facilitate retransmission of the bits if necessary. The V5G_DL_Src model generates OFDM signal and passed to the Tx Beamforming model.

The V5G_DL_TxBeamManagement model defines the transmitter side antenna array as an 8x8 array in the YZ axis with the spacing between each antenna element to be 0.5 wavelengths in the y,z-axis direction. beamforming weights are calculated from this module.

The V5G_DL_TxBeamforming model gets the OFDM signal and also the beamforming weights calculated from the V5G_DL_TxBeamManagement as inputs. Beamforming is performed on the OFDM signal and modulates the signal with the carrier frequency of 28e+9 Hz.

5.2 Channel parts involved and working:

- 3DChannel_5G

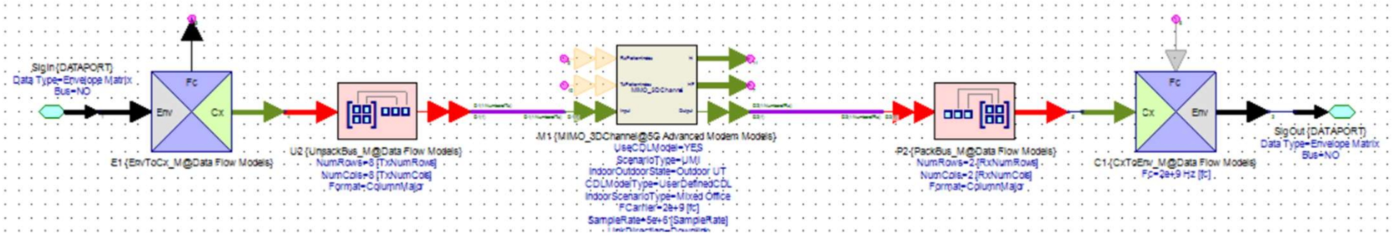

Fig 5.4. 3DChannel_5G model

The modulated output is then sent to the 3DChannel_5G model, which is a SISO channel. This model unpacks the 8x8 bus data and passes it through a SISO channel to provide output for a 2x2 antenna array at the receiver end or the user equipment. The MIMO channel model is designed to work as a SISO channel. The model is configured to work in CDL model (Clustered Delay Line) and cluster angles are defined.

5.3 User Equipment parts involved and working:

- AddNDensity_M@Data Flow Models
- V5G_DL_RxBeamforming

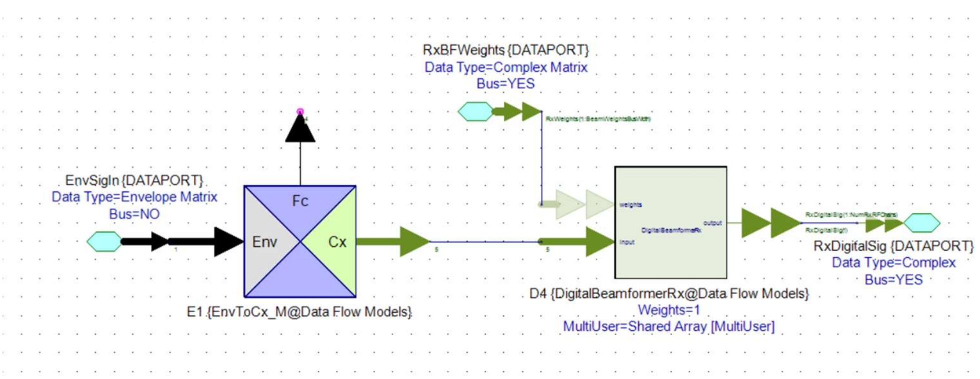

Fig 5.5. V5G_DL_RxBeamforming

- V5G_DL_Rcv@5G Advanced Modem Models
- V5G_DL_RxBeamManagement@5G Advanced Modem Models

The Noise density model (AddNDensity_M) adds constant noise to the output signal from the SISO channel to mimic the noise due to atmospheric disturbance to the signal. The parameter NDensity is calculated as:

$$NormalizationOfCh = 10*\log10(NumTxAnts) \tag{5.1}$$

$$BFGain\_Expected = 10*\log10(NumTxAnts*NumRxAnts) \tag{5.2}$$

$$NDensity = 10 - 10*\log10(1200*75e3) - (SNR - BFGain\_Expected - NormalizationOfCh) \tag{5.3}$$

The signal from the noise density model is then sent to the V5G_DL_RxBeamforming model.

The V5G_DL_RxBeamManagement similar to the V5G_DL_TxBeamManagement calculates the weights for beamforming. The V5G_DL_RxBeamManagement defines the receiver end to be a 2x2 antenna array in URA configuration in the YZ axis. The spacing between the antenna elements is 0.5 times the wavelength in y,z direction.

The Receiver beamforming model(V5G_DL_RxBeamforming) performs beamforming to the input given, with the weights calculated from the V5G_DL_RxBeamManagement model.

The signal is then finally sent to the receiver (V5G_DL_Rcv) model. Most parameters definitions are the same as the parameter definitions in the source (V5G_DL_Src) model. This model upon decoding the signal, gives output as transport block size, HARQ bits, and the sync enable/disable along with Beam Index for Tx and Rx.

5.4 Pattern visualisation and Throughput analysis:

The pattern visualization and analysis involve the following parts:

- BeamAnalysis

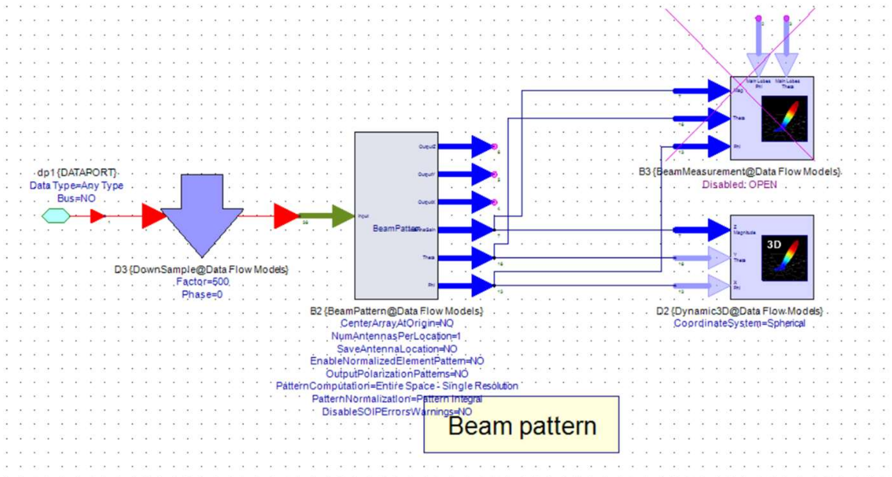

Fig 5.6. BeamAnalysis model

- V5G_Throughput@5G Advanced Modem Models

The beamformed signal at the base station and the user equipment are visualized and analyzed using the BeamAnalysis model. This model produces a run time 3D pattern of the beam. However, to reduce the system load on processing, the pattern is calculated at a rate down sampled by a factor of 500.

The throughput is measured using the V5G_Throughput model. This model uses the RxTBS and the HARQ bits from the V5G_DL_Rcv model to determine the throughput. The throughput is calculated from the 10th subframe till the 100th subframes received.

CHAPTER 6

RESULT AND CONCLUSION

In this work, the design of 5 mm wave beamforming from the Base station thorough the SISO channel, till the user equipment is done. The Noise density model acts as the external noise that degrades the signal. Upon varying the SNR to the Noise density model, we obtain signals of different strength at the output, that is the receiver.

The V5G_ThroughPut module analyses the output signal at the user equipment. Its take in the default parity bits to be the HARQ bits and the TBS at the receiver as its input. Upon running the data flow analysis with default sample setting, we obtain the Fraction % of maximum Throughput, Averaged BER and Averaged throughput at runtime of the simulation. The generated output values are updated for every 10 subframes received.

The data flow simulation is run several times corresponding to different values of SNR at the noise density model, to analyze the throughput. The line chart of SNR vs Fraction % of maximum Throughput is shown in Fig 6.2. Also, the dynamic plot of the beam pattern is obtained using the beamAnalysis model. This model displays the dynamic 3D plot of the beam pattern at the receiver as well as the transmitter end. The dynamic graph is shown in Fig 6.1.

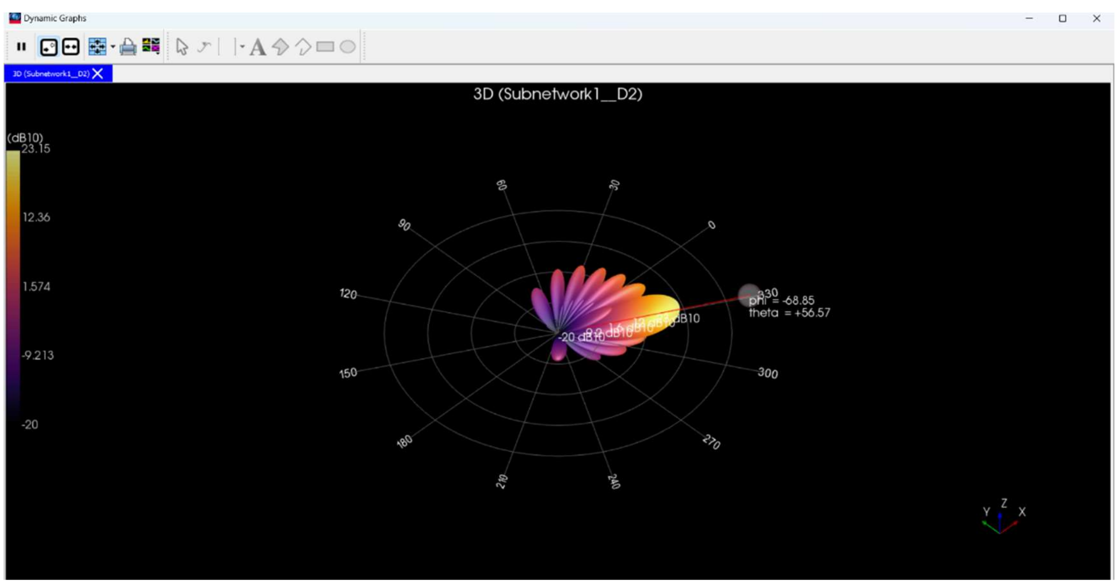

Fig 6.1. Dynamic 3D graph of the beampattern

SNR value	Fraction % of maximum Throughput	Averaged BER	Averaged throughput
0	0	1.000000	0
0.25	0	1.000000	0
0.5	1.18	0.988235	145333
0.75	25.88	0.741176	3197334
1	72.94	0.270588	9010667
1.25	95.29	0.047059	11772001
1.5	100.00	0.000000	12353334
2	100.00	0.000000	12353334
5	100.00	0.000000	12353334
10	100.00	0.000000	12353334

Table 6.1. Data Flow simulation output for different SNR

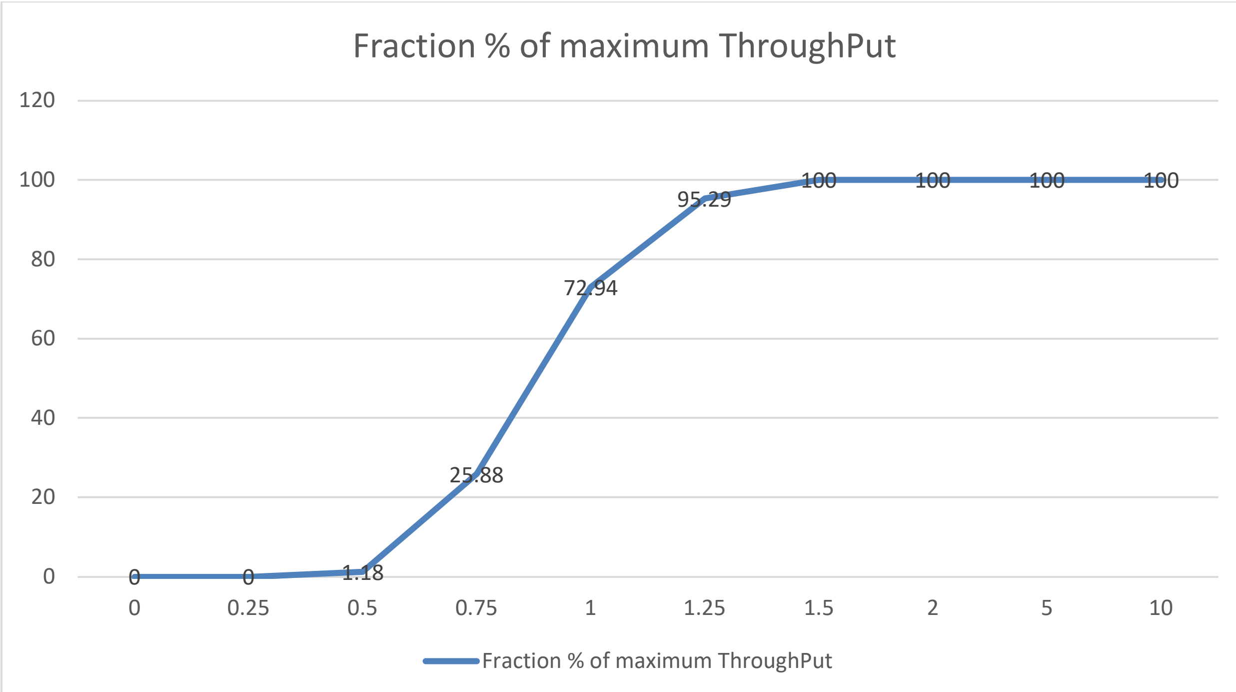

Fig 6.2. SNR vs Fraction % of maximum Throughput chart

As we can see from the data, when the SNR is zero or very low, the Fraction % of maximum ThroughPut is also zero. This is because the noise in the system is too high to allow any meaningful data transmission. As the SNR increases, the ThroughPut also increases gradually, until a certain threshold is reached.

At an SNR of 0.5, the ThroughPut is 1.18% of the maximum possible throughput. At an SNR of 0.75, the ThroughPut increases significantly to 25.88%, indicating a significant improvement in the system's performance. As the SNR increases further, the ThroughPut also increases rapidly, reaching 72.94% at an SNR of 1 and 95.29% at an SNR of 1.25.

At an SNR of 1.5 and above, the ThroughPut reaches its maximum value of 100%. This means that there is no further improvement in the ThroughPut even if the SNR is increased further.

The system's performance remains constant at 100% even at very high SNR values of 2, 5, and 10. This is because the system has already reached its maximum capacity, and any further increase in SNR does not result in any additional improvement in the ThroughPut.

Overall, the data shows that the SNR has a significant impact on the performance of a communication system. As the SNR increases, the ThroughPut also increases, until it reaches its maximum value. Beyond this point, any further increase in SNR does not result in any additional improvement in performance.

CHAPTER 7

REFERENCES

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APPENDIX

PLAGIARISM REPORT

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Document Information

Analyzed document	5.docx (D167094253)
Submitted	2023-05-16 04:11:00
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Sources included in the report

W	URL: https://www.everythingrf.com/community/what-is-beamforming Fetched: 2020-03-22 15:11:59	1
W	URL: https://www.techtarget.com/searchnetworking/definition/beamforming Fetched: 2021-09-20 11:58:51	1
W	URL: https://www.researchgate.net/publication/287699241_Design_and_Implementation_of_Phased_Array_A... Fetched: 2021-02-21 21:31:52	1

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Hit and source - focused comparison, Side by Side

Submitted text As student entered the text in the submitted document.

Matching text As the text appears in the source.

1/3	SUBMITTED TEXT 17 WORDS	62% MATCHING TEXT 17 WORDS
	Beamforming is a technique by which the antenna array can be steered to a specific direction	Beamforming is a technique by which an array of antennas can be steered to transmit radio signals in a specific direction.

W https://www.everythingrf.com/community/what-is-beamforming

2/3	SUBMITTED TEXT 48 WORDS	42% MATCHING TEXT 48 WORDS
	This change determines the optimum path for the signal to reach the client device. Beamforming, in a sense, moulds the Radiofrequency beam as it moves across physical space.	This adjustment determines the best path for the signal to take to reach the client device. In a sense, beamforming shapes the RF beam as it traverses a physical space.

W https://www.techtarget.com/searchnetworking/definition/beamforming

3/3	SUBMITTED TEXT 40 WORDS	84% MATCHING TEXT 40 WORDS
	A phased array is an array of antennas in which the relative phases of the signals feeding the antennas are varied in such a way that the signal is reinforced in a desired direction and suppressed in unwanted directions.	a phased array is an array of antennas in which the relative phases of the respective signals feeding the antennas are varied in such a way that the effective radiation pattern of the array is reinforced in a desired direction and suppressed in undesired directions.

W https://www.researchgate.net/publication/287699241_Design_and_Implementation_of_Phased_Array_Ante ...