ANALYSIS OF ANTENNA ARRAYS FOR MILLIMETER WAVE COMMUNICATION

Arpit Yadav[1], Mr. Nadeem Ahmad[2]

[1]*M.Tech, Electronic and Communication Engineering, GITM, Lucknow, India*
[2]*Assistant Professor Electronic and Communication Engineering, GITM, Lucknow, India*

---***---

Abstract - *This research combines a front-end RFIC with arrays of antennas operating at 60 and 28 GHz to steer the beam inside a 50-degree arc. Antenna arrays operating at 28 GHz enable 5G's high-speed, broadband data services. In order to send such a large amount of data to the core network through a fixed wireless access (FWA) link, a broadband, high-gain, steerable narrow-beam array is required. Antenna arrays at 60 GHz are presented in this thesis for use in FWA and backhaul applications. At 60 GHz (57-66 GHz), the proposed arrays consist of stacked patches and connected slots that are fed by a high gain lens antenna. Over 20 dBi of gain is available from the 216 stacked patches antenna array. The array and RFIC front end combine to provide a module with an EIRP of more than 40 dBm. The other array of 60 GHz antennas has sixteen parallel slots. A high-gain dielectric lens is fed by this source. This antenna has a maximum gain of 25.4 dBi. When the lens is used to deflect the beam away from the broadside, it actually increases in brightness. At 24.25–29.50 GHz, two tiny arrays of antennas transmit and receive. LP and CP arrays may be found in fan-out embedded wafer level ball-grid array (eWLB) packaging. Because the feed lines are shorter and there is no geometrical discontinuity, the antenna in package (AiP) approach saves money compared to PCB arrays and reduces integration losses. The LP array is made up of dipole antennas that are fed into a novel horn-shaped heatsink. The RF module's beam-steering range is 35°, and its peak EIRP is 34 dBm. The CP antenna array is made up of crossed dipoles, and the RF module can steer the antenna's beam by up to 50 degrees.*

***Key Words*:** Antenna arrays, Millimeter wave communication, Beamforming, Gain, Channel modeling, Link budget analysis, 5G wireless networks.

1. INTRODUCTION

Millimeter-wave frequency bands typically refer to the range of electromagnetic frequencies between 30 GHz and 300 GHz. This range of frequencies is higher than those typically used for traditional wireless communication systems, which typically operate in microwave frequency bands (less than 30 GHz). The millimeter-wave frequency bands offer several advantages for communication, including the ability to transmit large amounts of data at high speeds, as well as the ability to support a large number of simultaneous connections. However, these higher frequency bands also present several challenges, including higher atmospheric absorption, limited range, and sensitivity to blockage by obstacles. Despite these challenges, millimeter-wave communication is becoming increasingly important in applications such as 5G wireless networks, autonomous vehicles, and virtual reality systems, and research continues to explore ways to optimize millimeter-wave communication systems for reliable and efficient operation.

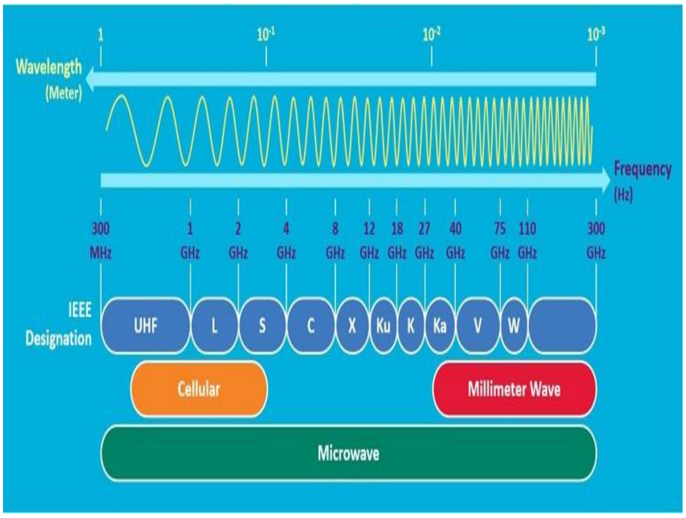

Figure-1: Millimeter-wave frequency bands.

The principle of millimeter-wave frequency bands is that they operate in the high-frequency range between 30 GHz and 300 GHz. Millimeter waves have a short wavelength, typically ranging from 1 mm to 10 mm, which is why they are called millimeter waves.

The use of millimeter waves for communication purposes offers several advantages over lower frequency bands. For example, millimeter waves have a large available bandwidth, which means that they can transmit large amounts of data at high speeds. Additionally, millimeter waves have a short range, which makes them ideal for use in densely populated areas where interference can be a problem.

However, millimeter waves have a limited ability to penetrate obstacles such as buildings and foliage. This means that they are not suitable for long-range communication, and are typically used for short-range, line-of-sight communication applications such as wireless local area networks (WLANs) and point-to-point communication links.

In summary, the principle of millimeter-wave frequency bands is based on their high frequency, short wavelength, large available bandwidth, and short-range communication capabilities.

The purpose of millimeter-wave frequency bands is to provide high-speed data communication and other applications that require high data rates and low latency. These frequency bands are used for a wide range of applications, including:

1. 5G Wireless Communication: Millimeter-wave frequency bands are a key component of 5G wireless communication networks, which offer faster data speeds and lower latency than previous generations of wireless networks.
2. Wireless Backhaul: Millimeter-wave frequency bands are used for wireless backhaul applications, which involve the use of wireless links to connect network components, such as cell towers and data centers.
3. Point-to-Point Communication: Millimeter-wave frequency bands are used for point-to-point communication links, which enable high-speed communication between two points without the need for physical cables.
4. Imaging and Sensing: Millimeter-wave frequency bands are also used for imaging and sensing applications, such as airport security scanners, automotive radar systems, and medical imaging devices.

1.1. Moisture Vapour and Oxygen Absorption Cause Mm-Wave Attenuation.

There is a possibility that moisture vapour, which is a component of the Earth's atmosphere, might absorb millimetre waves with frequencies ranging from 22 GHz to 183 GHz. Because the water molecules in the atmosphere are resonant at these frequencies, they are able to absorb and scatter the millimetre waves that are transmitted through the atmosphere. This resonance is the reason of this absorption that takes place. The degree of attenuation that takes place may be influenced by the amount of moisture that is present in the air, which may vary depending on the circumstances that are present in the atmosphere at the time.

On the other hand, oxygen absorption takes place at frequencies greater than 60 gigahertz. This is the point at which oxygen molecules in the atmosphere are able to absorb millimetre waves and cause them to scatter across the surrounding space. The absorption that occurs at these frequencies is caused by the spinning resonance of the oxygen molecules. Attenuation may be affected by the amount of oxygen that is present in the air in the same way that it can be affected by the amount of water vapour that is present in the air.

Several techniques, such as operating at higher frequencies, making use of directional antennas, and employing technologies that facilitate beamforming, are utilised in order to lessen the adverse effects that are brought on by the millimeter-wave signals' capacity to absorb oxygen and water vapour. Additionally, researchers are working to develop new materials and technologies, such as frequency-selective surfaces and metamaterials, that have the potential to lessen the impact of the attenuation that is caused by these factors. This work is currently ongoing.

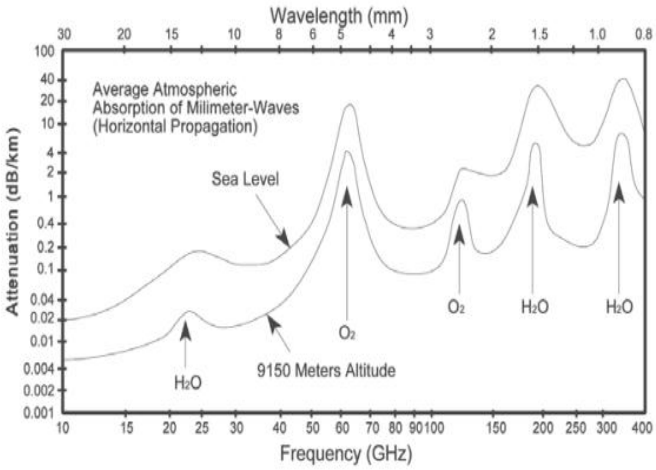

Figure-2: Moisture vapor and oxygen absorption cause mm-wave attenuation

2. ARRAY ANTENNA

An array antenna is a type of antenna that uses multiple individual antennas arranged in a specific pattern to create a combined signal with increased signal strength, directivity, and other desirable characteristics.

In an array antenna, each antenna element is usually connected to a single radio frequency (RF) chain, such as a transmitter or receiver. By combining the signals from multiple antenna elements, the array antenna can achieve various antenna characteristics, such as beamforming, beam steering, and spatial filtering.

There are various types of array antennas, including linear arrays, planar arrays, and conformal arrays. Linear arrays are typically used for directional applications and consist of a series of closely spaced, parallel antenna elements. Planar arrays, also known as planar phased arrays, are arranged in a two-dimensional plane and can achieve both directional and two-dimensional scanning. Conformal arrays are designed to conform to the shape of a specific object or surface, such as the fuselage of an aircraft.

Array antennas are commonly used in various applications, including wireless communication, radar systems, satellite communication, and radio astronomy. They offer several advantages over traditional single-element antennas, including improved signal strength, reduced interference, and increased flexibility and control over the antenna radiation pattern.

3. SMALL STRIP PATCH ANTENNA

A small strip patch antenna is a type of microstrip antenna that is characterized by a rectangular or square patch of metal that is printed on one side of a dielectric substrate, with a ground plane printed on the opposite side. A small strip patch antenna typically has a length that is much greater than its width, and a feed line or probe is used to connect the patch to the transmission line or other electronic circuitry.

The small strip patch antenna is commonly used for applications that require a low-profile, lightweight, and compact antenna. These antennas are typically less than one-tenth of a wavelength in size and are often used for wireless communication applications, such as in mobile phones, laptops, and other portable devices.

The performance of a small strip patch antenna is influenced by several factors, including the size and shape of the patch, the type and thickness of the dielectric substrate, and the feed point location. The resonant frequency of the antenna is determined by the dimensions of the patch and the effective dielectric constant of the substrate material.

Small strip patch antennas have several advantages over other types of antennas, including low cost, ease of fabrication, and the ability to integrate with other electronic components. However, they also have some limitations, such as low efficiency and narrow bandwidth, which can limit their performance in some applications.

4. PROBLEM STATEMENT

The rapid advancement in wireless communication technologies, particularly in the millimeter wave frequency range, has created a demand for highly efficient and reliable antenna systems. Antenna arrays have emerged as a promising solution for achieving high data rates, increased system capacity, and improved coverage in millimeter wave communication systems. However, the design, analysis, and optimization of antenna arrays for millimeter wave communication present several challenges that need to be addressed to fully exploit their potential.

The problem at hand is the lack of a comprehensive analysis and evaluation of antenna arrays specifically tailored for millimeter wave communication. Existing research primarily focuses on individual antenna elements or simplistic array configurations, without considering the intricate characteristics and challenges associated with millimeter wave frequencies. The limited understanding of the impact of array geometry, antenna element spacing, beamforming techniques, and other critical factors on the performance of millimeter wave antenna arrays hampers the development of optimal and efficient systems.

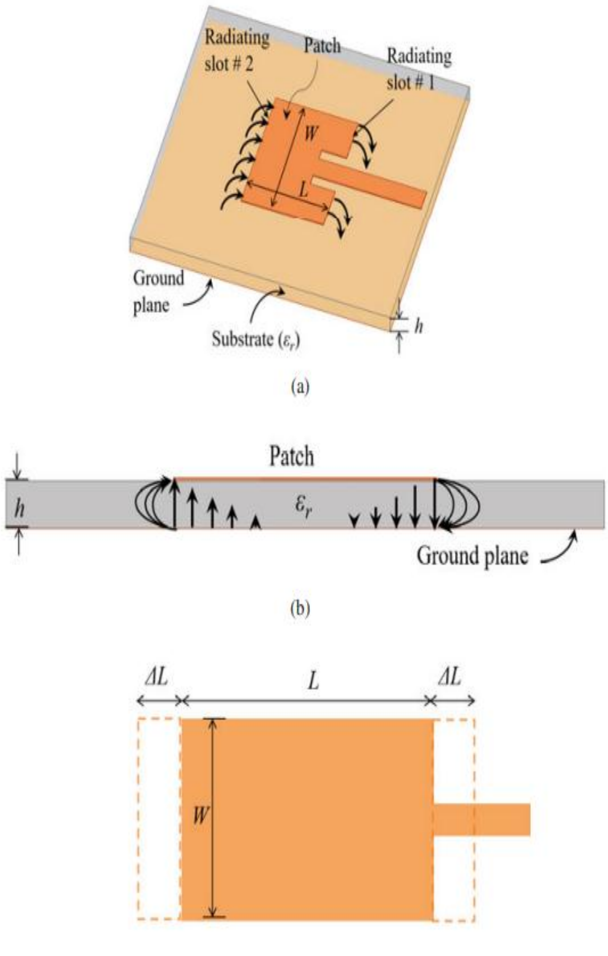

Figure-3: Microstrip patch antenna

5. RESULT AND ANALYSIS

Internet connectivity, mobile consumers and services, IoT, HD video streaming, and video chatting increase cellular data communications demand. Millimeter-wave bandwidth replaces microwave bands. This thesis' front-end RFIC and 60 GHz and 28 GHz antenna arrays guide the beam ±50° azimuth. 28 GHz 5G antenna arrays boost bandwidth. FWA transmits high-volume data to the core network from broadband, high-gain, steerable narrow-beam arrays. This thesis addresses FWA and backhaul 60 GHz antenna arrays. Stacks and slots feed a high-gain lens antenna in two 60 GHz (57-66 GHz) arrays. 20+ dBi 2×16 stacked patches antenna array. Array and front-end RFIC module EIRP surpasses 40 dBm. Another 60 GHz antenna array features sixteen evenly spaced linear slots. High-gain dielectric lens. 25.4 dBi peak gain. Lens scans away from broadside. 24.25–29.50 GHz antenna arrays operate. eWLBs feature LP/CP arrays. Shorter feed lines and no geometrical discontinuity make AiP technology cheaper than PCB arrays and eliminate integration losses. LP array dipole antennas power a horn-shaped heatsink. peak EIRP RF module beam-steers ±35°. RF module beam-steering is ±50° with 31 dBm peak EIRP. crossed dipoles. LHC accelerators and experiments need faster data rate front-end readout devices. This research explores 60 GHz wireless network CERN data readout. Different episodes attack 60 GHz wireless devices with 17 MeV protons (7.4 Mrad (RX) & 4.2 Mrad (TX)) and 200 MeV electrons (270 & 314 Mrad). Irradiated chips worked. Good results promote complex wireless communications research.

6. STACKED PATCHES OF ANTENNA

A stacked patches antenna is a kind of microstrip antenna that is made up of two or more patch elements that are either rectangular or square in shape. These patch elements are placed one on top of the other, with a dielectric substrate in between each layer, to create an antenna that has a stacked appearance. To connect each patch element to the feed line, either a through connection or another kind of electrical connection of some sort is used.

The performance of a stacked patch antenna is dependent on a variety of characteristics, some of which include the size and shape of the patch components, the distance between them, and the dielectric constant of the substrate material. Other parameters include the shape of the patch components and the distance between them. Because multiple patch components are piled atop one another in a stacked patches antenna, it is possible for this kind of antenna to attain superior gain, a wider bandwidth, and increased radiation characteristics when compared to a single patch antenna.

It is possible to construct stackable patch antennas in a number of different configurations, some of which include the co-planar configuration, the parallel configuration, and the series configuration, amongst others. In the co-planar configuration, the patch elements are placed so that they are all on the same side of the substrate, whereas in the parallel configuration, the patch elements are arranged so that they are all on separate sides of the substrate. The co-planar configuration is the more common of the two configurations. In the series design, the patch components are placed one on top of the other in a stacked pattern, with a dielectric layer providing electrical isolation in between each layer. This design is referred to as a "stacked" design.

Stacking patch antennas is a common technique that is used in a broad range of applications, such as radar systems, satellite communication, and wireless communication, amongst others. When compared to other types of antennas, they offer a number of advantages, including a lower overall cost, an easier manufacturing process, and the capacity to provide greater signal strength and a wider bandwidth than single-patch antennas. One illustration of these benefits is the capability of receiving frequencies from a wider spectrum. On the other hand, they do have a few downsides, such as a greater level of complexity and a lower level of efficiency at particular frequencies. These negatives are the result of a higher degree of complexity.

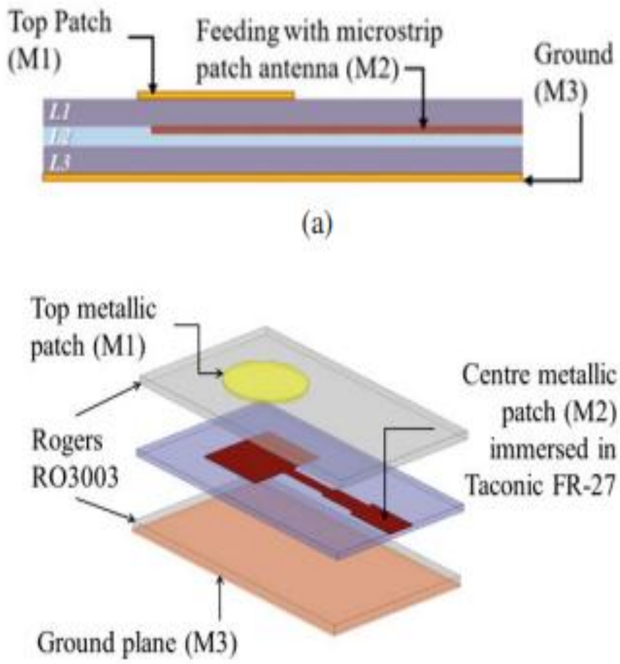

Figure-4: A proximity-fed circular patch and a microstrip-fed rectangular patch each have their viewpoint.

7. BEAM-BOOK GENERATION

Utilising a motorised turntable to spin the antenna in a plane that is perpendicular to the axis of the antenna is one of the more typical approaches that is used when monitoring beam-steering. In order to construct a radiation pattern, the antenna is first linked to a signal source and then to a power metre. Next, the signal power is measured at a number of different angles. The direction of the main lobe, the beamwidth, and the levels of the sidelobes are all crucial factors for the functioning of the beam-steering system, and they can all be determined by looking at the radiation pattern.

Utilising a phased array antenna is yet another way that may be used to measure beam-steering. An antenna known as a phased array is one that is made up of a number of radiating components, each of which is capable of being independently controlled to produce a beam that may be aimed in a particular direction. Adjusting the phase and amplitude of the signals that are delivered to each radiating element of a phased array allows one to steer the beam in a particular direction, which may be used to test the beam-steering performance of a phased array. After this, the signal power is measured at the target angle in order to assess the performance of the beam-steering system.

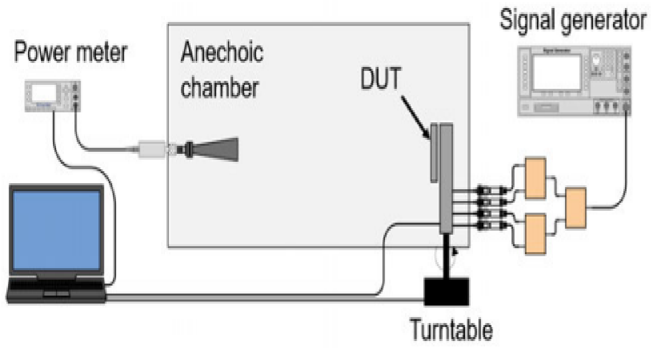

Figure-5: The measuring system used to create the TX beam book is shown in a block diagram.

8. ANTENNA ARRAY WITH STACKED 60 GHZ PATCHES

In the next portion of the paper, we will go through the findings of our investigation into the use of beam-steering on stacked patch antenna arrays. Due to the fact that the RFIC splits the paths for transmitting and receiving signals, full-duplex communication may be accomplished with just two arrays, each of which has sixteen antennas. In addition, when the scan angle is raised, the beam widths at -3 dB expand from roughly 6 degrees at the broadside to nearly 11 degrees at the extremes of the beam.

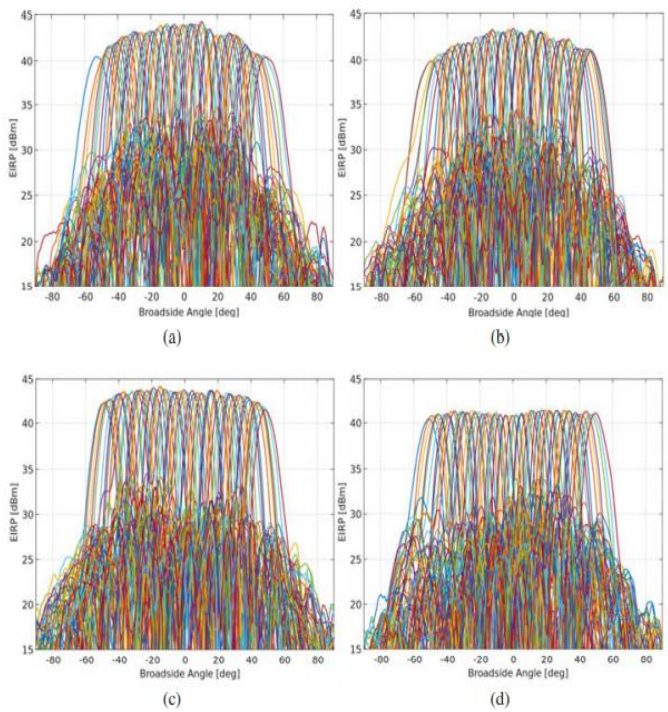

Figure-6: Antenna module supports four WiGig channels and 64 beam emission patterns. At 58.32, 60.48, 62.64, and 64.80 GHz, phase shifters have maximum gain and the signal chain is saturated.

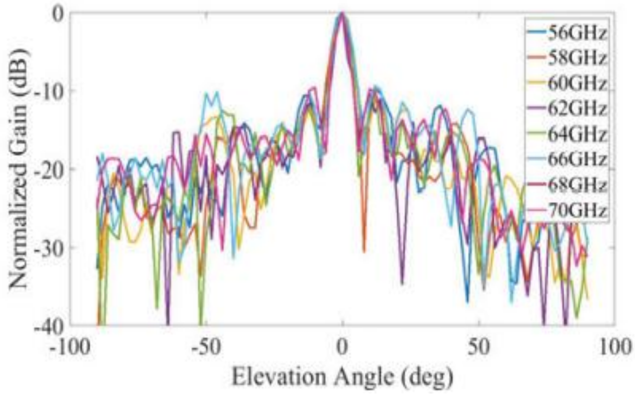

Figure-7: Radiation pattern at various frequencies between 56 GHz and 70 GHz, as measured in the elevation plane (E-plan).

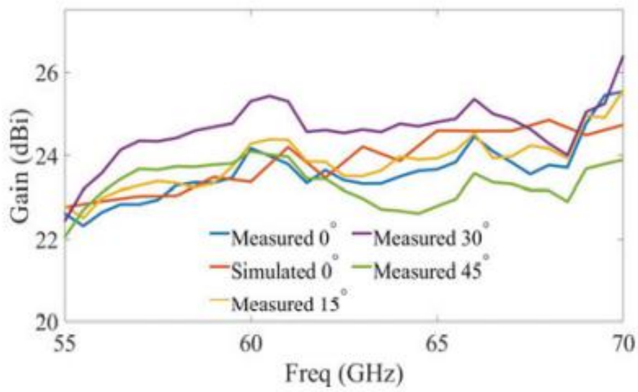

Figure-8: Gain was measured at a variety of beam angles, and simulated gain was also provided for the zero-degree beam.

9. CONCLUSION

Wireless data demand is rising, requiring millimeter-wave frequency ranges. Wireless data use has skyrocketed. Due to their greater bandwidths, 28 GHz and 60 GHz may meet these data needs, although propagation loss would increase. Losses need high-gain aerial arrays. Concentrating the beam requires beam-directing apparatus. This thesis examined 28–60 GHz aerial arrays. Front-end RFIC arrays guide the beam from -50 degrees to +50 degrees. 5G aerial arrays at 28 GHz will provide high-speed internet services. Aerial arrays use this frequency. Aerial arrays should give this. Fixed wireless access (FWA) homes and businesses in densely populated regions will get these services. Broadband, high-gain, steerable narrow-beam arrays require FWA connections. FWA connections move data faster. The primary network gets the massive data. This thesis describes 60 GHz aerial arrays meeting these criteria. They're suitable for front- and back-haul communications.

Input to a slot linked linearly at sixteen evenly spaced locations creates the 60 GHz second aerial array. This slot feeds an efficient dielectric lens, finishing the process. Weighted 16-degree feeds may azimuth-direct the main beam. This requires clockwise feeding. Four power splitters test the design's beam direction at 0, 15, 30, and 45 degrees. Power splitters direct beams. 0, 15, and 30 degrees. This aerial tested 25.4 dBi. It's potential. The lens eliminates scan loss when the beam is directed non-parallel, increasing gain. Something happens when the beam points away from the broadside.

REFERENCE

[1] Cisco. Cisco annual Internet report (2018–2023) white paper, March 9, 2020. https://www.cisco.com/c/en/us/solutions/ collateral/executive-perspectives/annual-internet-report/ white-paper-c11-741490.html.

[2] GSMA. Mobile internet connectivity 2019 global factsheet, 2019, Accessed on 2020-10-26. https://www.gsma. com/mobile for development/wp-content/uploads/2019/07/ Mobile-Internet-Connectivity-Global-Factsheet.pdf.

[3] Statista. Global mobile data traffic from 2017 to 2022, 2020, Accessed on 2020-10-26. https://www.statista.com/statistics/271405/ global-mobile-data-traffic-forecast/#statisticContainer.

[4] O. Semiari, W. Saad, M. Bennis, and M. Debbah. Performance Analysis of Integrated Sub-6 GHz-Millimeter Wave Wireless Local Area Networks. In GLOBECOM 2017 - 2017 IEEE Global Communications Conference, pages 1–7, 2017.

[5] Rohde Schwarz. 802.11ad - WLAN at 60 GHz A Technology Introduction, White Paper., 2017, Accessed on 2021-01-26. https: //scdn.rohde-schwarz.com/ur/pws/dl_downloads/dl_application/application_notes/1ma220/1MA220_3e_WLAN_11ad_WP.pdf.

[6] GSMA. The WRC Series – 26 GHz and 28 GHz, Oct 2019. Accessed on 2020- 10-27. https://www.gsma.com/spectrum/wp-content/uploads/2019/ 10/26-and-28-GHz-for-5G.pdf.

[7] S. Dittmeier, N. Berger, A. Schöning, H.K. Soltveit, and D. Wiedner. 60 GHz wireless data transfer for tracker readout systems - First studies and results. Journal of Instrumentation, 9(11), 2014.

[8] R Brenner and S Cheng. Multigigabit wireless transfer of trigger data through millimetre wave technology. Journal of Instrumentation, 5(07):c07002–c07002, jul 2010.

[9] H K Soltveit, R Brenner, A Schöning, and D Wiedner. Multi-gigabit wireless data transfer at 60 GHz. Journal of Instrumentation, 7(12):C12016–C12016, Dec 2012.

[10] R. Brenner, S. Ceuterickx, C. Dehos, P. De Lurgio, Z. Djurcic, G. Drake, J. L. Gonzalez Gimenez, L. Gustafsson, D. W. Kim, E. Locci, D. Roehrich, A. Schoening, A. Siligaris, H. K. Soltveit, K. Ullaland, P. Vincent, D. Wiednert, and S. Yang. Development of Wireless Techniques in Data and Power Transmission - Application for Particle Physics Detectors. pages 1–20, 2015.

[11] Karolos Potamianos. The upgraded Pixel detector and the commissioning of the Inner Detector tracking of the ATLAS experiment for Run-2 at the Large Hadron Collider. In The European Physical Society Conference on High Energy Physics, 2016.

[12] S. Dittmeier, R. Brenner, D. Dancila, C. Dehos, P. De Lurgio, Z. Djurcic, G. Drake, J.L. Gonzalez Gimenez, L. Gustafsson, D.-W. Kim, E. Locci, U. Pfeiffer, D. Röhrich, A. Rydberg, A. Schöning, A. Siligaris, H.K. Soltveit, K. Ullaland, P. Vincent, P. Rodriguez Vazquez, D. Wiedner, and S. Yang. Wireless data transmission for high energy physics applications. EPJ Web of Conferences, 150:1–8, 2017.

[13] K. C. Huang and D. J Edwards. Millimetre Wave Antennas for Gigabit Wireless Communications, chapter 1, pages 1–36. John Wiley & Sons, Ltd, 2008.

[14] Zhouyue Pi and F. Khan. An introduction to millimeter-wave mobile broadband systems. IEEE Communications Magazine, 49, 2011.

[15] H. T. Friis. A note on a simple transmission formula. Proceedings of the IRE, 34(5):254–256, 1946.

[16] David J. Lockwood. Rayleigh and Mie Scattering, pages 1097–1107. Springer New York, 2016.

[17] everything RF. 60 GHz long range communication, Accessed on 2020-10-07. https://www.everythingrf.com/community/ why-is-the-60-ghz-band-not-good-for-long-range-communications.