Lecture Notes in Networks and Systems 981

Mohamed Ridda Laouar ·
Valentina Emilia Balas · Vincenzo Piuri ·
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New Trends in Artificial Intelligence, Computing and Decision Making. Volume 1

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Contents

Bridging Sky to Network: FSO in 5G

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Abstract. A new optical transmission technique that offers high data speeds is known as free space optics (FSO), wide bandwidth, free licensing, and strong security. It presents an attractive solution to meet the connectivity needs of 5G, which has revolutionized our lives, as well as the requirements of the Internet of Things (IoT). However, FSO communication faces challenges, particularly in adverse weather conditions. This paper focuses on analyzing the performance of FSO links based on Orthogonal Frequency Division Multiplexing (OFDM) for 5G and IoT applications. Our study aims to evaluate the effectiveness of FSO technology by considering key factors such as data rate, laser power, bandwidth, and range. The obtained results demonstrate the successful achievement of a data rate of 10 Gbit/s, a laser power of 10 dBm, and a wide bandwidth of 6 GHz, which are suitable for 5G applications. Moreover, under clear weather conditions, a maximum range of 10 km has been achieved. The performance of the system is seriously affected by weather conditions such as snow and rain, and this must be noted in order to highlight the need for more focus in real FSO installations for 5G and IoT networks.

Keywords: FSO · 5G · optical network · free space optical · EVM · constellation · Link

1 Introduction

Rapid changes are being made to the telecommunications industry to keep up with users' increasing desire for constant access, regardless of where they are. As people look for new applications and services, technological development and societal needs have been the driving drivers behind this growth. Starting with the early intelligent telephone networks and continuing with today's high-speed vast area networks, communication networks have experienced constant development to keep up with these changing needs.

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However, the issues brought on by the rise in smartphone users and the extensive usage of social networking applications have not been entirely resolved by the introduction of fifth-generation (5G) networks. Due to the exponential rise in data consumption, the telecoms industry is currently experiencing a bottleneck as the demand for high-speed data rates continues to make it up. To offer smooth connectivity to users, this bottleneck presents a considerable barrier that needs to be overcome [1].

A type of optical-wireless communication called free-space optical communication (FSO) has surpassed conventional radio frequency (RF) communications in popularity [2, 3]. FSO communication has a number of benefits, including fast data transfer, secure communication, no use of electromagnetic waves, and no licensing requirements [4].

The ability to deploy FSO communication in a variety of locations and use the atmosphere as a medium for information signal transmission between the transmitter and receiver is another benefit. For best effectiveness, it does need a line of sight (LOS) link [5, 6]. In order to meet the bandwidth needs of data-intensive applications like social networking sites, video conferencing, high-definition television, cloud computing, and over-the-top services like Amazon Prime and Netflix, FSO networks offer high-bandwidth wireless communication links [5, 6].

Considering all of the benefits of FSO communication, it can be successfully used in new applications that need for fast transmission speeds. For instance, it can be used for 100 Gbps or more data transmission between high-altitude platforms and optical ground stations. Similar to how fixed-wing aircraft and hospitals may communicate using FSO technology to transmit data at speeds up to 1 Gbps. Furthermore, as shown in Fig. 1, it can satisfy the data communication requirements between quadcopter drones and residential buildings.

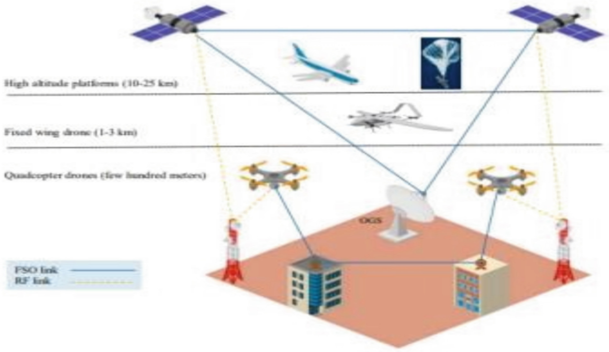

Fig. 1. FSO links have diverse applications in 5G and beyond networks [7].

However, diverse weather elements including snow, fog, and dust cause optical beam attenuation, which degrades the signal and affects the overall performance [8, 9]. The paper is structured as follows: Sect. 2 provides an overview of FSO technology, Sect. 3 presents the FSO system, Sect. 4 discusses the results obtained, and finally, Sect. 5 presents the conclusion.

2 FSO Technology

An advanced method called free-space optics (FSO), also known as fiber-free or fibreless photonics, permits the transmission of modulated light pulses by the free space medium, such as air or the atmosphere, to achieve high-speed and broadband communications [10]. In FSO communication, digital data is transmitted across the free space atmosphere using a narrow, tightly focused, and modulated optical laser beam, which is then received and processed at the receiving station [11]. It should be noted that line-of-sight (LOS) is a key component of FSO communication.

This means that at each networking location, the FSO transmitter and the FSO receiver must have a clear, straight line of sight in order to successfully communicate. The LOS condition makes sure that there are no natural obstructions, like trees or buildings, in the way of the transmission path between the two ends. This requirement is illustrated in Fig. 2, which demonstrates how a clear line of sight between the FSO transmitter and the FSO receiver is necessary for optimum performance. FSO lines show potential uses for 5G and future networks in a number of different applications. To satisfy the growing demand for data-intensive applications in urban settings, FSO lines provide a stable and fast connectivity option.

In addition, they offer a practical last-mile connectivity choice, bringing high-bandwidth services to underserved regions. As they efficiently manage the data transfer between cellular base stations and core networks, FSO connections are perfect for mobile backhaul. FSO lines are essential for quickly restoring communication infrastructure in disaster recovery situations. FSO links also make it possible for IoT devices to connect securely and effectively, facilitating the growth of IoT applications. The large capacity and secure communication channels of FSO networks are useful to the military and defense industries.

FSO links are also used in remote sensing and monitoring, which makes it easier to monitor and keep an eye on the environment. In general, FSO connections offer adaptable solutions across several domains to satisfy the evolving demands of 5G and future networks.

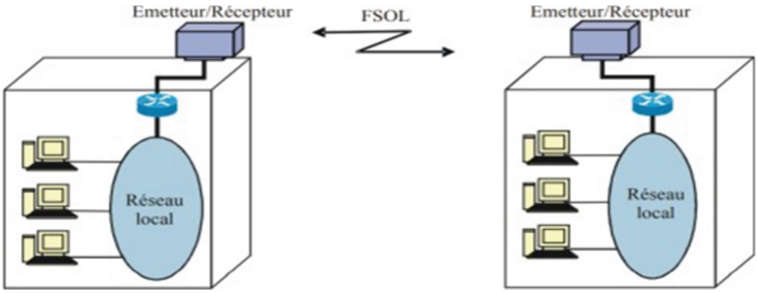

Fig. 2. The transmission in Free Space Optics (FSO) communication [12]

3 FSO System Description

The FSO system is composed of interconnected components that facilitate the transmission and reception of optical signals, as depicted in Fig. 3. The signal transmission process begins with a Pseudo Random Binary Sequence (PRBS) generator, which generates a 16-level Quadrature Amplitude Modulation (QAM) signal. This QAM signal is then fed into an Orthogonal Frequency Division Multiplexing (OFDM) modulator, which converts the serial data into parallel data using orthogonal multiplexing techniques. To optimize the bandwidth of the OFDM signal's subcarriers in the time domain, a Low-Pass Cosine Roll-Off filter is applied.

This filter is separately applied to the in-phase (I) and quadrature (Q) components of the OFDM signal, operating at a radio frequency of approximately 6 GHz.

Its purpose is to reduce the bandwidth and mitigate interference between subcarriers. The modulated data is then routed to a quadrature modulator, which performs the final modulation step before transmission. The modulated signal is used to modulate a Continuous Wave (CW) laser using a Mach-Zehnder (MZ) modulator. This process results in a modulated optical signal that is transmitted through free space, with the aid of amplifiers to enhance the power of the FSO signal.

On the receiving end, a PIN photo detector is employed to receive the optical signal and convert it into an electrical signal. To extract the original data, an OFDM demodulator and a QAM demodulator are utilized. These components reverse the modulation and multiplexing steps performed at the transmitter, effectively decoding the received signal.

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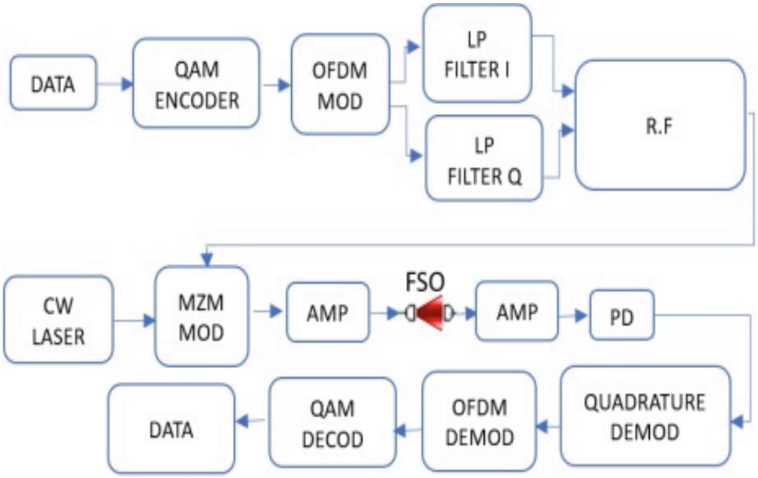


Fig. 3. Diagram illustrating the FSO system configuration.

Lastly, a constellation viewer is utilized to analyze and visualize the system's output. This component allows for the assessment of transmission quality and accuracy, providing valuable insights into the performance of the FSO system.

4 Results and Discution

The system's performance is assessed by considering various parameters, including the data rate, communication distance, and the impact of meteorological conditions. The Error Vector Magnitude (EVM) is used as a performance metric to evaluate the accuracy and quality of transmission. The specific parameter values used in the evaluation are provided in Table 1, reflecting practical models.In the transmitter section, the constellation viewer is employed to observe the generated signal's constellation (refer to Fig. 4) and obtain an ideal constellation where the points are well-defined and evenly spaced. This ideal constellation serves as a reference for calculating the EVM. Constellation analysis and EVM calculation are crucial tools for assessing transmission quality in our free-space optical communication system. They allow us to measure the deviation between the actual positions of the constellation points and the ideal positions, enabling us to quantify the precision and fidelity of the transmitted signal.This following table shows the parameters used in the simulation.

Table 1. Simulation's parameters

Parameter	Value
Data rate	10 Gbit
Power of spatial laser	10 dBm
Laser Wavelength	193.1 THz
Radio frequency	6 GHz
Sequance length	262144 Bits
Transmitter aperture diameter	5 cm
Receiver aperture diameter	20 cm
Beam divergance angle	2 mrad
FSO range	From 200 m to 10 km

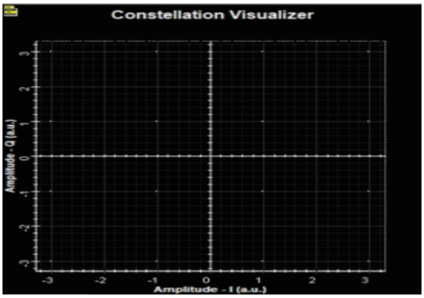


Fig. 4. Constellation in the transmitting section

4.1 FSO Range

To evaluate the performance of our system at different distances, we conducted experiments with a fixed data rate of 10 Gbps and an optical source power of 10 dBm in clear weather conditions. We systematically varied the distance from 200 m to 10 km and analyzed the resulting transmission quality using the Error Vector magnitude (EVM) metric. The EVM values obtained for each distance are illustrated in Fig. 5, providing insights into the relationship between distance and transmission quality in our FSO system.

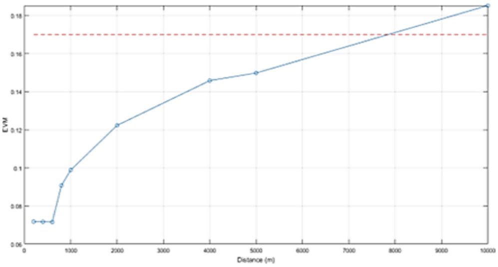


Fig. 5. EVM Variation with Distance

As the distance increases, the EVM exhibits a noticeable rise, indicating a degradation in the link quality beyond a threshold of 0.17%. This observation highlights the impact of distance on the fidelity of the transmitted signal.

Figure 6 displays the constellations obtained at distances of 10 km, allowing us to visualize the effects of increasing distance on the signal fidelity and identify any distortions that may occur.

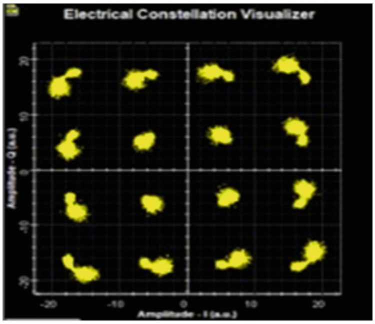


Fig. 6. Constellation Comparaison: 10 km Distance Variation

4.2 Effect of Data Rate on the FSO Link

In this section, we investigate the impact of modifying the data rate generated by the PRBS (Pseudo-Random Binary Sequence) on our system, building upon the findings from the previous distance-variation analysis. We maintain a fixed link distance of 600 m and vary the data rate within the range of 1 Gbps to 40 Gbps. By examining the resulting constellations at different data rates (6G, 10G, 20G, 40G) as illustrated in Fig. 8, we can assess the effect on transmission quality.

According to the results depicted in Fig. 7, as the data rate surpasses 30 Gbps, the link quality starts to deteriorate, resulting in an EVM increase of more than 0.17. This suggests that pushing the data rate beyond this threshold adversely affects the overall performance and fidelity of the transmitted signal.

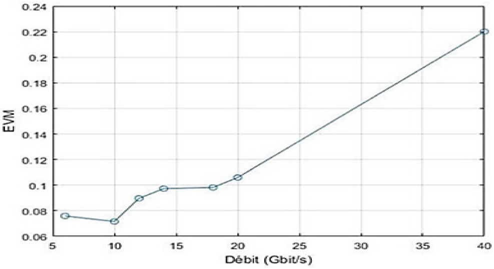
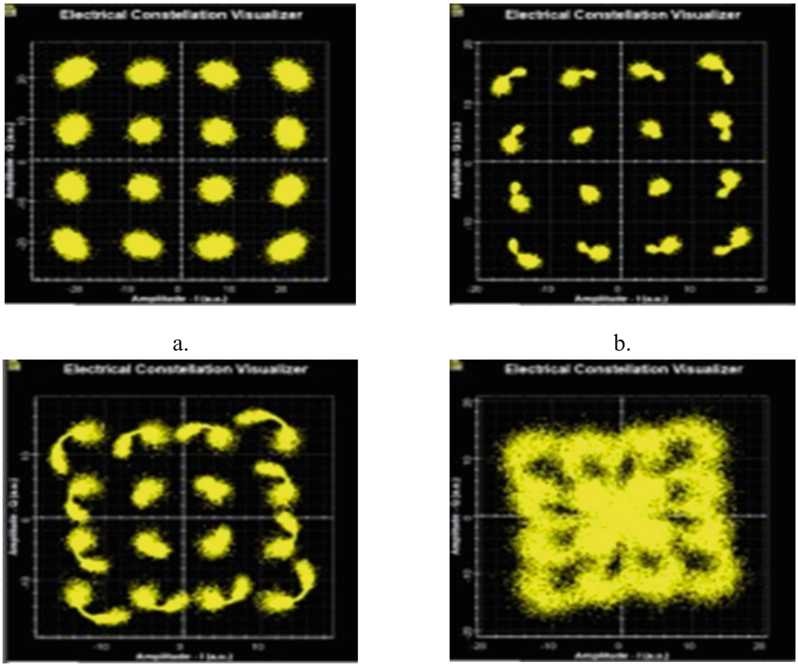


Fig. 7. EVM versus da ta rate



a. b.

c. d.

Fig. 8. Constellations at Varied Data Rates, a. constellation for 6 Gbit b. constellation for 10 Gbit, c. constellation for 20 Gbit, d. constellation for 40 Gbit

4.3 Effect Meteorological Condition on the FSO Link

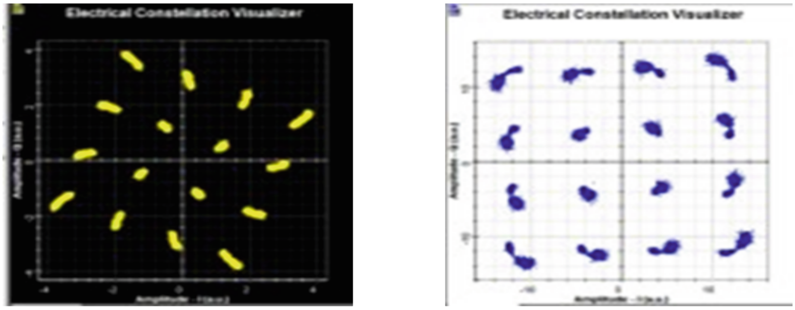
Weather conditions pose a significant challenge for free-space optical links, as they act as obstacles and adversely affect link quality. In our study, we examined the impact of weather conditions on our optical communication system, focusing on the EVM metric. We maintained a data rate of 10 Gbps for our analysis.

Figure 9 presents the results, depicting the relationship between the EVM and distance for different weather conditions. These findings allow us to gain insights into the influence of weather conditions on the quality of free-space optical transmission.

The results of our study clearly indicate that weather conditions have a significant impact on the performance of free-space optical links. Adverse weather conditions, such as heavy rain or dry snow, act as obstacles in the path of the optical signal, leading to degradation in link quality.

In contrast, under clear weather conditions, the link demonstrates optimal performance, with the ability to achieve longer distances while maintaining a desirable EVM below 0.17.

These observations underscore the importance of considering weather conditions in the planning and deployment of free-space optical communication systems. By accounting for these conditions, engineers and network planners can optimize link performance and ensure reliable transmission quality in various weather scenarios.



a. b.

Fig. 9. Constellations for different weather conditions and distances, a.constellation for heavy rain for 4 km, b.constellation for distance 600 m for clear weather

5 Conclusion

Our article focuses on evaluating the performance of an open-space optical communication system using FSO technology in conjunction with grows of 5G. We then ran a simulation using an OFDM modulation and a 10 dBm laser to achieve high-bandwidth 6 GHz connectivity, 10 Gbit/s speed over a distance approximately to 10 km, and an EVM of less than 0.17 under clear weather conditions. However, we have also found that unfavorable weather conditions, such as heavy rainfall or dry snow, can result in a significant reduction in the transmission distance.

In conclusion our article contributes to the advancement of knowledge in the field of optical communications in free space and provides valuable information for the implementation of effective solutions in the context of 5G next generation mobile networks.

It also paves the way for future research and development to improve the performance and reliability of optical communication systems in open space for new generations of mobile communication.

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Enhancing Gain and Bandwidth in 5G Wireless Communication Systems

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Abstract. With the increasing demand for fast and dependable wireless communication, 5G technology has emerged as a highly promising solution. This study addresses the critical objective of enhancing gain and bandwidth performance in 5G wireless communication systems, with particular emphasis on utilizing Multiple-Input Multiple-Output (MIMO) techniques. To achieve our objective, we propose an optimized 2 × 1 microstrip antenna array design tailored for 5G applications operating in the FR1 frequency range. The antenna array consists of rectangular patch microstrip antennas, with each element measuring 9.6 mm × 13 mm. For accurate simulation and analysis, we employ the HFSS software at a frequency of 6.8 GHz. The selected substrate material is F R4, known for its favorable characteristics, including a relative permittivity ($\epsilon ef\ f$) of 4.4. Our main goal is to leverage the advantages provided by the proposed design of the antenna array to enhance both gain and bandwidth. By doing so, we aim to optimize the performance of 5G wireless communication systems. The antenna array showcases a significant gain improvement of 6 dB, resulting in expanded bandwidth at 540 MHz. These enhancements are essential for achieving superior coverage, increased data rates, and improved overall system efficiency in the demanding 5G environment.

Keywords: Array patch antenna · gain · bandwidth

1 Introduction

Antennas are essential to the communications industry. They are, to put it simply, machines that transform radio signals into electrical energy and the other way around [1]. The fifth generation (5G) of cellular communication technology is distinguished by its capacity to deliver high data rates (throughput), low latency, support for numerous users

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in a specific region, effective mobility, and reduced power consumption [2]. The use of antennas with multiple-input multiple-output (MIMO) capabilities, a large number of elements, beamforming capabilities, and wide bandwidth is one of the key technologies that enables the high-speed 5G network [3]. Microstrip antennas are the most popular choice when creating MIMO antennas for 5G applications because to its low profile, simplicity of installation, and small size. Microstrip antennas do, however, have several drawbacks, such as low strength and a limited band-width [4].

Developing MIMO antennas with a large number of elements brings about a notable challenge known as the high mutual coupling effect between adjacent elements. Overcoming this challenge is crucial to achieve desired characteristics such as wide bandwidth, enabling high data rates, and facilitating the use of MIMO antennas in various applications, including Internet of Things (IoT) devices. By effectively addressing the mutual coupling issue through careful design techniques and innovative signal processing approaches, MIMO antennas can harness their full potential, providing enhanced wireless communication capabilities for a range of IoT applications [5].

The remaining sections of this paper are organized as follows. In Sect. 2, we delve into Antenna Design, exploring the considerations, techniques, and tools involved in optimizing the performance of antennas, both for simple antennas and MIMO systems. Section 3 focuses on Antenna Result, where we analyze and compare the performance of simple antennas and MIMO antennas in terms of parameters such as gain, bandwidth, and overall system performance [6]. In Sect. 4, we present a Comparison between the two antenna types, highlighting the advantages and limitations of each approach. Finally, in Sect. 5, we draw a Conclusion summarizing the key findings, discussing the implications of the comparison, and suggesting potential areas for further research in the field of antenna design for both simple and MIMO systems [7].

2 Antenna Design

In this study, a rectangular patch microstrip antenna was designed as a 1 × 2 array operating at a frequency of 7 GHz. The antenna design utilized two different materials, Cooper and FR-4. The Cooper material was employed for both the patch and ground, while the substrate material utilized was FR-4 with a thickness of 1.575 mm [8].

2.1 Dimensions of Rectangular Patch Microstrip Antenna

The dimensions of the proposed antenna were calculated using well-known formulas for microstrip patch antennas, as outlined below [9].

- The width of the Patch

$$W = \frac{C}{2fr}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

- The length of the patch:

$$L = L_{eff} - 2\Delta L \tag{2}$$

$$Leff = \frac{1}{2fr\sqrt{\mu_0\varepsilon_0}\sqrt{\varepsilon_{eff}}} \tag{3}$$

- The effective refractive index can be expressed as:

$$\varepsilon eff = \frac{\varepsilon r + 1}{2} + \frac{\varepsilon r - 1}{2\sqrt{1 + 12\frac{h}{w}}} \tag{4}$$

- The extension of length of each side can be expressed as:

$$\Delta l = 0.412\frac{(\varepsilon r + 0.3)(\frac{w}{h} + 0.264)}{(\varepsilon r - 0.258)(\frac{w}{h} + 0.8)} \tag{5}$$

The equations mentioned above highlight the significance of various parameters in the design of rectangular microstrip antennas. These parameters play a crucial role in determining the antenna's performance and characteristics [10].

- **Patch** (Fig. 1): $W_p = 13$ mm, $L_p = 9.6$ mm

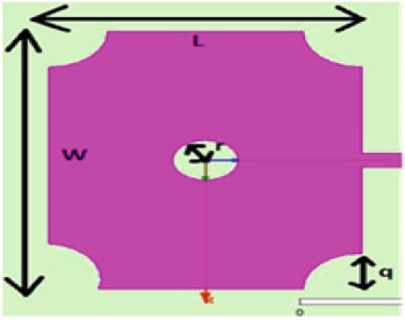


Fig. 1. Patch Dimensions

- **Slots**: $r = 1.4$ mm, $q = 1$ mm
- **Ground** (Fig. 2): $W_s = 41.5$ mm, $L_s = 29$ mm

The ground plane dimension, i.e., length (Lg) and width (Wg) for this design would be given as:

$$\mathrm{Lg} = 6\mathrm{h} + \mathrm{L}$$

$$\mathrm{Wg} = 6\mathrm{h} + \mathrm{W}$$

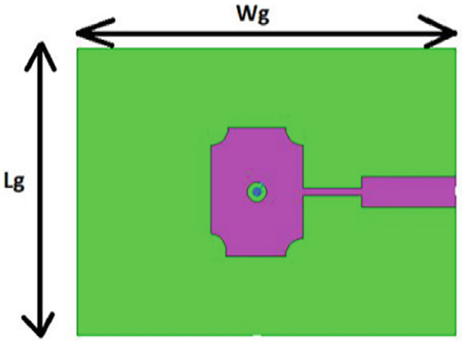


Fig. 2. The Ground

2.2 Feed Dimensions

- Width of transmission line [11]:

$$\text{if } \frac{w}{h} < 1 : z = \frac{60}{\sqrt{\varepsilon r}} \ln\left(\frac{8h}{w} + \frac{w}{4h}\right) > \frac{126}{\sqrt{\varepsilon r}} \tag{6}$$

$$\text{if } \frac{w}{h} > 1 : z = \frac{120\pi}{\sqrt{\varepsilon r} \times \left(\frac{w}{h} + 1.393 + 0.667 \ln\left(\frac{w}{h} + 1.44\right)\right)} < \frac{126}{\sqrt{\varepsilon r}} \tag{7}$$

- The total input impedance of the patch antenna

$$za = 90 \frac{\varepsilon_r^2}{\varepsilon_r - 1} \left(\frac{L}{w}\right)^2 \tag{8}$$

- Characteristic impedance of the transmission line

$$Z1 = \sqrt{Z_2 \times Z_a} \tag{9}$$

whith Z_2: probe impedance

Length of the transmission line is

$$TL = {}^{\lambda_d}/_{4} = {}^{\lambda_0}\Big/_{4\sqrt{\varepsilon reff}} \tag{10}$$

Feed Dimensions of Patch Antenna
(See Fig. 3 and Table 1)

$$\text{Za} = 279.46\Omega$$

Feed Dimensions of 2 × 1 Array Antenna
(See Fig. 4 and Table 2)

$$\text{Za} = 197\Omega\ \text{Z1} = 118.2\Omega\ \text{Z2} = 50\Omega\ \text{Z3} = 70.7\Omega\ \text{Z4} = 100\Omega$$

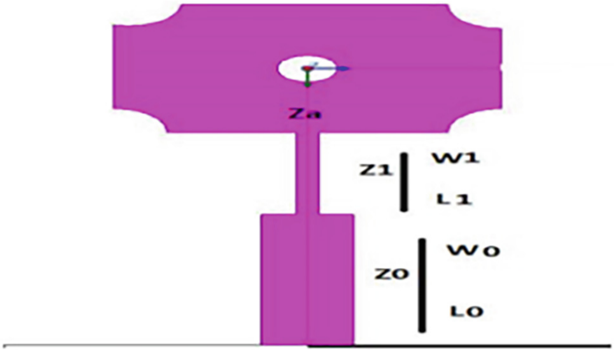


Fig. 3. The patch antenna

Table 1. Feed Dimensions of Patch Antenna

	Width (mm)	Length (mm)
Z1 = 118.2	0.20	2
Z0 = 50	1.56	5.5

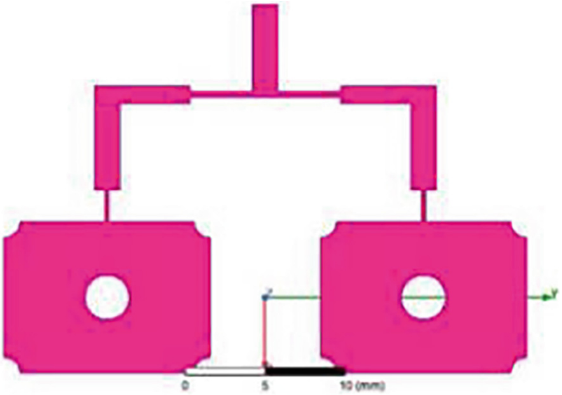


Fig. 4. Array Antenna

Table 2. Feed dimensions of 2 × 1 Array Antenna

	Width (mm)	Length (mm)
Z1 = 118.2	0.2	2
Z2 = 50	1.56	5.5
Z3 = 70.7	1.07	6
Z4 = 100	0.38	4

3 Antenna Result

In contemporary times, it has become a common practice to assess the performance of a system through simulations before its physical realization. This approach finds practical applications, and for our study, we employed the simulator"Ansoft HFSS" to evaluate key parameters such as gain, bandwidth, return loss, and voltage standing wave ratio (VSWR) of the proposed antenna. By leveraging simulation tools like Ansoft HFSS, we were able to reduce fabrication costs by optimizing the design and ensuring its efficacy prior to the manufacturing stage [12].

3.1 Return Loss

To ensure the usability of the antenna, it is essential for the return loss value to be below −10 dB. A lower return loss value indicates a better-designed antenna. In the case of the 2 × 1 array configuration, the return loss is −30.6 dB (Fig. 5), while for the single-element antenna, the return loss is −27.3 dB [13].

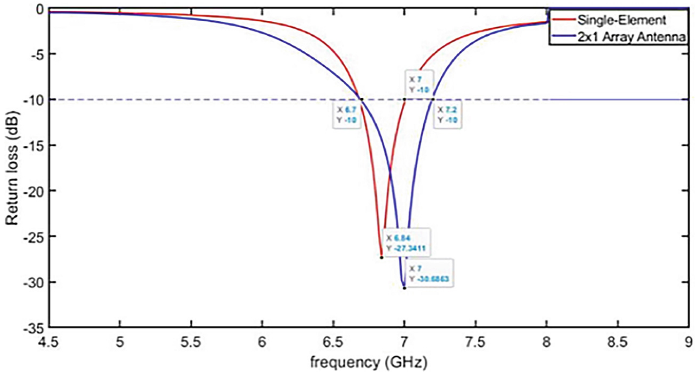


Fig. 5. S11 for patch antenna et 2 × 1 array antenna

3.2 Gain

The gain of an antenna in a specific direction is defined as the ratio of the intensity in that direction to the radiation intensity that would be achieved if the power accepted by the antenna were radiated equally in all directions (isotropically) (Fig. 6) [14].

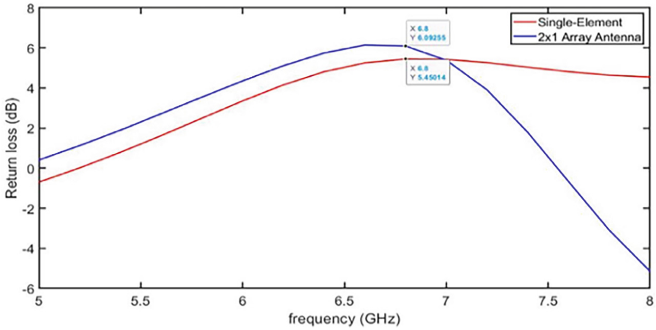


Fig. 6. The gain for the single-element antenna and the 2*1 Array Antenna

From the figure provided, it can be observed that the gain of the array element is 6.86, which is higher than the gain of the single element antenna, which is 4.6. This visual representation reinforces the comparison, illustrating the higher gain achieved by the array element [15].

3.3 Voltage Standing Wave Ratio VSWR

The Fig. 7 illustrates the VSWR response of the antenna. In practical terms, the ideal value for VSWR is less than 2, as it indicates the best performance. The plot in the figure confirms the VSWR values obtained for the antenna and highlights its adherence to the desired performance criteria (Fig. 7) [16].

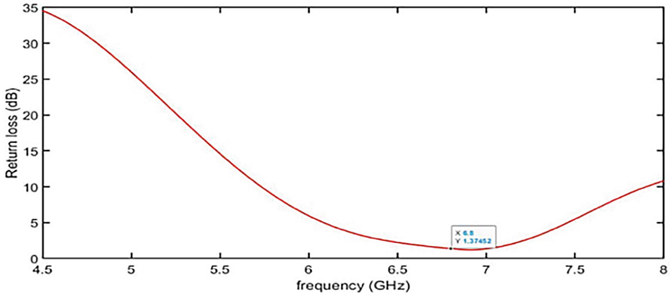
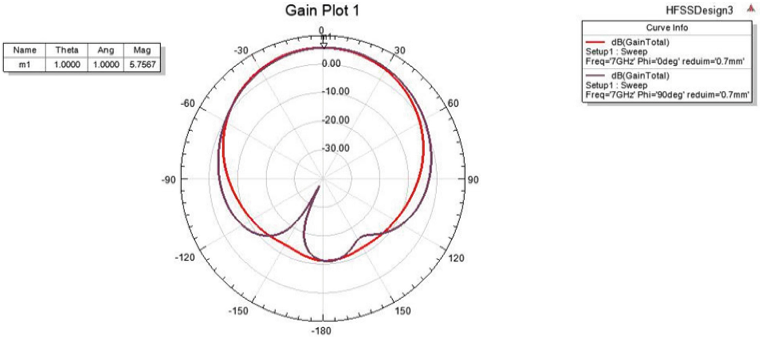


Fig. 7. VSWR for the 2*1 Array Antenna

3.4 Radiation Pattern

(See Fig. 8)

– Single-Element



– 2*1 Array Antenna

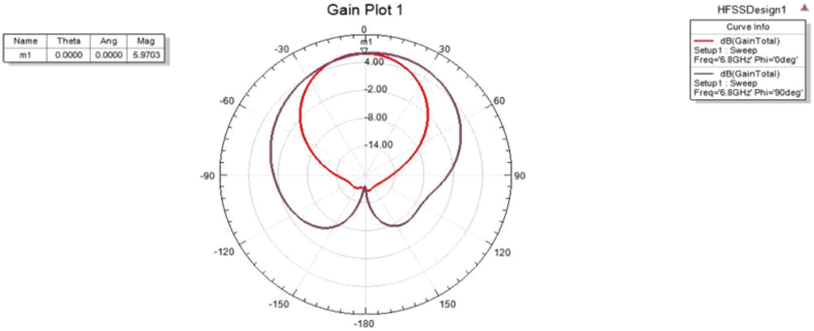


Fig. 8. Radiation Pattern for Array antenna

4 Comparison

When comparing the gain of a single antenna with that of a single element array antenna, we observe that the single antenna has a gain of 5.4, while the array antenna achieves a higher gain of 6. This comparison clearly demonstrates the advantage of utilizing an array configuration, as it results in an increased gain [17]. Moreover, in the context of Internet of Things (IoT) applications, the wider bandwidth of the array antenna (500) becomes even more significant. The expanded bandwidth allows the array antenna to operate over a broader range of frequencies, catering to the diverse communication requirements of IoT devices. This wider bandwidth is particularly valuable in IoT deployments, as it