Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

Design and Analysis of a Compact Monopole Antenna Operating in 4G/Lte Band for Wireless Communication Network

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The high demand for wireless communication systems has stimulated the need for compact, high-performance antennas. The aim of this study was to design and optimization a small monopole antenna for 4G/LTE application. With parameter height of 31 mm and a radius of 0.5 mm, the initial antenna achieved moderate performance metrics, including a gain of 5.2 dB, directivity of 5.25 dB, efficiency of 87%, return loss of -15 dB, and a bandwidth of 200 MHz. Despite being functional, this design's bandwidth is somewhat limited for broader applications. Through a series of optimizations, three configurations were evaluated for improved performance. The first optimized antenna improved efficiency to 89% and increased the bandwidth to 600 MHz, but with a slight reduction in gain and directivity, -5.19dB and 5.16dB respectively. The second had the best impedance matching with a return loss of -17 dB, but its narrow (150 MHz) bandwidth limited its applicability. The final optimized antenna, with a height of 29 mm and a radius of 0.55 mm, had a gain of 5.12 dB, directivity of 5.17 dB, with highest efficiency of 90%, and broadest bandwidth of 900 MHz. The results show that

the first configuration would work better in the 4G/LTE environment.

1. Introduction

In the rapidly evolving landscape of wireless communication, the demand for efficient and compact antennas has surged, particularly with the advent of 4G/LTE technologies. These advancements necessitate antennas that not only meet stringent performance criteria but also occupy minimal space, making them ideal for integration into mobile devices and IoT applications. Monopole antennas have emerged as a popular choice due to their simple structure, ease of fabrication, and favorable radiation characteristics. This paper presents the design and analysis of a compact monopole antenna specifically tailored for operation within the 4G/LTE frequency bands. By leveraging innovative design techniques and materials, the aim is to enhance the antenna's performance metrics, including bandwidth, gain, and radiation efficiency, while maintaining a compact form factor. The proposed antenna design is subjected to rigorous simulations and measurements to validate its operational capabilities in real-world scenarios.

Through this study, areas to be critically explored include the parameters influencing antenna performance, such as impedance matching, radiation pattern, directivity, efficiency and the impact of various geometrical configurations. The findings will contribute to the ongoing development of advanced antenna solutions that can support the increasing data demands of modern wireless communication networks. This work not only addresses current technological challenges but also lays the groundwork for future research in compact antenna design for next-generation communication systems.

2. Related Literature

This section highlights the review of the critical literature directly related to the topic of discussion. A 3D electromagnetic simulator (ANSYS HFSS) was used to simulate a monopole antenna using parameters such as gain, directivity, return loss and bandwidth. The antenna with height of 31mm and radius of 0.5mm was optimized to attain an impedance of 50 ohms produced simulation results of 5.2 dB, 5.25 dB, 15 dB, 87% and 200 MHz for the gain, directivity, return loss, efficiency and bandwidth respectively [1]. The compact size and high efficiency make this antenna an attractive option for integration into wireless devices, however, the main limitation is the simulation-based analysis, which may not accurately represent real-world performance. According to [2], a monopole antenna was designed and analyzed for 5G applications, where high-speed data communication and seamless connectivity are critical within the 24-28 GHz frequency range. The HFSS software was deployed for the simulation and results returned a designed antenna with 4 GHz bandwidth and 8 dB gain. These results form the fundamental requirements for the operationalization of 5G. In the same manner, another monopole antenna was designed by [3] to take up 5G and IoT use cases within the 3-6 GHz frequency range, with the right specification for big data, reliable transmission, and properly aligned to evolving standards for new wireless communications. The outcome indicates that 10 dB gain and 3 GHz bandwidth were recorded, which meet the specifications for the applications of 5G and IoT.

A 2.4 GHz was designed by [4] for wireless sensor network (WSN), with the aim of achieving small-size, high-gain and analysis of the performance through simulation, and optimization of design parameters. The outcome showed that the optimized antenna was 60% smaller than the original and yet achieved a gain of 5dB, making the results very critical for WSNs. In the case of [5], a monopole antenna was designed to produce a high-gain device for applications in a long-range wireless communication system, and using ANSYS HFSS to achieve a gain >20 dB and beamwidth <10°. The results prove that the gain was 22.5 dB and a beamwidth was 8°, indicating an overshoot in the gain but the beamwidth was satisfied. The authors believe that the results were achieved via simulation only and need to be verified and validated experimentally. Just as the previous author, [6], [7] used ANSYS HFSS to design a monopole antenna and compared its performance with a rectangular microstrip patch antenna for short range wireless communication. The results revealed that the microstrip patch antenna had a gain of 7 dB, indicating that there is a positive correlation between the simulation and measured results. Similar simulations were conducted by [8], [9], [10],[11],[12], and though there were slight differences among some of them, all showed that monopole antennas are excellent and can be designed to serve diverse operational applications. For instance, 10.6 GHz was achieved for ultra-wideband, between 3.50 to 6.50 GHz was designed for 5G networks, including 80% efficiency and from 3.49 to 10 dB under various conditions. Another type of monopole antenna was DGS-based, with a gain of 9 dB and 1.4 GHz bandwidth. These investigations and their results were highly corroborated by [13],[14],[15],[16],[17], with similar results. The method adopted by the last paper was both experimental and simulation through electromagnetic method. The outcomes were a gain of 2.5dB and return loss of -15dB. Fundamentally, the bandwidth was pegged at 100MHz, which may have contributed to the results obtained. To improve the low bandwidth, the authors suggested the deployment of a different substrate material.

The innovation in diagnostic techniques and medical imaging are centered on the technological advancements of UWB to enable detection of brain stroke and high-resolution images [18]. It has been determined that monopole antennas with their wide bandwidth and resolution are particularly excellent for high-resolution image detection and precision applications [19]. By the estimation of [20], the technological advancement in UWB due its broad frequency band has made it desirable over the past years for accurate imaging, localization and high data transfers. However, a key challenge associated with UWB systems is that it promotes interference on close by services such as WLAN and WiMAX. In this regard, designing band-notched UWB could help resolve the challenge.

3. The Monopole Antenna

The design characteristics and installed outlook diagrams, as well as the simulation parameters of the monopole antenna have been illustrated under this section.

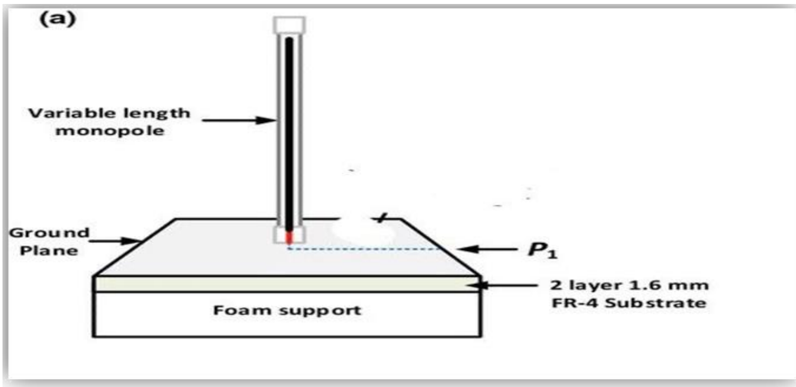

Figure 1a: Monopole Antenna Design

Figure 1b: Installed Monopole Antenna

A monopole antenna is a special version of a dipole antenna with one end grounded and the other radiating. Figure 1a depicts the monopole antenna in the design stage, while Figure 1b shows an installed monopole antenna in an environmentally friendly space. Characteristics of this type of antenna include radiation pattern, which is similar to dipole antennas, it has moderate gain and frequency range from medium to high. Aperture antennas on the other hand consist of an opening in the conductive surface, used for transmitting and receiving radio waves. The aperture antenna is characterized by directional radiation pattern, high gain and a wide bandwidth.

The key characteristics of the various antennas are comparable, pointing out their particular strengths and weaknesses. Wire antennas can find applications in long-range communications, while loop antennas have narrowband recommendations. Monopole antennas are helpful in medium-frequency ranges. Aperture antennas exhibit a high gain and directivity. These characteristics must be known to enable one pick the right type of antenna design for optimum operation. For these reasons, the monopole antenna with its several advantages is best suited for wireless communication operational within the 4G/LTE band. They provide high gain and high directivity, which assures reliable and high-speed communication in 4G/LTE networks. Also, monopole antennas can operate with a wide frequency range and hence are suitable for 4G/LTE applications requiring high speed data transfer. Besides, they are immune to interference and multipath effects introduced by nearly every wireless communications system. In addition, monopole antennas are compact and cost-effective, which makes them quite appropriate for implementation in 4G/LTE base stations and devices. Easy installation and maintenance reduce the general cost of ownership of the monopole antenna and guarantee its faultless operation. Among all antennas, the monopole antenna is the optimum in terms of gain, directivity, bandwidth, and cost; thus, it is rather quite suitable for wireless communication via 4G/LTE.

3.1 Parameters used in Designing and Simulating the Antenna

The elements involved in this monopole antenna design are the monopole, feedline, mesh, ground, and radiation box. Below are the functions of each element. The parameters involved are:

- Return loss
- Voltage Standing Wave Ratio (VSWR)
- Total Gain
- Total Directivity
- Efficiency
- Radiation Pattern Gain
- Radiation Pattern for Directivity

4. Simulation and Analysis of the Monopole Antenna

In this section, the design, simulation, findings and analysis from the research have been presented. The simulation was conducted first for an existing antenna and then for the optimized antenna, based on the parameters outlined in sub-section 3.1.

4.1 Simulation of the Existing Antenna

This sub-section reflects simulation of all the parameters required.

4.1.1 Return Loss

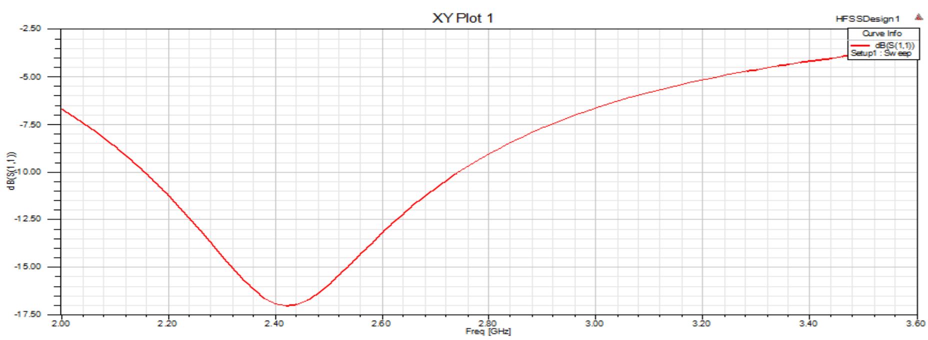

Figure 3: S (1, 1) Parameter (Solomon Nsor-Anabiah, 2024)

The plot provided in Figure 3 shows the S11 values for frequencies ranging from 2.00 GHz to 3.60 GHz. The plot has a clear dip at 2.42 GHz, where the S11 value reaches its lowest point, -17 dB. The return loss at this frequency (2.42 GHz) is 17 dB. The Bandwidth is given by m2-m1: Bw= 2.500-2.300, which is 0.2GHZ or 200MHz.

4.1.2 VSWR (Voltage Standing Wave Ratio)

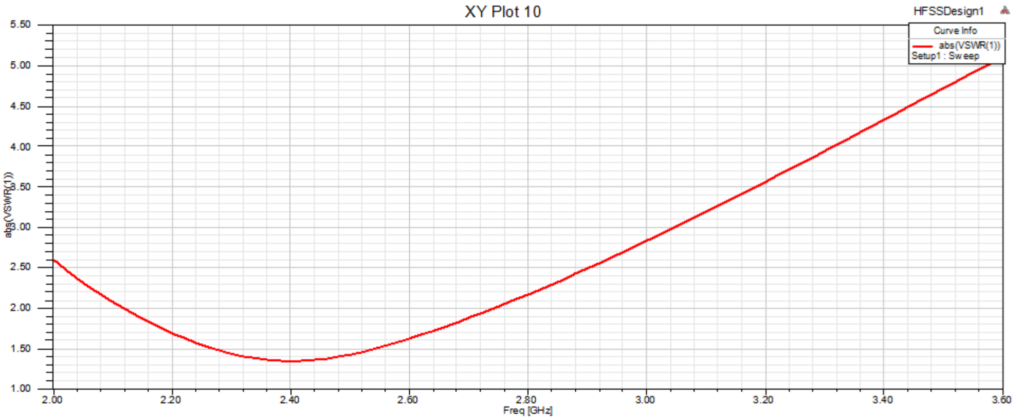

Figure 4: Voltage Standing Wave Ratio (VSWR) Simulation Curve (Solomon Nsor-Anabiah, 2024)

The plot provided figure 4 shows the VSWR (Voltage Standing Wave Ratio) versus frequency for the antenna design. The plot shows VSWR values across a frequency range from 2.00 GHz to 3.60 GHz. The lowest VSWR value is observed around 2.4 GHz, where the VSWR drops to about 1.4. This indicates that at this frequency, the antenna has a good impedance matching, where most of the power is transmitted rather than reflected. The antenna is well-matched and operates most efficiently around 2.4 GHz, with a usable bandwidth where VSWR is below 2.0. This range is suitable for applications like 4G/LTE in the 2.4 GHz band. The VSWR plot provides a clear visual confirmation that the antenna design is optimized for this frequency range.

4.1.3 Total Gain

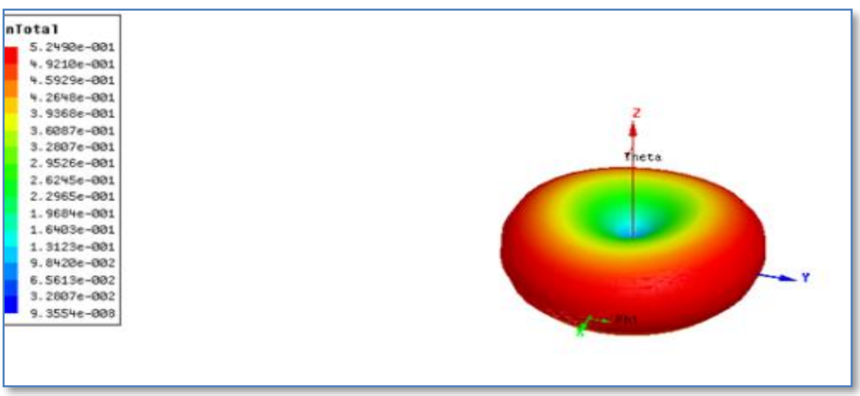

Figure 5: 3D Polar Diagram for Total Gain (Solomon Nsor-Anabiah, 2024)

The image above Figure 5 depicts the total gain in a 3D plot. The color bar on the left represents the total gain of the antenna in dB, with different colors corresponding to different gain levels. Red and Orange: Indicate areas of higher gain. Green, Blue, and Cyan: Indicate areas of lower gain. The total gain from the diagram is the highest and represented by 5.24dB.

4.1.4 Total Directivity

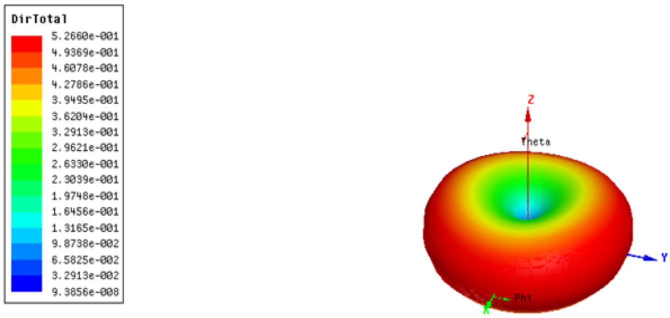

Figure 6: 3D Plot for Total Directivity (Solomon Nsor-Anabiah, 2024)

This is the total 3D plot of the total directivity. This Figure 6 shows the direction of which most of the signal is radiated to. The red area indicates the region of maximum gain. With this we can determine the efficiency of the antenna which is gain/directivity. The total directivity from the diagram is highest at 5.25dB, and the associated efficiency is 87%.

4.1.5 Radiation Pattern for Gain

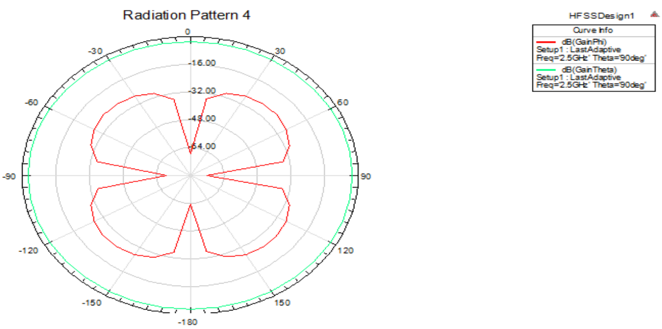

Figure 7: Radiation Pattern for Gain (Solomon Nsor-Anabiah, 2024)

Figure 7 represents radiation pattern for the Gain, the main lobe is an omnidirectional full circle, exhibiting maximum radiation in all directions. The side lobes secondary lobes are divided into four distinct patterns with reduced gain compared to the main lobe. These are four null directions of minimal radiation at 90-degree intervals (north, south, east and west)

The Gain value represents the strength of the antenna energy. The first lobe has a gain of -16.00dB (relatively higher radiation), the other two lobes have gains of -32.00dB and -48.00dB (lower radiation), and the last lobe has a gain of -64.00dB (very low radiation). This shows that the antenna is radiating minimal energy in the direction.

4.1.6 Radiation Pattern for Directivity

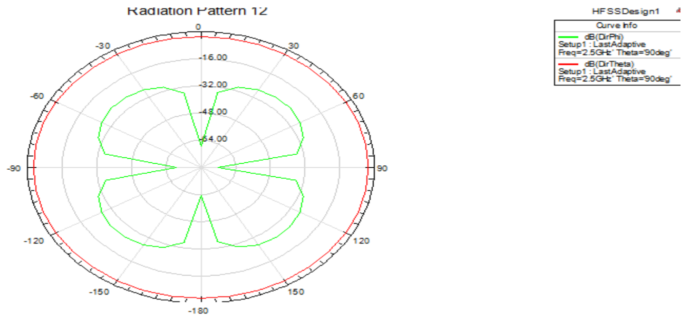

Figure 8: Radiation Pattern for Directivity (Solomon Nsor-Anabiah, 2024)

Figure 8 shows the direction radiation pattern with gains of -16.00, -32.00, -48.00 and -64.00 and the main lobe is 360degree coverage but divided into section. This suggest that the antenna has an omnidirectional pattern (360-degree) in the main lobe but with different value in different sections. The Gain value indicate that the radiation power reduces as the user move away from the maximum gain direction. The main lobe has a 360-degree coverage, but divided into four sections with different gain value. One lobe has a gain of -16.00dB (relatively higher radiation), Lobe two has a gain of -32.00dB and -48.00dB (lower radiation), and the other lobe has a gain of -64.00dB (very low radiation).

4.2 Optimized Antenna Design

This section provides simulation results for the optimized versions of the antenna. It involves three different simulations with varying key parameters to determine the behavior of the antenna.

4.2.1 Result Obtained from Simulation 1

The subsection provides results for the first simulation.

4.2.1.1 Return loss

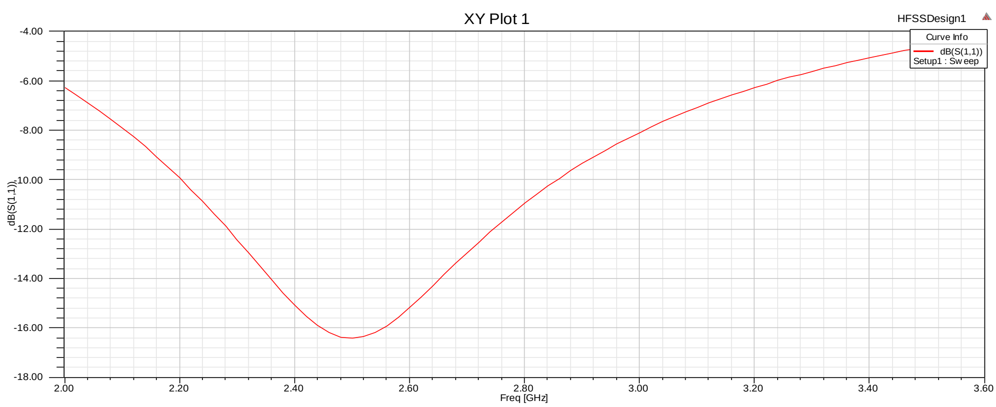

Figure 9: S (1, 1) Parameter (Solomon Nsor-Anabiah, 2024)

In the plot you provided, the S11 values are shown across a frequency range from 2.00 GHz to 3.60 GHz. The plot has a noticeable dip around 2.5 GHz, where the S11 value reaches its lowest point, approximately -16dB. This means that at 2.5 GHz, the antenna is very well matched to the transmission line, effectively radiating most of the signal with minimal reflection. This frequency would likely be the optimal operating frequency for this antenna, making it highly efficient at this point. The return loss of the antenna is -16dB and the bandwidth is given as Bw = 2.8 GHz−2.2 GHz = 0.6 GHz of 600MHz.

4.2.1.2 Voltage Standing Wave Ratio (VSWR)

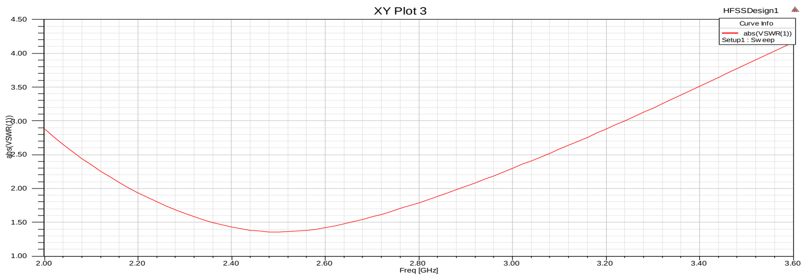

Figure 10: Voltage Standing Wave Ratio (VSWR) Curve (Solomon Nsor-Anabiah, 2024)

The Figure 10 is a plot showing the VSWR (Voltage Standing Wave Ratio) versus frequency for the antenna design. The plot shows VSWR values across a frequency range of 2.00 GHz to 3.60 GHz, it is observed that around 2.5 GHz, the VSWR drops to about 1.49. This indicates that at this frequency, the antenna has a good impedance match most of the power is being transmitted rather than reflected. The antenna is well-matched and operates most efficiently around 2.5 GHz, with a usable bandwidth where VSWR is below 2.0. This range is suitable for applications like 4G/LTE in the 2.5 GHz band. The VSWR plot provides a clear visual confirmation that the antenna design is optimized for this frequency range.

4.2.1.3 Total Gain

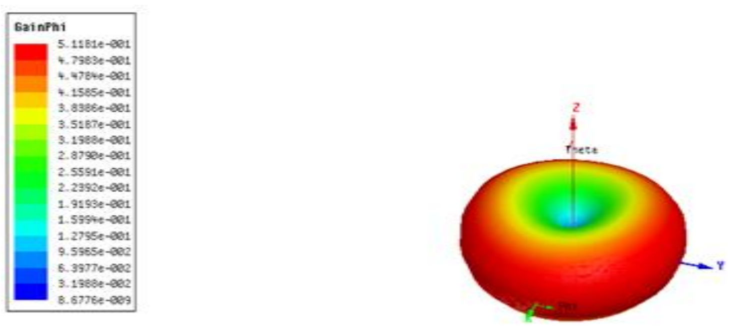

Figure 11: 3D Plot of Total Gain (Solomon Nsor-Anabiah, 2024)

The total gain is 5.19dB as per the 3D plotted image in Figure 11.

4.2.1.4 Total Directivity

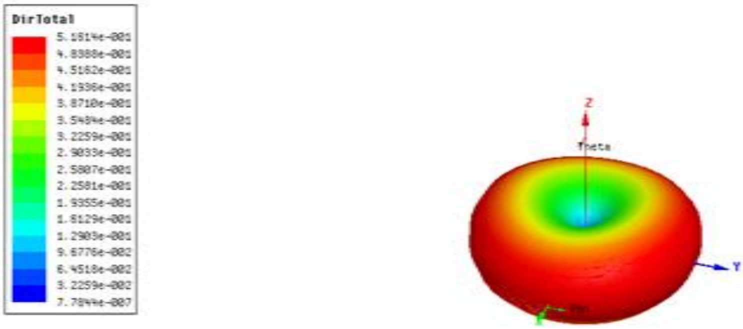

Figure 12: 3D Plot of Total Directivity (Solomon Nsor-Anabiah, 2024)

The image in Figure 12 shows the total directivity in 3D plot, representing 5.16dB. The color bar on the left represents the total gain of the antenna in dB, with different colors corresponding to different gain levels. Red and Orange: Indicate areas of higher gain. Green, Blue, and Cyan: Indicate areas of lower gain. This means that the antenna radiates most strongly in the horizontal direction (along the XY plane) and less strongly directly above or below it (along the Z-axis). Efficiency =89%.

4.2.1.5 Radiation Pattern of Gain

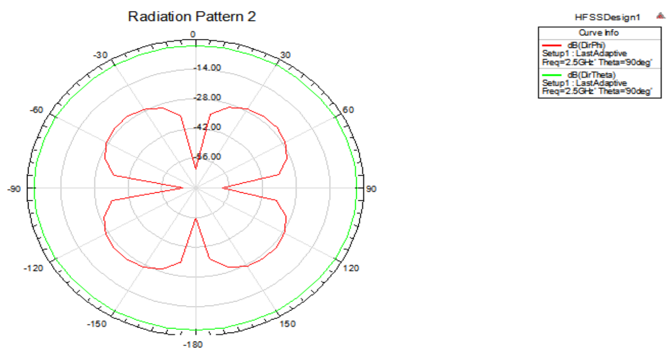

Figure 13: Radiation Pattern of Gain Diagram (Solomon Nsor-Anabiah, 2024)

This diagram in Figure 13 shows the radiation pattern for the Gain. There are four nulls direction of minimal radiation at 90-degree intervals (north, south, east and west). The Gain value represent the strength of the antenna energy.

- One lobe has a gain of -14.00dB (relatively higher radiation).
- Two lobes have gains of -28.00dB and -48.00dB (lower radiation).
- The last lobe has a gain of -56.00dB (very low radiation).

This shows that the antenna is radiating minimal energy in the direction.

4.2.1.6 Radiation Pattern for Directivity

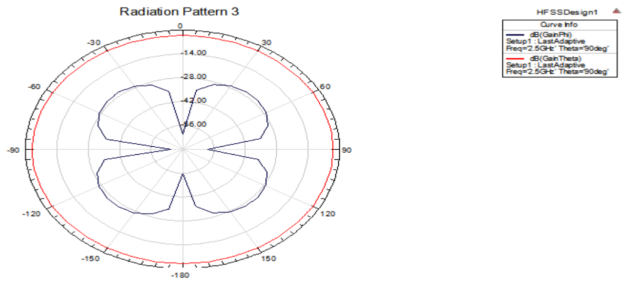

Figure 14: Radiation Pattern for Directivity (Solomon Nsor-Anabiah, 2024)

This diagram Figure 14 shows the direction radiation pattern (Dir). The radiation pattern has a gain of -14.00, -28.00, -42.00 and -56.00 for the respective lobes and even though the main lobe has 360-degree coverage, is divided into the four individual inner lobes at 90-degrees each with the gain values afore mentioned.

- One lobe has a gain of -14.00dB (relatively higher radiation).
- Two lobes have gains of -28.00dB and -48.00dB (lower radiation).
- The last lobe has a gain of -56.00dB (very low radiation).

This show that the antenna is omnidirectional.

4.2.2 Result Obtained from Simulation 2

The subsection provides results for the second simulation.

4.2.2.1 Return loss

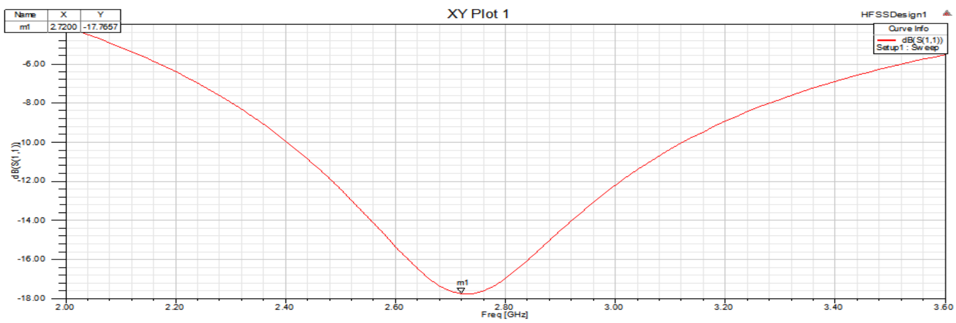

Figure 15: S (1, 1) Parameter for the Return Loss (Solomon Nsor-Anabiah, 2024)

The S11 values are shown across a frequency range of 2.00 GHz to 3.60 GHz as shown in Figure 15. The plot has a noticeable dip around 2.70 GHz, where the S11 value reaches its lowest point, approximately -17.60dB. This means that at 2.70 GHz, the antenna is very well matched to the transmission line, effectively radiating most of the signal with minimal reflection. This frequency would likely be the optimal operating frequency for this antenna, making it highly efficient at this point. While the return loss is -17.60dB, the bandwidth is given by Bw = m2-m1 = 2.80-2.70, resulting in 0.10GHz or 100MHz.

4.2.2.2 Voltage Standing Wave Ratio (VSWR)

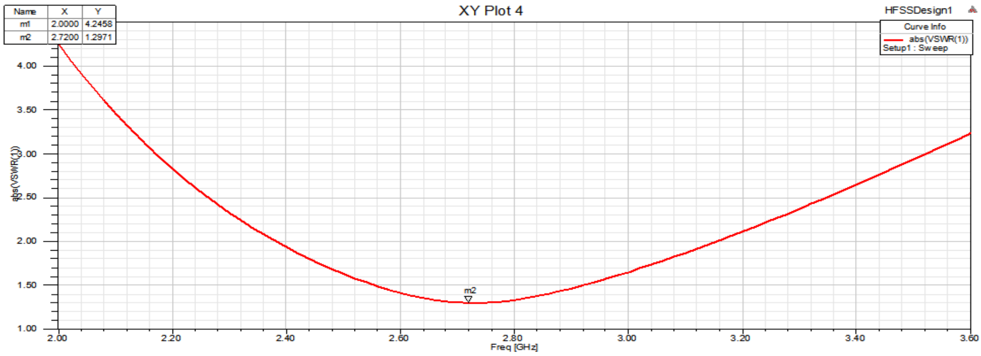

Figure 16: VSWR Curve (Solomon Nsor-Anabiah, 2024)

The plot in Figure 16 shows VSWR values across a frequency range from 2.00 GHz to 3.60 GHz. The y-axis represents the VSWR value and the x-axis represents the frequency in GHz. The lowest VSWR value is observed at 2.7 GHz, where the VSWR drops to about 1.30. The antenna is well-matched and operates most efficiently around 2.7 GHz, with a usable bandwidth where VSWR is below 2.0. This range is suitable for applications such as 4G/LTE in the 2.5 GHz band. The VSWR plot provides a clear visual confirmation that the antenna design is optimized for this frequency range.

4.2.2.3 Total Gain

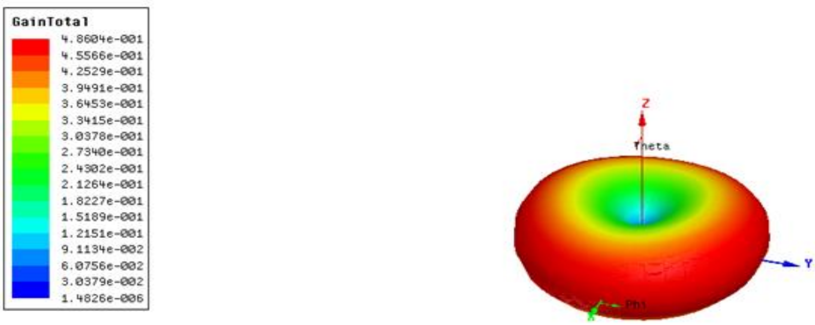

Figure 17: 3D Plot for the Total Gain (Solomon Nsor-Anabiah, 2024)

The image in Figure 17 is the total gain plotted in 3D. The color bar on the left represents the total gain of the antenna in dB, with different colors corresponding to different gain levels. The maximum total gain per the plot is 4.86dB, which is quite remarkable.

4.2.2.4 Total Directivity

Figure 18: 3D Plot for the Total Directivity (Solomon Nsor-Anabiah, 2024)

The image in Figure 18 depicts the total directivity in a 3D plot. The color bar on the left represents the total gain of the antenna in dB, with different colors corresponding to different gain levels. The highest point on the color bar is 4.8920, meaning the total directivity is approximately 4.90dB, yielding an 89% efficiency.

4.2.2.5 Radiation Pattern of Gain

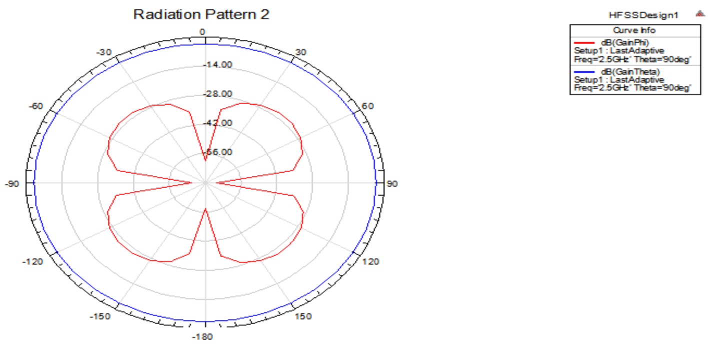

Figure 19: Radiation Pattern for the Gain (Solomon Nsor-Anabiah, 2024)

Figure 19 shows the radiation pattern for the Gain. The main lobe is omnidirectional full circle, with maximum radiation in all directions. It consists of four nulls in directions of minimal radiation at 90-degree intervals (north, south, east and west)

The Gain value represent the strength of the antenna energy.

- One lobe has a gain of -14.00dB (relatively higher radiation).
- Lobe two has a gain of -28.00dB and -48.00dB (lower radiation).
- One lobe has a gain of -56.00dB (very low radiation).

This shows that the antenna is radiating minimal energy in the right direction.

4.2.2.6 Radiation Pattern of Directivity

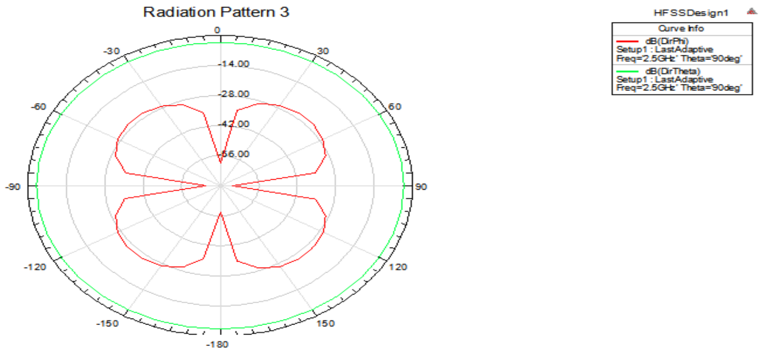

Figure 20: Radiation Pattern of Directivity (Solomon Nsor-Anabiah, 2024)

The radiation pattern indicated in Figure 20 has a gain of -14.00, -28.00, -42.00 and -56.00 for the various lobes and the main lobe is 360-degree coverage but divided into four sections. This suggest that the antenna has an omnidirectional pattern (360-degree) in the main lobe but with different value in different sections. The Gain value indicate that the radiation power reduces as the user move away from the maximum gain direction.

The main lobe has a 360-degree coverage, but divided into four sections with different gain value.

- One lobe has a gain of -14.00dB (relatively higher radiation).
- Lobe two has a gain of -28.00dB and -48.00dB (lower radiation).
- One lobe has a gain of -56.00dB (very low radiation).

This show that the antenna is omnidirectional.

4.2.3 Result Obtained from Simulation 3

The subsection provides results for the third simulation.

4.2.3.1 Return Loss

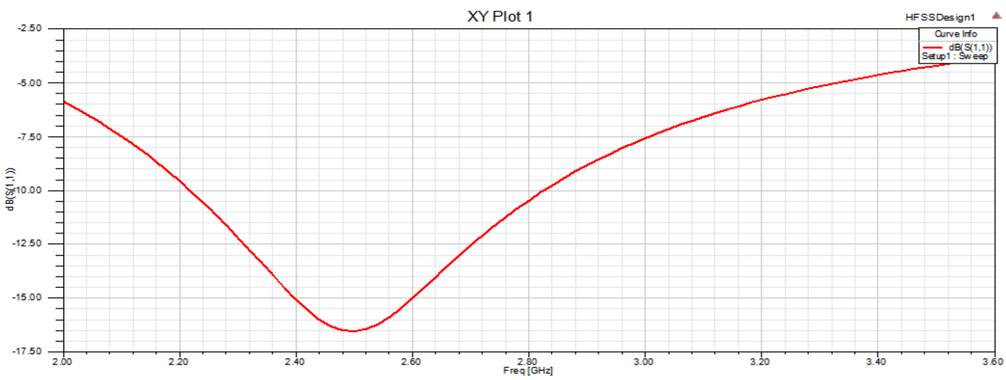

Figure 21: Return Loss (Solomon Nsor-Anabiah, 2024)

The S11 parameter Figure 21 represents the reflection coefficient of the antenna, the S11 values are shown across a frequency range of 2.00 GHz to 3.60 GHz. The plot has a noticeable dip around 2.5 GHz, corresponding to the lowest value of S11, approximately -16.50dB. This means that at 2.5 GHz, the antenna is very well matched to the transmission line, effectively radiating most of the signal with minimal reflection. This frequency would likely be the optimal operating frequency for this antenna, making it highly efficient at this point. The return loss is given as -16.50dB and operational bandwidth represented by; Bandwidth =m2−m1 = 2.6 GHz−2.4 GHz = 0.2 GHz or 200 MHz.

4.2.3.2 Voltage Standing Wave Ratio (VSWR)

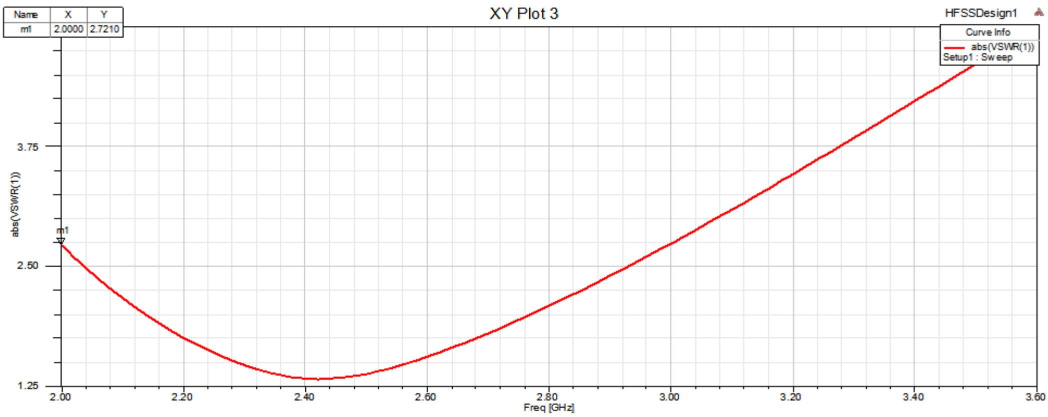

Figure 22: VSWR (Solomon Nsor-Anabiah, 2024)

The plot Figure 22 shows the Voltage Standing Wave Ratio (VSWR) across a frequency range from 2.00 to GHz 3.60 GHz. The VSWR curve has a minimum point at around 2.4 GHz, where the VSWR is just above 1.25, indicating very good matching at this frequency. The VSWR increases as the frequency moves above 2.4 GHz, reaching values above 3.0 as the frequency approaches 3.4 GHz.

4.2.3.3 Total Gain

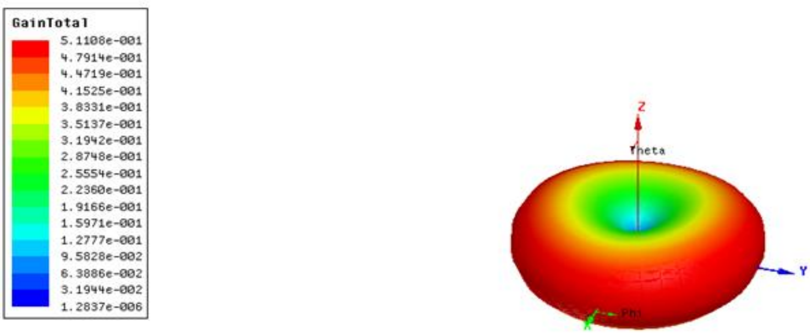

Figure 23: 3D Polar Plot of Total Gain (Solomon Nsor-Anabiah, 2024)

The image in Figure 23 shows the total gain of the third optimized antenna in 3D plot. The color bar on the left represents the total gain of the antenna in dB, with different colors corresponding to different gain levels. By inspection of the color bar, the total gain is 5.12dB.

4.2.3.4 Total Directivity

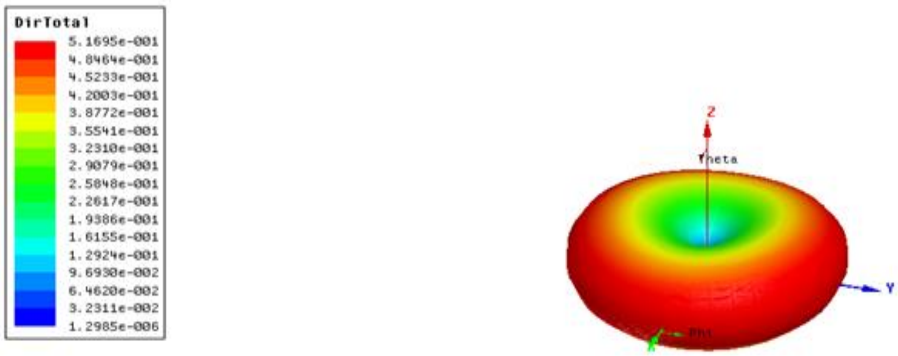

Figure 24: 3D Plot of Total Directivity (Solomon Nsor-Anabiah, 2024)

Figure 24 shows the total gain of directivity in 3D plot. The color bar on the left represents the total gain of the antenna in dB, with different colors corresponding to different gain levels. The value of the total directivity is 5.17dB, with efficiency of 90%.

4.2.3.5 Radiation Pattern for Gain and Directivity

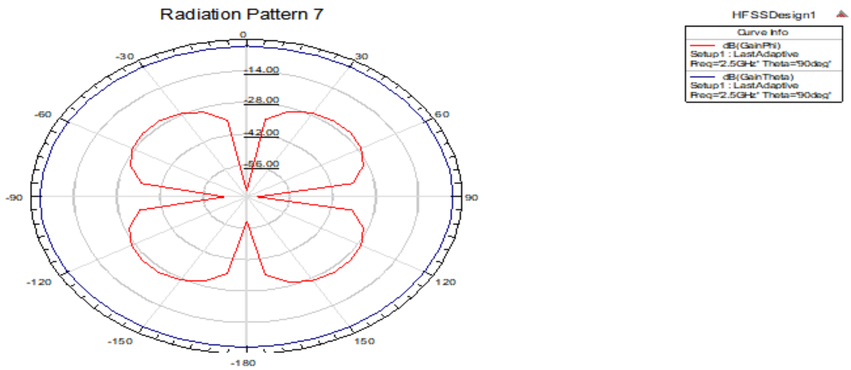

Figure 25: Radiation Pattern for Gain and Directivity (Solomon Nsor-Anabiah, 2024)

The radiation pattern for gain and directivity in Figure 25 shows an omnidirectional full circle with maximum radiation in all directions. The side lobes have four distinct patterns, with reduced gain compared to the main lobes. These have four directions of minimal radiation mounted at 90-degrees intervals (north, south, east and west). The Gain value represent the strength of the antenna energy.

- One lobe has a gain of -14.00dB (relatively higher radiation).
- Lobe two has a gain of -28.00dB and -48.00dB (lower radiation).
- One lobe has a gain of -56.00dB (very low radiation).

This shows that the antenna is radiating minimal energy in these directions and confirms the omnidirectional nature.

4.3 Summary of all the Results Obtained from the Four Simulations

Table 1.1: Summary of Results for the Existing and Three Simulations of the Optimized Antenna

PARAMETER	EXISTING ANTENNA	OPTIZED ANTENNA		
		Simulation 1	Simulation 2	Simulation 3
Height	31mm	29mm	26.5mm	29mm
Radius	0.5mm	0.75mm	0.7mm	0.55mm
Gain	5.24dB	5.19dB	4.90dB	5.12dB
Directivity	5.25dB	5.16dB	4.90dB	5.17dB
Efficiency	87%	89%	80%	90%
Return Loss	-15dB	-16dB	-17dB	-16.50dB
Bandwidth	0.2GHz (200Mhz)	0.6GHz (600Mhz)	0.15GHz (150MHz)	0.2GHz (200MHz)

The existing antenna design provides a moderate gain and directivity with an efficiency of 87%. The return loss is -15 dB, indicating a good impedance matching, and the bandwidth is 200 MHz. While this design is functional, the bandwidth might be somewhat limited for broader applications. Comparing simulation 1,2 and 3 results in Table 1.1, it can be deduced that optimized antenna one most satisfies the requirements for G4/LTE Communications With a gain of 5.19 dB, return loss of -16dB, efficiency of 89% and bandwidth of 600 MHz is testament to a better design than the others.

5. CONCLUSION

For 4G/LTE wireless communication, the most suitable antenna design appears to be the configuration with a height of 29 mm and a radius of 0.75 mm. It has the highest frequency among the options, and provides the second highest efficiency (89%), a good return loss value (-16.00dB), and highest bandwidth of 0.6 GHz, all of which are crucial for supporting the high data rates and wide frequency spectrum required in 4G/LTE networks. Also, [4] designed a monopole to operate within the 4G/LTE band and comparing their results obtained in 2020 shows that these results are and improvement over theirs.

5.1 LIMITATION

One major limitation to this study is that the results from the simulation-based optimization may not truly reflect the real-world situation. Also, the impact of the immediate surroundings and interference on the design and simulation was not factored into the implementation and could have an effect on the results obtained.

5.2 RECOMMENDATION

Based on the simulation results, the optimized antenna with a height of 29 mm and a radius of 0.75 mm is recommended for 4G/LTE wireless communication applications. This configuration offers the best balance between gain, directivity, efficiency, return loss, and bandwidth, ensuring reliable and high-performance communication. However, considering the limitations in subsection 5.1, the following considerations have been made for future studies.

- The antenna design should be refined by adjusting or using a different material.
- Alternative geometries of the antenna should be explored, they may yield even better performance, especially in specific use cases like mobile devices or IoT applications.
- A real-world design and implementation would provide a better comparison to confirm or deny the results obtained in this study.

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