Study and Analysis of "W- Shaped" Meander Line Antenna

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Abstract

This report details the design and analysis of a W-shaped meander line antenna utilizing ANSYS HFSS (High-Frequency Structure Simulator). The antenna is distinguished by its compact design, wide bandwidth, and efficient performance for wireless communication applications. Simulation results, including gain, return loss, efficiency, and directivity, confirm the effectiveness of the W-shaped structure in achieving the desired frequency response. The W-shaped antenna employs a meander line pattern resembling the letter 'W,' which contributes to a reduction in the antenna's physical size while maintaining the necessary electrical properties. The simulation of this antenna was conducted in ANSYS HFSS v2021. Key results obtained include return loss, radiation pattern, 3D polar plot, sidelobe level, beamwidth, radiated power, and accepted power. This meander line W-shaped antenna is designed for a frequency of 5.2 GHz, demonstrating a return loss of less than -10 dB and a bandwidth of 2 GHz. The antenna achieves a gain of 10 dB at perpendicular angles. A significant advantage of this antenna is its capability to provide a wider bandwidth and a radiation efficiency of 98%.

Keywords: W-shaped Structure, ANSYS HFSS (High-Frequency Structure Simulator), Meander Line Antenna, Wireless Communication, Microstrip Patch Antenna.

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1. Introduction

In a microstrip patch antenna, the radiating patch serves as the essential component responsible for the emission and reception of electromagnetic waves. Its design significantly influences the antenna's performance in terms of frequency, gain, bandwidth, polarization, and radiation pattern. Microstrip patch antennas can be designed in various shapes, including square, rectangular, triangular, and circular configurations. Among these, the meander line antenna is a type of compact antenna that achieves a reduced physical size while maintaining effective electrical performance. It falls within the broader category of microstrip antennas and is frequently utilized in space-constrained applications such as mobile devices, RFID systems, wearable electronics, and Internet of Things (IoT) devices. Meander line antennas can be customized in various shapes based on specific applications. One important criterion for employing a meander line antenna is to increase its effective height. Several meander line shapes are detailed in Table 1.

Table 1. Various Shapes of Meander Line Antenna

Shape Type	Description
Linear Meander	Straight line that zigzags in one plane (X or Y direction)
Planar Meander	Pattern lies flat on a plane, ideal for printed antennas
Spiral Meander	Coiled into a spiral for extreme compactness
Meander on Patch	Integrated into a microstrip patch to reduce size or support multiband
3D Meander	Folded in multiple planes, often used in wearable or conformal devices

This paper focuses on the W-shaped meander line antenna. This antenna structure employs a meandering design to maximize effective length while minimally increasing physical dimensions, making it particularly suitable for mobile devices and compact communication systems. The analysis and design of such antennas are enhanced through simulation tools like ANSYS HFSS, which offers advanced electromagnetic modeling capabilities.

2. Related Work

Lin et al. [1], proposed a compact meander line antenna that operated at 2.4 GHz, achieving a gain of 5.5 dB and a return loss of -20 dB, thus demonstrating good performance for wireless applications. Rana et al. [2] (2020) explored the optimization of meander line antennas for IoT applications, reporting a cut-off frequency of 2.45 GHz with a gain of 6.0 dB and an efficiency of 88%, showcasing their suitability for low-power devices. Harish et al. [3] (2019) introduced a W-shaped meander line antenna that provided significant size reduction while maintaining a directivity of 7.2 dB and a return loss of -25 dB, affirming its effectiveness in space-constrained environments. Islam et al. [4] (2021) focused on the impact of various substrate materials on antenna performance, noting that the choice of material can improve gain and reduce losses, with reported values of 6.5 dB gain and 30 dB isolation. Lofti et al. [5] (2007) highlighted the potential for W-shaped designs in achieving wider bandwidths, achieving an efficiency of 90% with a cut-off frequency around 3.0 GHz. Collectively, these studies emphasize the advantages of W-Shaped meander line antennas in providing compact size, improved efficiency, and high performance, making them suitable for a range of applications in contemporary wireless communication.

3. Proposed Work

3.1 Antenna Design

The “W-shaped” Meander Line Antenna allows for a reduced footprint, essential for modern compact devices. The model is designed as per Lotfi et al. [5] and Hlaing et al. [6]. The antenna can be designed with any kind of feeding methodology. Usually, the meander line antenna is designed using a coaxial feeding type or a proximity fed antenna.

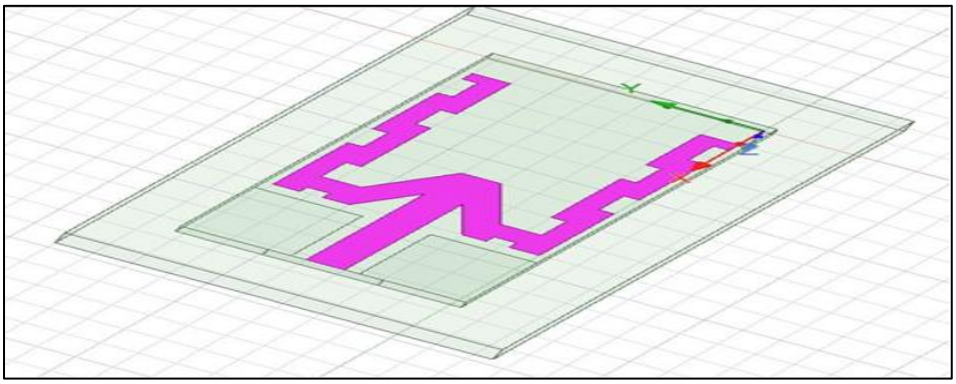

Figure 1. W-Shaped Meander Line Antenna

Here, we have designed it using a microstrip inset fed type. The meander line structure is shown in Figure 1, and the zigzag pattern structure is given in Figure 2.

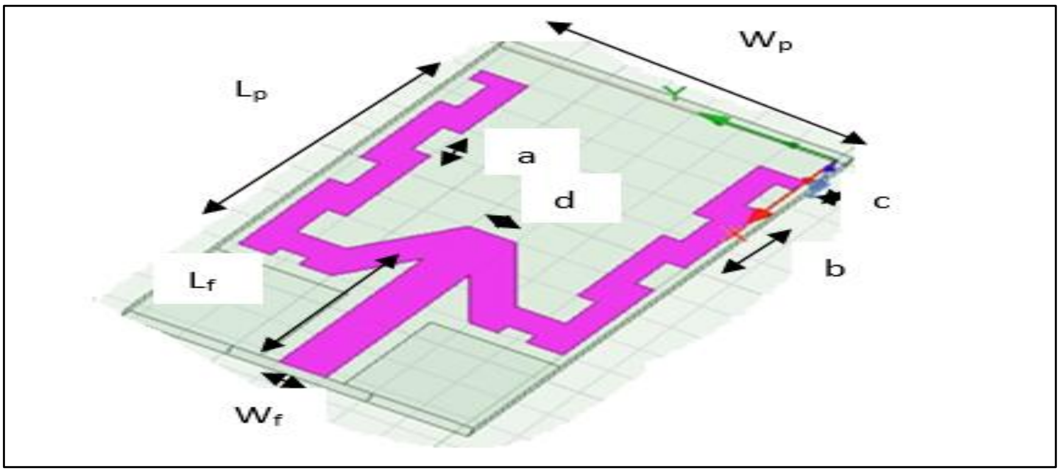

Figure 2. ZIG ZAG Pattern Structure of Antenna

The electrical equivalent of the circuit is calculated from the patch length, width, and the number of zigzag patterns. Its input impedance is given by

Zin=RD+RL+j(XC-XD) (1)

Where Rin=RD+RL (2)

By changing the length of the patch,

$$R_L = \frac{L}{2\pi r}\sqrt{\frac{w\mu_0}{\sigma\lambda}} \tag{3}$$

RL value can be changes as well as input impedance, to create the necessary oscillation condition. Maximum power is radiated at the self-resonating condition when XC=XD.

The ratio of length to width is given, as per MinJie Ma et al [7] by

$$\frac{W}{d} = \begin{pmatrix} \dfrac{8e^{A}}{e^{2A}-2} & (for\, W/d < 2) \\ \dfrac{2}{\pi}[B-1-\ln(2B-1)+\dfrac{\varepsilon_r -1}{2\varepsilon_r}\left\{`\ln(B-1)+0.39-\dfrac{0.61}{\varepsilon_r}\right\}] & for\, W/d > 2 \end{pmatrix} \tag{4}$$

Where,

$$A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right) \quad (5)$$

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} \quad (6)$$

One more thing to be considered is wavelength, it is given in equation in Calla et al. [7]

$$\lambda_g = \frac{\lambda}{\epsilon_{reff}} \quad (7)$$

3.2 Design Methodology

Create a Model or Geometry

By defining specific parameters, the design can be optimized for the W-shaped zigzag structure. Here, we have chosen to design at 5.2 GHz, making it efficient for ISM band applications. The relative permittivity of 4.4 with an FR4 substrate is utilized here for its easy availability. The parameters are specified in Table 2.

Table 2. Parameter Configuration

Parameter	**Values (mm)**
Substrate length	12.5
Substrate width	7.5
Patch length (L_p)	8
Patch width (W_p)	7.5
Feed length (L_f)	6.25
Feed width (W_f)	1
Zig zag pattern inner length (a)	1
Zig zag pattern outer length (b)	1.5
Zig zag pattern last end length (c)	0.3
Zig zag pattern centre edge length (d)	0.8
Zig zag pattern height	1

Assignment of Boundaries

The next step in the antenna design process within HFSS is assigning the correct boundaries to the structure. To create an open model, radiation boundaries should be set approximately one-quarter wavelength away from the antenna surface. In Figure 3. We can see the boundary assignment.

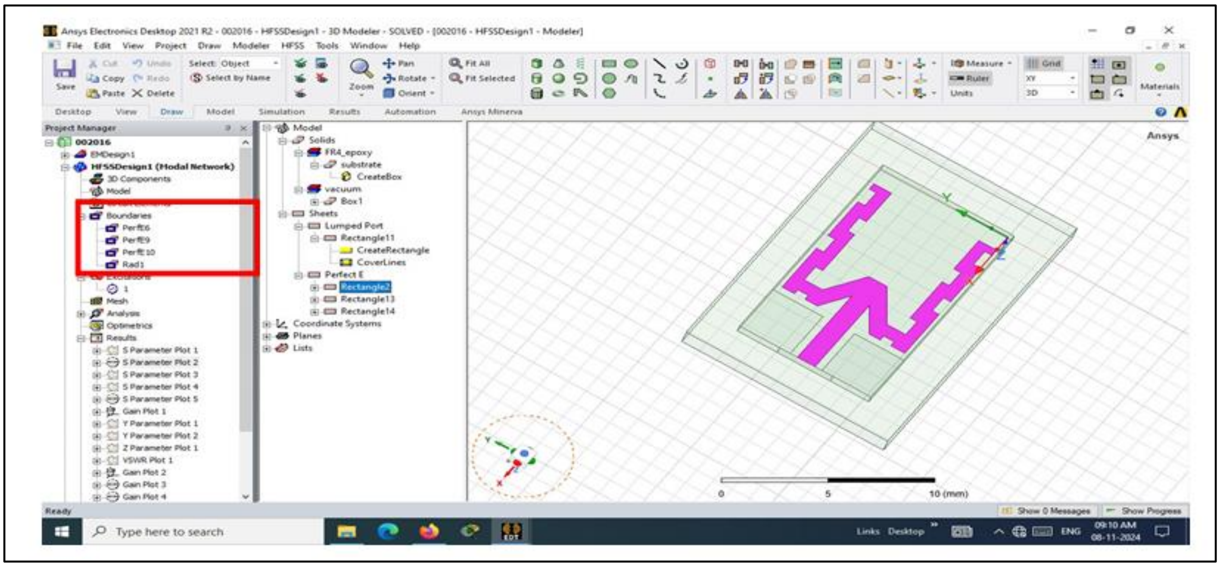

Figure 3. Assignment of Boundaries

Assignment of Excitation

The excitations or ports need to be connected after the assignment of boundaries. Again, this assignment of ports also plays a vital role. The antenna result provided by the HFSS software greatly depend on the assignment of excitations or ports. Excitation is shown in Figure 4.

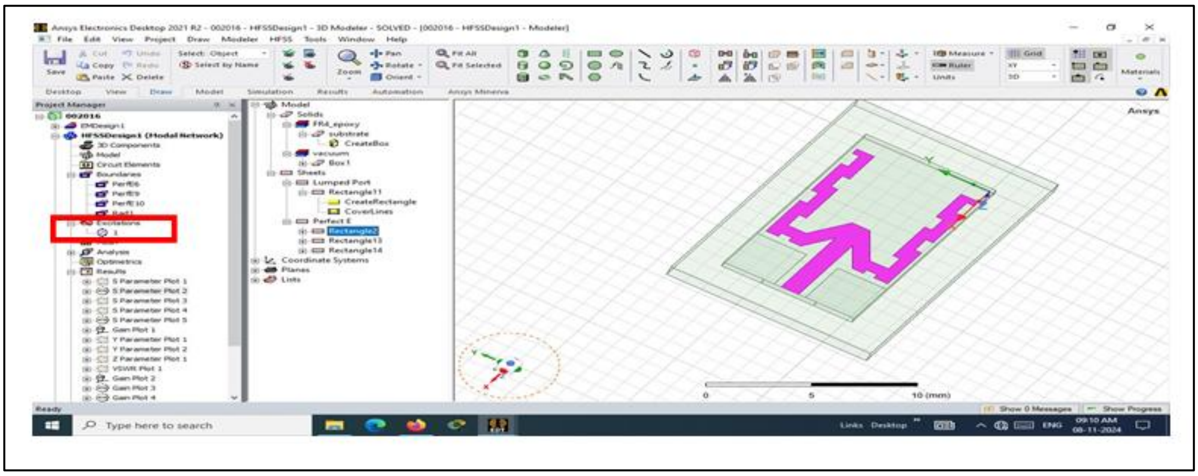

Figure 4. Assignment of Excitation

Setting up the Solution

After assigning the boundaries and excitations to the 2D and 3D models, the parameters need to be analyzed. The fast sweep is preferred in simulations that have numerous sharp resonances. To accurately determine the behavior of the antenna near a resonance, a fast sweep is used. A major advantage of the rapid range is that it allows the user to post-process and show fields at any region within the frequency sweep, as well as the fields at any frequency. Once the above steps are completed, the model needs to be analyzed and validated. An error will be thrown if any issues occurin the previous steps.

4. Results and Discussion

4.1 S-Parameter

Return loss is a measure of the power reflected from the antenna compared to the power transmitted into it. It quantifies how well the antenna is matched to the transmission line and is expressed in decibels (dB). The return loss structure is shown in Figure 5.

$$\text{Return Loss} = -20\log\left(\frac{V_{\text{reflected}}}{V_{\text{incident}}}\right) = -10\log\left(\frac{P_{\text{reflected}}}{P_{\text{incident}}}\right)$$

At the Frequency of 5.76 GHz we obtain return loss as -15.07.

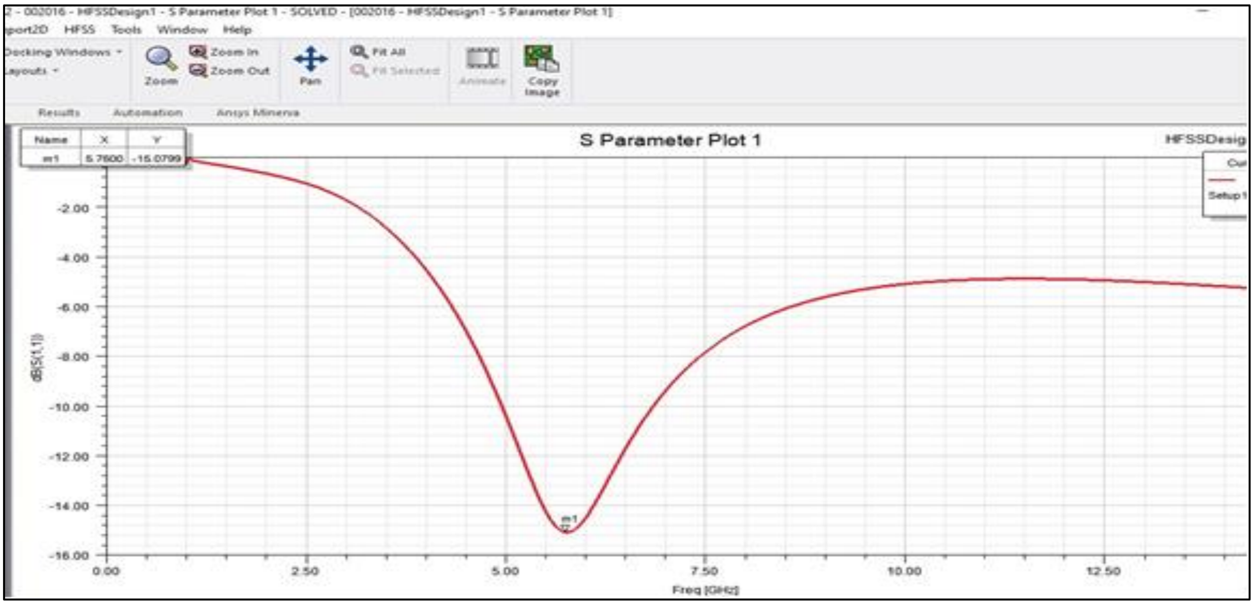

Figure 5. S-Parameter

4.2 VSWR

Definition: The Voltage Standing Wave Ratio (VSWR) is a metric that assesses the efficiency of radio frequency (RF) power transmission from a power source through a transmission line to the load, such as an antenna. It quantifies the degree of mismatch between the transmission line and the load, offering valuable insight into the quality of the impedance match.

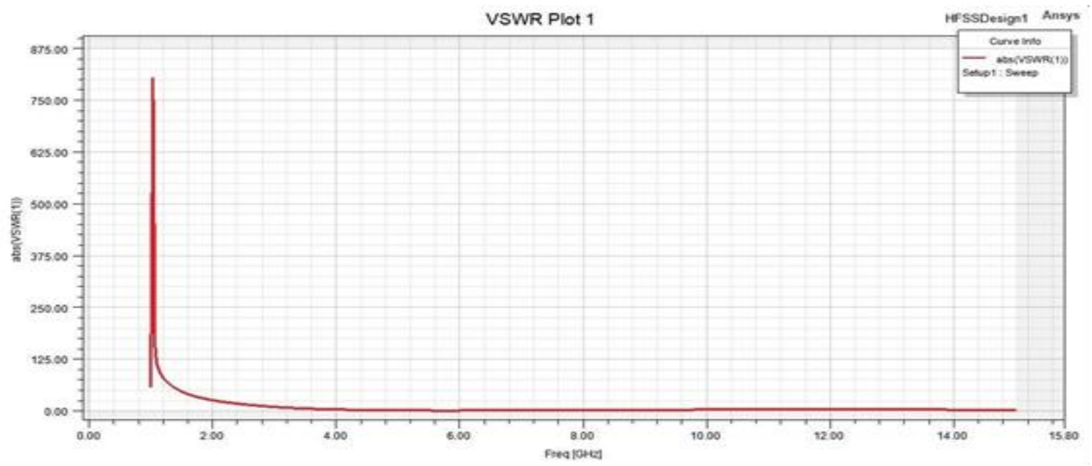

Figure 6. VSWR Plot

From Figure 6. we can infer that the VSWR is less than 1 from a frequency of 2 GHz to 14 GHz onwards.

4.3 Antenna Gain

The directionality of the antenna is measured by a factor called Antenna Gain or Gain of an Antenna. It quantifies the ability of the antenna to direct energy in a particular direction and is expressed in decibels (dB).

In particular, power gain is defined in terms of the ratio of the radiated intensity of an antenna in a particular direction at a random distance to the radiated intensity of an isotropic antenna at the same distance, as shown in Figures 7 and 8 as its two-dimensional and three-dimensional quantities, respectively.

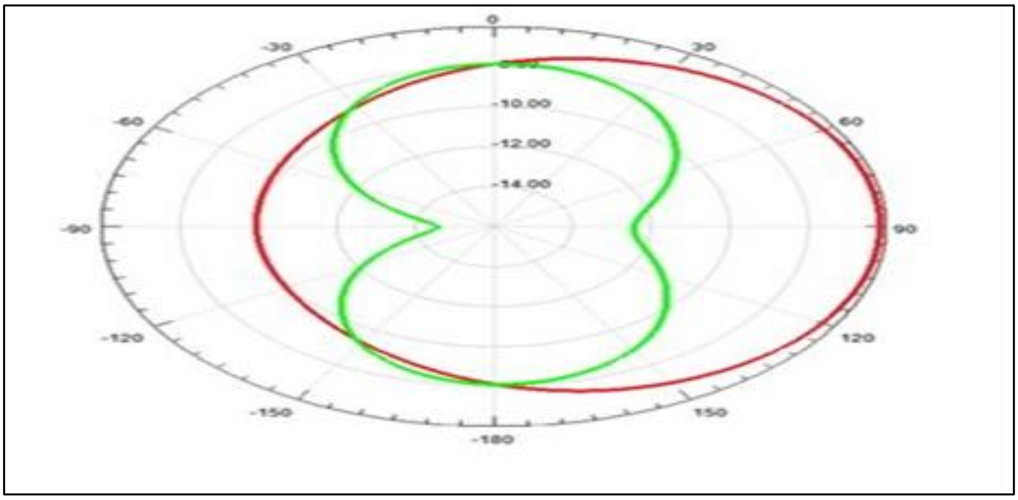

Figure 7. 2D Gain Plot

Gain can also be given by,

Gain = Directivity × Efficiency

If the gain is higher, then the signal strength is higher in that particular direction.

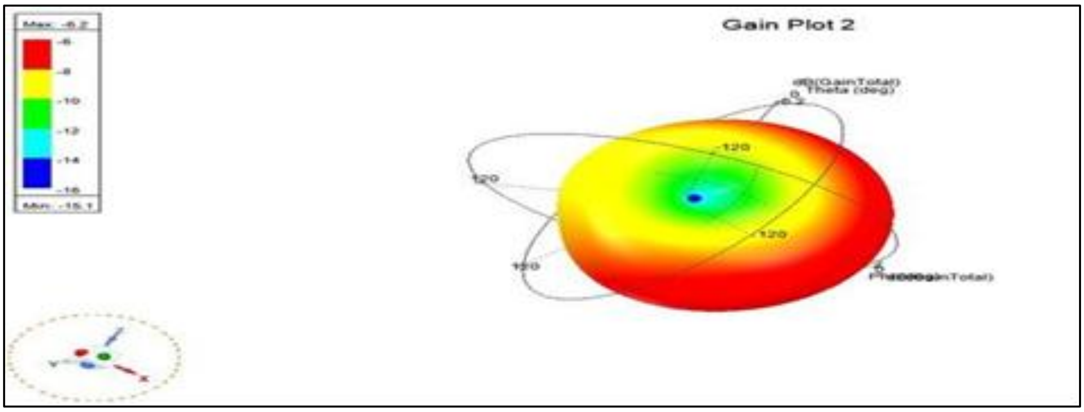

Figure 8. 3D Gain Plot

4.4 Field Distribution

Antennas are designed to transmit and receive electromagnetic waves. The field distribution for our antenna is discussed in Figure 9.

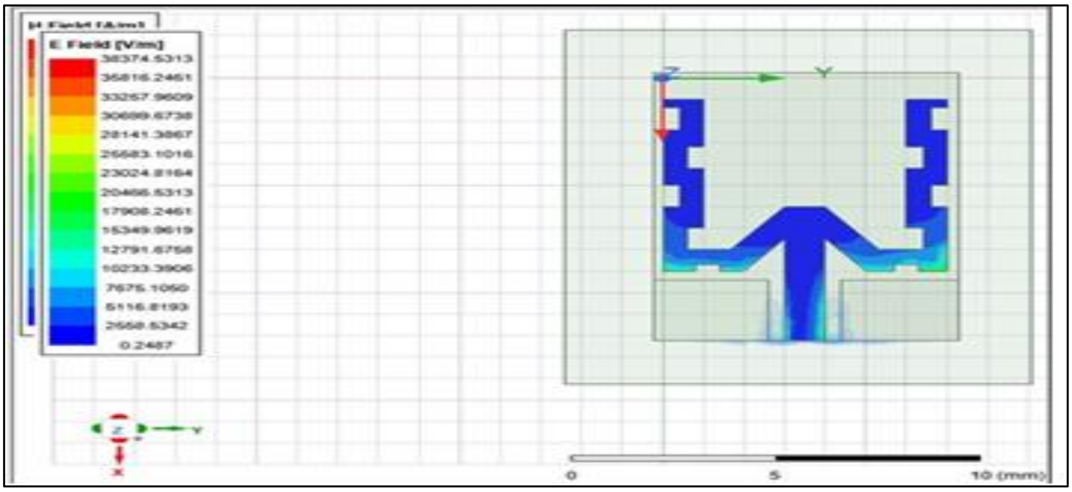

Figure 9. Field Distribution Pattern

Finally, we get the results shown in Table 3.

Table 3. Result Parameters for W-shaped Meander Line Antenna at 5.76 GHz

Parameter	**Value**
Peak directivity(dB)	0.24663
Peak gain(dB)	0.24187
Radiation efficiency	0.98072
Radiated power	677.67mW
Total efficiency	0.67767

Comparison with existing literatures is shown in Table 4

Table 4. Comparison of Results

Author	**Cut off frequency (GHz)**	**Gain (dB)**	**Directivity (dB)**	**Efficiency (%)**	**Return loss (dB)**
Lin et.al (2018)	2.4	5.5	6.0	85	-20
Rana et.al (2020)	2.45	6.0	7.0	88	-25

Harish et.al (2020)	2.5	7.2	8.0	90	-22
Islam et.al (2021)	2.6	6.5	7.5	87	-30
Lofti et.al (2022)	3.0	7.0	8.0	90	-28
Proposed	5.2	10	12	98	-14

Applications

RFID Systems

RFID tags and readers, particularly in passive RFID, benefit from small size and low power consumption.

Biomedical Applications

RFID technology is incorporated into implantable or body-worn devices for health monitoring, thanks to its biocompatibility and compact design.

5. Conclusion

The W-shaped meander line antenna was designed using ANSYS HFSS, with appropriate measurements and the substrate material specified as "FR4." Boundaries and excitations were assigned, and the design was validated to yield favorable results. The methodology involved simulating the antenna in HFSS, where performance evaluation was conducted based on key parameters: An S-parameter of -15.07, a Voltage Standing Wave Ratio (VSWR) of less than one at a frequency of 5.76 GHz, and a radiation efficiency of 98%. Future work will focus on optimizing the antenna for specific applications to ensure compliance with the evolving demands of wireless communication technology. This report analyzes the design and performance of the W-shaped meander line antenna, emphasizing its efficiency, compact size, and frequency response. In comparison to conventional antenna designs, the W-shaped meander line configuration achieves a favorable balance between reduced physical size and maintained performance, positioning it as a viable candidate for various applications.

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