Ultra-Wideband Microstrip Patch Antenna with Semi-Circular Slot and Modified Inset Feed for Wireless Applications

Proposed Design:

The antenna is designed on an FR4 substrate, which is a common dielectric material with a relative permittivity (εr) of approximately 4.4 and a loss tangent of about 0.02. The radiating patch is circular with a unique modification, including A semi-circular slot inside the circular patch and meander slots giving rise to inset feeding at top of the substrate and fully grounded plane at bottom. The semi-circular slot and meandered slot at the feed plays significant roles in enhancing antenna performance. The semi-circular slot modifies the current distribution on the patch, introducing an additional resonance. This helps in achieving multi-band operation or wider bandwidth, especially useful for Ultra-Wideband (UWB) and broadband applications. The slot can also improve impedance matching, reducing return loss (S11). The meandered slot fine-tunes the input impedance, allowing better impedance matching between the patch and the feedline. This reduces reflection (lower VSWR) and improves the antenna’s efficiency. The meandering structure increases the electrical length of the feedline without increasing physical size. This leads to improved bandwidth, crucial for applications like UWB communication. The dimensions of the antenna is presented in the figure 1.

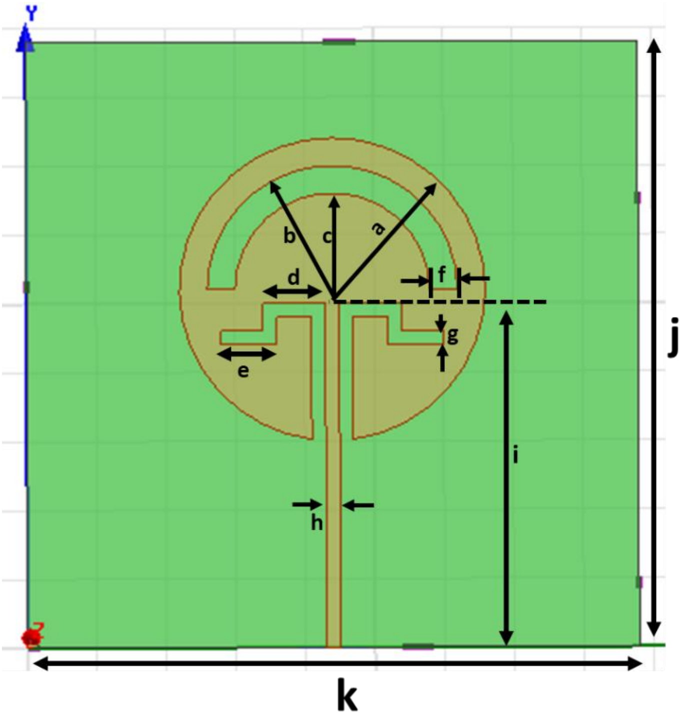

Figure 1: Top View of patch antenna

Table 1: Dimensions of components

Component	Dimensions
a	22 mm
b	18 mm
c	14 mm
d	9 mm
e	6 mm
f	4 mm
g	2 mm
h	2 mm
i	50 mm
j	88 mm
k	88 mm

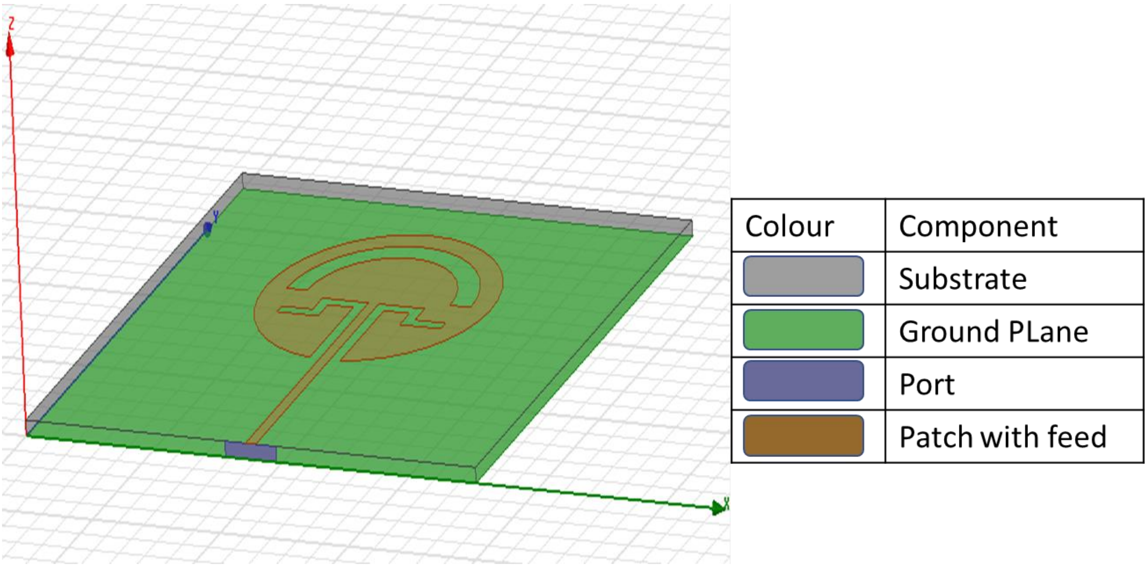

Figure 2: 3D View of antenna: colour coding.

Component	Dimensions (mm)
Substrate	88 × 88 × 1.6
Ground	88 × 88 × 0.001
Patch Radium	22
Patch Thickness	0.001
Feed	50 × 2 × 0.001

Results and Discussions:

Return Loss: Return loss (S11) is a key parameter in antenna design that measures how much power is reflected back to the source when an RF signal is applied. It indicates how well an antenna is matched to the transmission line or source impedance (typically 50 Ω). S11 is expressed in dB (decibels) and is always negative. A lower (more negative) S11 value means better impedance matching, resulting in less reflected power and higher efficiency. The operating bandwidth of an antenna is typically defined by the frequency range where S11 is below -10 dB. -10 dB return loss means only 10% power is reflected, and 90% is transmitted. A broadband antenna has a wide frequency range with S11 < -10 dB, while a narrowband antenna has a small range of operation.

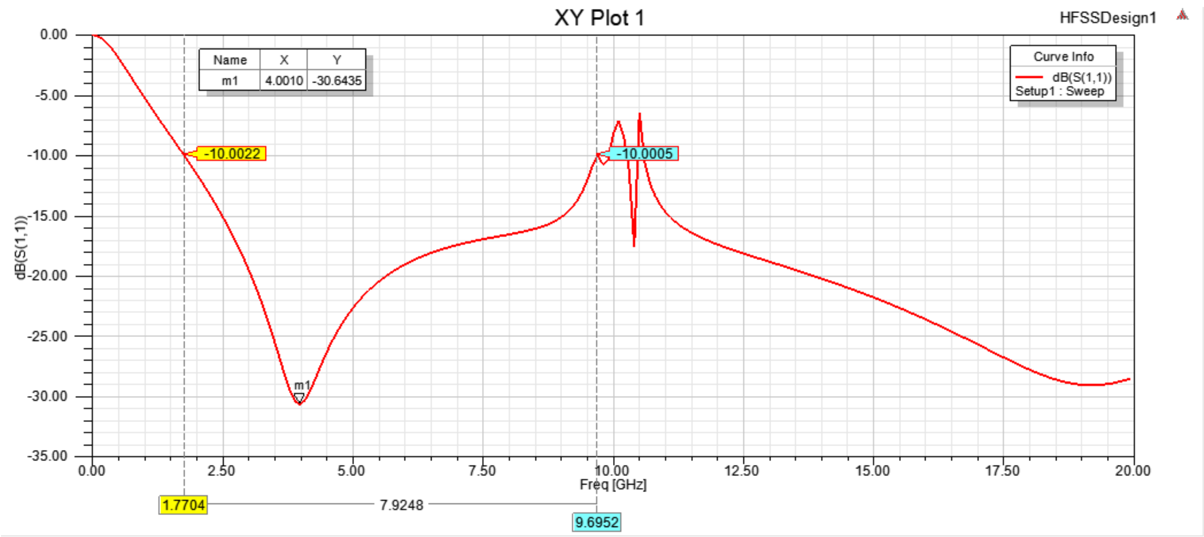

Figure 3: Return Loss (S11) of proposed antenna at 4GHz.

The S11 occurs at 4.001 GHz with a return loss of -30.64 dB. It indicates excellent impedance matching with nearly negligible power reflection. Most of the power is efficiently radiated or absorbed, making this frequency the primary operational band. The antenna exhibits a ultra-wide bandwidth of 7.92 GHz operational between 1.77 GHz to 9.69GHz.

Percentage of Impedance Bandwith: The impedance bandwidth of an antenna refers to the range of frequencies over which the antenna maintains an acceptable impedance match (typically S11 ≤ -10 dB or VSWR ≤ 2). Within this range, the antenna effectively transmits and receives signals with minimal reflection and maximum efficiency.

$$\text{Percentage Bandwidth} = \left(\frac{f_h - f_l}{f_c}\right) \times 100$$

Here F_H = 9.69 GHz, FL=1.77GHz and Fc=4GHz. The percentage bandwidth of the antenna is 198%, which indicates an ultra-wideband (UWB) antenna with a very large operating frequency range.

VSWR: Voltage Standing Wave Ratio (VSWR) is a measure of how efficiently RF power is transmitted from a source (such as a transmitter) to an antenna without reflections. It indicates the impedance matching between the antenna and the transmission line (typically 50 Ω).

Ideal VSWR = 1: Perfect matching (all power is transmitted, no reflection).

Higher VSWR (>1): Indicates mismatching, leading to power reflections and losses.

Hence. VSWR value should be lessthan or equal to 1 for a better performance.

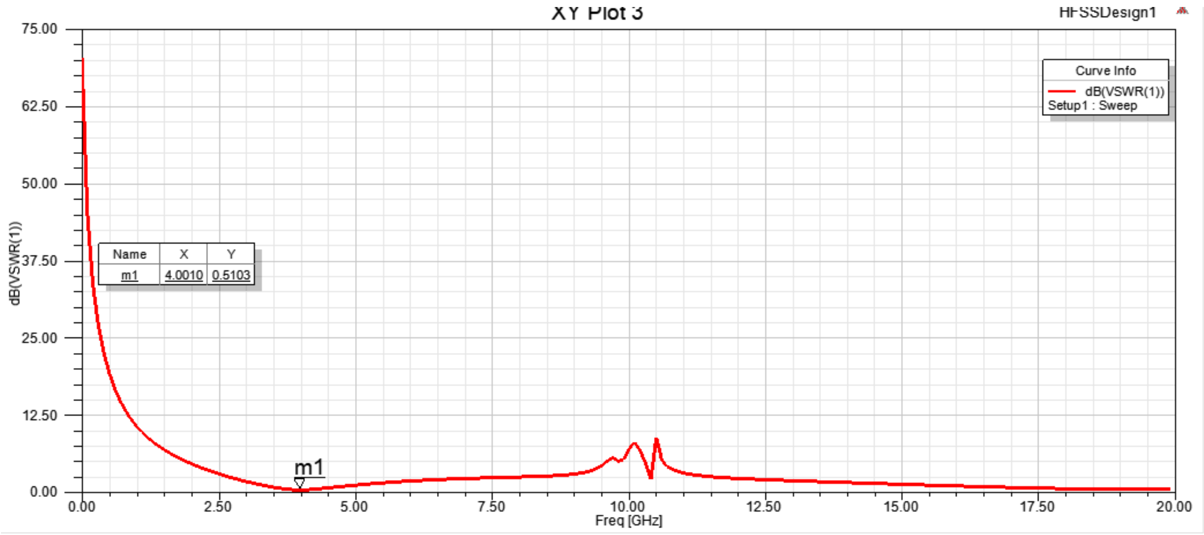

Figure 4: VSWR in dB of proposed antenna at 4GHz.

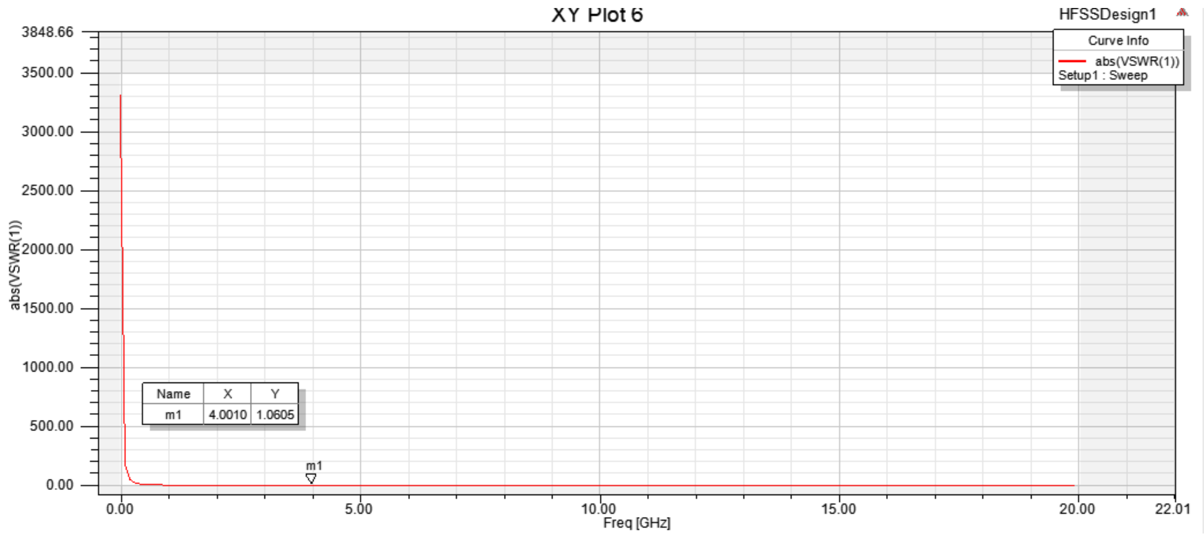

Figure 5: absolute value of VSWR of proposed antenna at 4GHz.

At 4 GHz, the VSWR value from the plot is 0.5103 dB, which translates to a linear VSWR of approximately 1.06, indicating excellent impedance matching. A VSWR close to 1 signifies that almost all the power from the source is efficiently transmitted to the antenna with minimal reflection, ensuring high radiation efficiency. This low VSWR reduces signal losses, improves overall system performance, and prevents potential damage to RF components due to power reflections.

Gain:

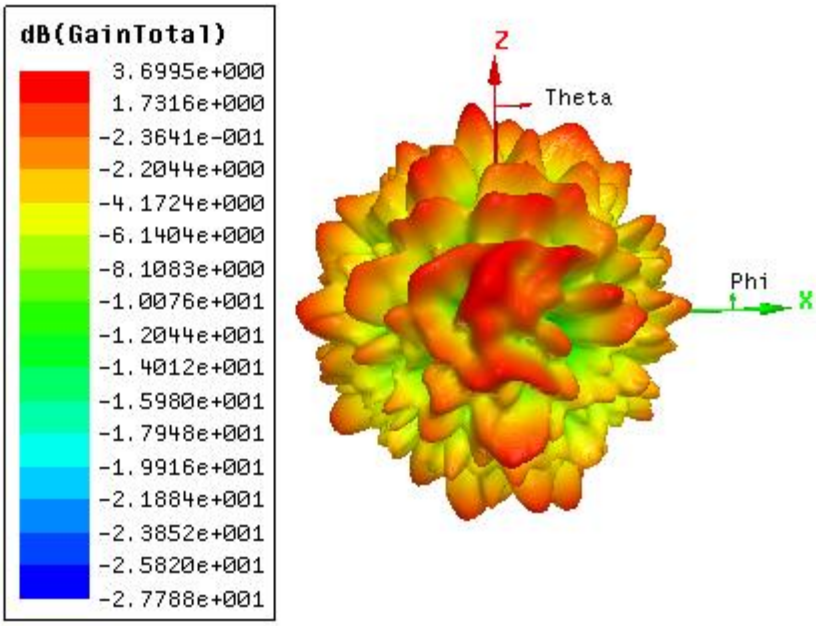

Figure 6: Gain of proposed antenna at 4GHz.

The given image represents the 3D gain radiation pattern of an antenna. The maximum gain of 3.69 dB, as shown in the radiation pattern, represents the directivity and efficiency of the antenna in its strongest radiation direction. A 3.69 dB gain means that the antenna radiates about 2.33 times the power compared to an isotropic radiator (0 dBi). This gain value suggests the antenna has a wide radiation pattern, covering multiple directions instead of focusing energy into a narrow beam. It is ideal for wideband applications like UWB communication, IoT, and sensor networks where multi-directional coverage is needed.

Radiation Pattern:

The given radiation pattern represents the far-field radiation characteristics of the antenna at 4 GHz. The plot is a polar radiation pattern, showing the total electric field in two different planes

Red Curve: Radiation pattern at Phi = 0° (E-plane)

Purple Curve: Radiation pattern at Phi = 90° (H-plane)

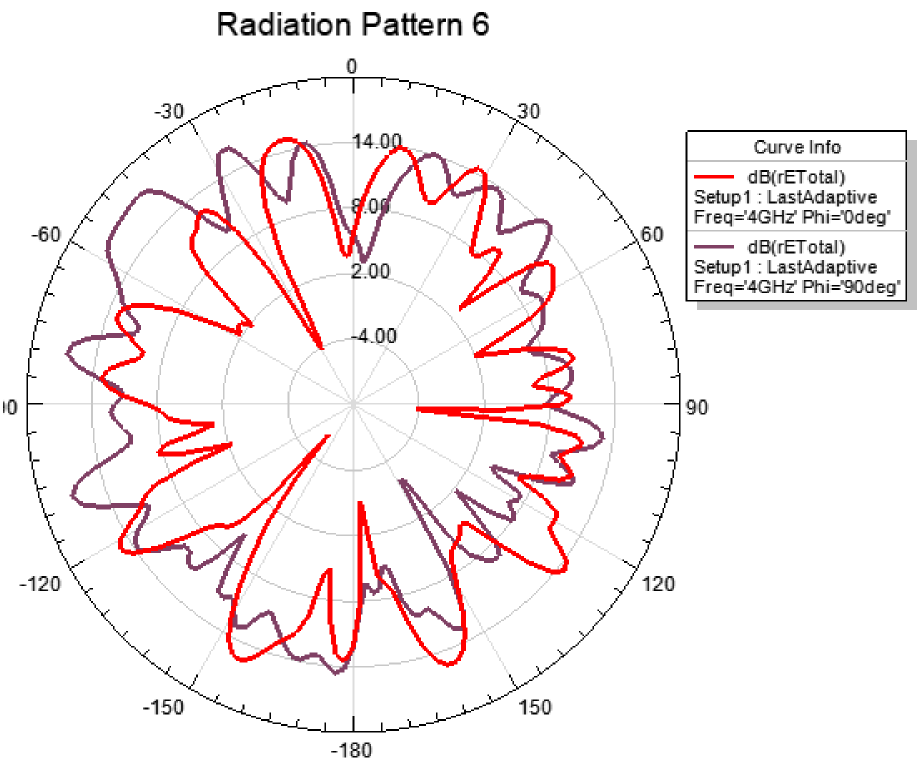

Figure 7: Radiation pattern corresponding to E-plane and H-plane of proposed antenna at 4GHz.

The radiation pattern suggests that the antenna exhibits multi-directional radiation with a complex lobe structure at 4 GHz. This type of pattern is often observed in slot antennas, fractal antennas, or modified patch antennas used in wideband or UWB applications.

<u>Conclusion:</u>

The designed antenna exhibits **moderate performance with wideband characteristics**, making it suitable for various wireless applications. The **return loss (S11) at 4 GHz is -30.64 dB**, indicating **excellent impedance matching and minimal signal reflection**, while the **VSWR of 0.51** ensures **efficient power transfer with low losses**. The **calculated impedance bandwidth of 197%** confirms its **ultra-wideband (UWB) capability**, making it ideal for **radar, satellite communication, and wireless sensor networks**. The **radiation pattern at 4 GHz** shows a **multi-lobed structure**, suggesting **moderate directionality with some side lobes**, beneficial for applications requiring **broad coverage**. With a **maximum gain of 3.69 dB**, the antenna provides **moderate radiation efficiency and a balance between omnidirectional and directional radiation**. Additionally, its **wide beamwidth and moderate directivity** further support applications needing **broad and efficient signal coverage**. Overall, the antenna design effectively supports **wideband communication while maintaining efficient radiation characteristics**.