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Research Article

Design and Performance Analysis of a 45-Degree Tilted Arbitrary-Shaped Pentagonal Microstrip Patch Antenna

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ABSTRACT

In this paper, we discuss the design and performance analysis of a microstrip patch antenna, which has a pentagonal shape and is tilted at 45 degrees, specifically for purposes such as present modern communication systems. The proposed design includes notches and strips with circular slots on the 45-degree tilted pentagon geometry for improved return loss, gain, and radiation characteristics. CST Microwave Studio used for design and analysis, Rogers RT5880 used as substrate along with dielectric constant ε_r of 2.2. Co-axial feeder was used to feed the antenna. The analysis results show that the antenna resonates at 14.11 GHz with return loss at -55.12 dB and VSWR of 1.003 with a peak gain of 6.35 dBi. This excellent great impedance broad and compact, as well as stable radiation characteristics, prove the antenna should be used for applications of wireless communications, IoTs, and satellites. The present work shows the potential of 45-degree arbitrary-shaped tilted microstrip antennas for next-generation communication systems.

1 Introduction

The advancements in communication systems there is an increased need for antennas that are compact, energy efficient and high performance. By considering all the types of antennas, microstrip patch antennas have gained a lot of focus because of their low profile, being lightweight, ease of fabrication and compatibility with planar circuits. These characteristics make them suitable for use in wireless communication systems, satellite systems, IoT systems, and in upcoming networks. However most of the times conventional microstrip patch antennas face several drawbacks for example limited bandwidth, lack of polarization diversity and low radiation effectiveness, so modern design concepts are needed.

In this work, the specific design and developed features of the 45-degree tilted arbitrary-shaped pentagonal microstrip patch antenna are aimed at addressing the above limitations by improving performance. The high gain and optimized radiation characteristics are achieved from the combination of the unique geometry of the antenna, tilted at 45 degrees, with an arbitrary pentagonal shape. Modifications to the patch by incorporating notches and strip slots and circular slots will further compact the size and ensure a versatile operational antenna.

Keeping this in mind, one of the active fields of research in microstrip patch antennas is the development of lightweight and compact antennas. They are widely used in modern communication systems because they are low weight and compact. Thus, several research works have been carried out to bring some advancements in microstrip patch antenna design to develop and eliminate certain drawbacks from traditional microstrip patch antennas and to try to improve parameters such as bandwidth, gain, and radiation characteristics.

A single-band antenna for RF energy harvesting operating at 2.45 GHz was designed using pentagonal radiating patches along with a microstrip feeding technique. This antenna was noted to have an operational bandwidth of 240 MHz, stable omnidirectional radiation, and a maximum gain of 8.02 dBi [1]. Another author proposed a convex-shaped pentagonal microstrip antenna multiband for telecommunication purposes. It worked at 1.8 GHz with a return loss of -19 dB, was proximity feed coupled, and showed dual-band ability using fractal geometry that reduced the patch size by 25.56% [2]. This shows that an ultrawideband

pentagon-shaped planar microstrip slot antenna was developed for wireless communications and achieved remarkable impedance bandwidth of 124% (2.65-11.30 GHz), more than the UWB requirement of 110% (3.10-10.60 GHz). It covered 25% ground plane length to leave free space for RF circuitry, and experimental verification confirmed that it was wide.

II. Antenna Design:

The 45-degree tilted arbitrary-shaped pentagonal microstrip patch antenna is designed using CST Studio Suite. The antenna utilizes the coaxial feed technique for excitation, ensuring efficient energy transfer. For this design, Roger's RT5880 is chosen as the substrate material due to its dielectric constant of 2.2, which is ideal for high-frequency applications. The dimensions of the antenna are determined using standard design formulas, ensuring optimal performance and accurate parameter calculations are as follows.

The side length (L) is evaluated from,

$$L = \frac{C}{2f\sqrt{\varepsilon_{reff}}} \quad - 2\Delta L$$

The value of the effective dielectric constant (ε_{reff}) is evaluated from

$$\varepsilon_{reff} = \frac{(\varepsilon_r+1)}{2} + \frac{(\varepsilon_r-1)}{2}\left[1 + 12\,\frac{h}{w}\right]^{-1/2}, \qquad \frac{w}{h} > 1$$

Where,

L = Side Length,

C = Speed of light

ε_r = Substrate dielectric Constant

f = Resonant Frequency

ε_{reff} = Effective dielectric constant

ΔL = Effective Length

h = Height of substrate

III. Antenna Design Parameters:

The design parameters for 45 degree tilted arbitrary-shaped pentagonal patch antenna in CST software are as follows:

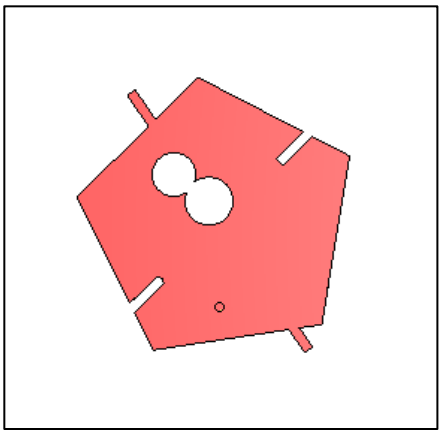


Figure 1: *The 45 Degree Tilted Arbitrary Shape Patch Antenna*

Patch dimensions: Side length of 7.73 mm

Substrate dimensions: 20 × 20 mm, with a thickness of 1.20 mm

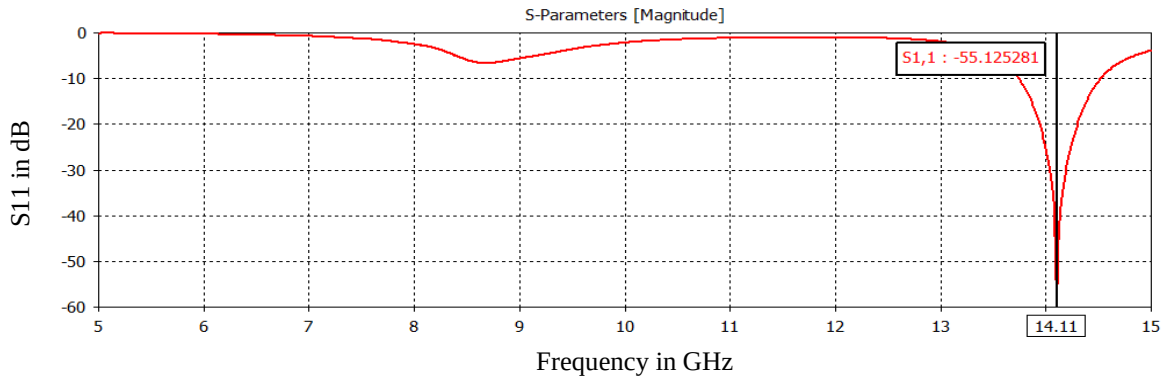
Substrate material: Rogers RT5880, with a dielectric constant (ε_r) of 2.2

Ground plane dimensions: Matches the substrate at 20 × 20 mm

Feeding technique: Coaxial feed

Notch dimensions: Lengths ln_1 = 1.89 mm, ln_2 = 1.74 mm, and width w_n = 0.44 mm

Strip dimensions: Lengths ls_1 = 1.72 mm and ls_2 = 1.64 mm, width w_s = 0.44 mm



Circular slots: Two slots, each with a radius of 1.1 mm

Using these design considerations, the 45-degree arbitrary-shaped pentagonal patch antenna is modeled in CST Studio, and a comprehensive parametric study was conducted. The results of the analysis for this design are presented in the following sections.

IV. CST Simulation Results:

4.1 S-Parameter Characteristics (S_{11}):

Reflection coefficient (S11) performance of the arbitrary-shaped pentagonal patch antenna 3, design B, over a frequency range of 5 GHz to 15 GHz.

Figure 2: The Return Loss of 45 Degree Tilted Arbitrary Shape Pentagonal Patch Antenna

The arbitrary-shaped pentagonal patch antenna 3, design B, has a resonating frequency at 14.11 GHz with an S11 value of -55.12 dB, which demonstrates unmatched impedance matching and almost zero power reflection. This exceptional performance indicates very high efficiency for such operations over the frequency.

4.2 Axial Ratio

Axial ratio of the arbitrary-shaped pentagonal patch antenna 3, design B, over a frequency range of 5 GHz to 15 GHz at θ = 0° and φ = 0°.

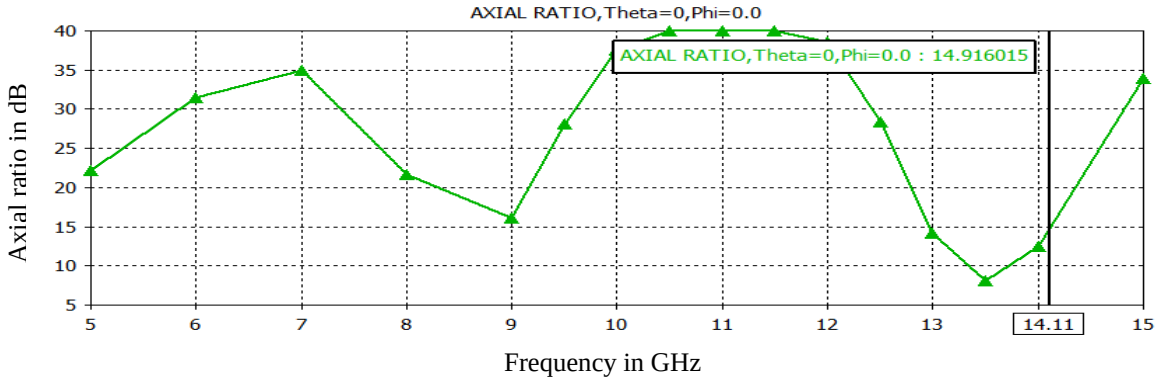


Figure 3: Axial Ratio of 45 Degree Tilted Arbitrary Shape Pentagonal Patch Antenna

From S-parameter analysis, 14.11 GHz has been located to be the frequency of resonance with this arbitrary pentagonal type patch antenna design B 3. Measured axial ratio at this given frequency is equal to 14.91 dB, thus clearly indicating that this antenna performs in linear polarization.

4.3 VSWR:

The Voltage Standing Wave Ratio (VSWR) performance of the arbitrary-shaped pentagonal patch antenna 3, design B, is analyzed across the frequency range of 5 to 15 GHz.

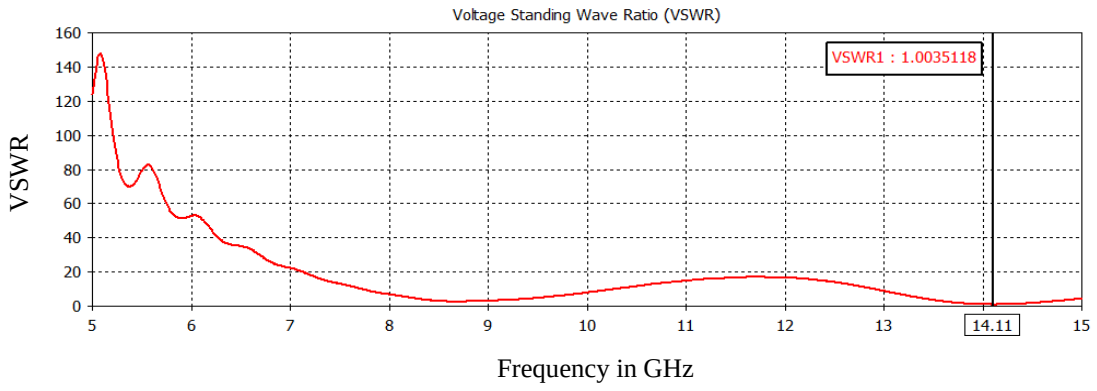
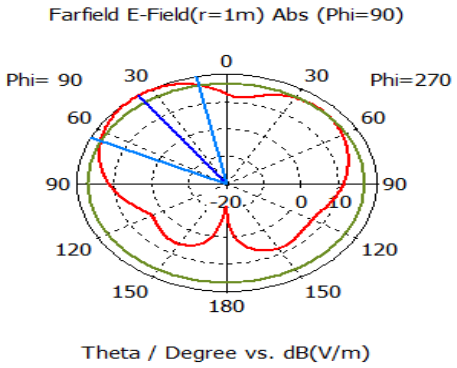


Figure 4: VSWR 45 Degree Tilted Arbitrary Shape Pentagonal Patch Antenna

The antenna has a VSWR value of 1.003 at 14.11 GHz, thus showing that its impedance matching is quite perfect and it is transferring power efficiently.

The far-field radiation patterns of the arbitrary-shaped pentagonal patch antenna 3, design B, are analyzed across the frequency range of 5 to 15 GHz

4.4 Radiation Pattern:



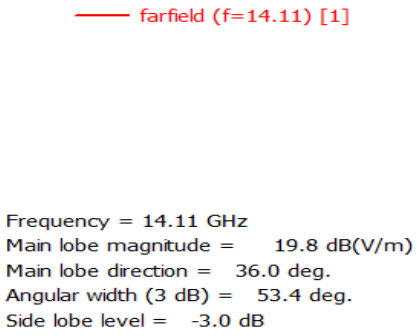


Figure 5: Radiation Pattern of 45 Degree Tilted Arbitrary Shape Pentagonal Patch Antenna

The antenna thus experiences a main lobe magnitude of 19.8 dB (V/m) at an angle of 36 degrees at 14.11 GHz and has a broader angular width of 53.4 degrees. Thus it will be better suited for applications that will require a wider coverage such as broadcasting or communication with more than one user. The side lobe level of -3.0 dB further complements these specifications through the efficient suppression of undesired radiation resulting into an improved performance of the antenna.

4.5 Gain

The graph illustrates the gain of the arbitrary-shaped pentagonal patch antenna 3, design B, across the frequency range of 5 to 15 GHz, measured in dBi.

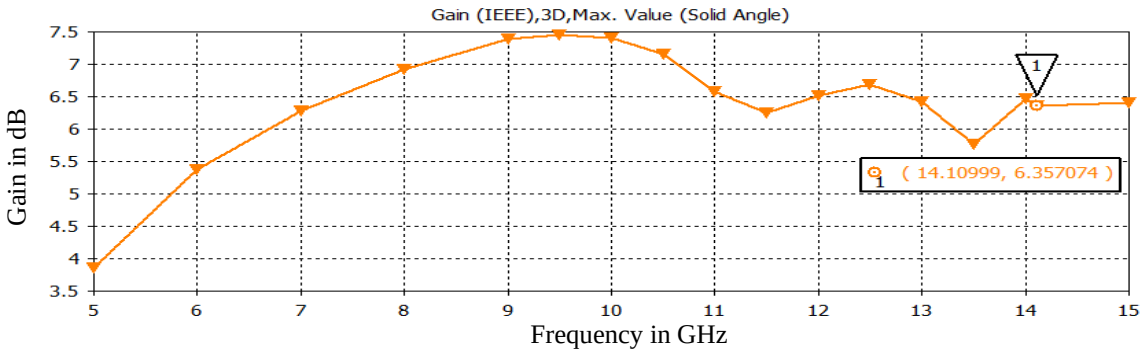


Figure 6: Gain of 45 Degree Tilted Arbitrary Shape Pentagonal Patch Antenna.

Design B gain plot has a peak of 6.35 dBi at 14.11 GHz, thus representing the optimum efficiency and sensitivity of directivity at this frequency. This performance confirms his usage in those applications that would require a focused energy transmission at the resonant frequency.

V. Conclusion:

The design and performance analysis of a microstrip patch antenna of arbitrary shaped pentagonal geometry, tilted at 45 degrees, substantiates its efficiency and effectiveness for high-band applications. The proposed antenna resonates at 14.11 GHz with excellent impedance matching and very low power reflection measured by -55.12 dB for S11. The value of the axial ratio 14.91 dB at the resonant frequency confirms linear polarization of the antenna and makes it appropriate for applications that require precision in the control of polarization. The VSWR at this frequency is 1.003, meaning the antenna conductively transfers power. At this frequency, the radiation will present a main lobe magnitude at 19.8 dB (V/m) directed toward 36 degrees with wider angular width of 53.4 degrees, making it appropriate for

applications like broadcasting or multi-user communication. The side lobe level is at -3.0 dB for improving performance relative to the effective suppression of undesired radiation. Antenna gain peaks at 6.35 dBi at the frequency of resonance, thus demonstrating the efficiency and directivity of energy focused transmission. All these results validate the suitability of the proposed design in advanced communication systems, proving to be effective in performance, reliable polarization, and efficient power handling at 14.11 GHz.

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