Design of Conformal Antenna for UAVs in 5G Midband for Reliable Coverage

C.Manikandan[1]
School of Electrical & Electronics Engineering,
SASTRA Deemed University,
Thanjavur, Tamil Nadu, India.
[1]manikandan@ece.sastra.edu

R Maheswari[2]
School of Electrical & Electronics Engineering,
SASTRA Deemed University,
Thanjavur, Tamil Nadu, India.
[2]rmaheshraj3@gmail.com

R Karpaga Rakshitha[3]
School of Electrical & Electronics Engineering,
SASTRA Deemed University,
Thanjavur, Tamil Nadu, India.
[3]rakshi15augrkr@gmail.com

A Rajesh[*4]
School of Electrical & Electronics Engineering,
SASTRA Deemed University,
Thanjavur, Tamil Nadu, India.
[*4]rajesha@ece.sastra.ac.in

S.Shreela[5]
School of Electrical & Electronics Engineering,
SASTRA Deemed University,
Thanjavur, Tamil Nadu, India.
[5]sridhar.shreela1@gmail.com

V Swetha[6]
School of Electrical & Electronics Engineering,
SASTRA Deemed University,
Thanjavur, Tamil Nadu, India.
[6]swethav745@gmail.com

***Abstract*—In today's technological development, unmanned aerial vehicles (UAVs) play a vital role in defense, military purposes, and various civil domains. In UAVs, conformal antennas are in active demand due to their low observability and ability to transform into any shape. In this paper, a conformal antenna was designed to support 5G UAV communication. The proposed antenna has a series-fed design with an even number of dissimilar patches. A novel inset feed is provided between the patches to achieve maximum radiation. The final stage of the patch is designed to allow maximum radiation at 3.13 GHz (mid-band for 5G) with a bandwidth of 33.8MHz. The proposed antenna in the targeted band offers reliable UAV 5G transmission coverage. The antenna performance is analyzed using parameters such as the reflection coefficient (return loss), bandwidths, and E-field and H-field radiation patterns.**

Keywords—Unmanned Aerial Vehicles, conformal, microstrip patch antenna

I. Introduction

An Unmanned Aerial Vehicle (UAV) is an aircraft designed to operate without human passengers or pilots. As the name implies, a Conformal antenna is designed to match an object's shape, such as a drone.[1] These antennas are commonly used in radio communication and avionics systems. By conforming to the surface of the UAV, they help minimize aerodynamic drag, which is the resistance encountered by an object as it moves through the air at a certain velocity. Aerodynamic drag occurs due to the compression of air particles at the front of the object and their dispersion at the back.

In the contemporary landscape, there's an apparent inclination among present-day mobile users towards swifter data speeds and heightened reliability in service provision. The progression from 4G to 5G is a testament to this evolving demand [2]. Fifth Generation (5G) technology emerges as the next frontier, offering many benefits, including enhanced data rates, heightened reliability, and increased network scalability and flexibility. Its attributes encompass remarkable speed, real-time responsiveness, heightened efficiency, and superior service provision, particularly in densely populated areas [3]. The burgeoning interest in adopting fifth-generation communication networks is palpable, reflecting a growing recognition of its transformative potential.

Antennas serve as transducers, converting electrical currents into electromagnetic waves. They are pivotal in transmitting and receiving non-ionizing electromagnetic fields, encompassing radio waves, microwaves, infrared radiation, and visible light.

The microstrip patch antenna is the most commonly used in wireless communication systems due to its ease of integration into devices. Its benefits include compact size, lightweight, low volume, less power consumption, directional radiation, higher gains, thin profile, easy manufacture, and cost-effectiveness. It is more frequently used in 5G communication systems because they offer more bandwidth at higher frequencies.[4]

This paper focuses on designing and simulating a microstrip patch antenna for compatibility with 5G communications. A microstrip antenna, called a patch antenna, consists of the ground plane, a dielectric material substrate and a thin metallic patch.[5] The substrate made of dielectric material is placed between the patch and the ground plane. The dielectric material substrate is covered on one side with a radiating metallic patch, and the other is grounded. Both the patch and ground are generally made of conducting material such as copper or gold. These can be easily integrated into devices and are mainly relevant at microwave frequencies, where the patches created are small due to shorter wavelengths.

Conformal antennas are designed with various types of substrate materials: polyurethane (PU)[6], Acrylic[7], Silicone[8], Epoxy[9], Parylene[10], Polyamide[11], etc., among all substrate Polyamide substrate, possesses better properties that are needed for conformal antenna

The advantages of polyamide substrates are flexibility, low relative permittivity, minimum dielectric loss, high thermal conductivity and low thermal coefficient. Additionally, the properties of polyamide material are that it exhibits high tensile, bending, and stretching strength. Due to these properties and low thickness(0.1mm), this is advantageous for our application.[12]

Insert feed is given to the patch to increase the bandwidth and improve the return loss and impedance matching. The impedance of the feeding line should be matched with the characteristic impedance of the patch.[13]

Section II of this research article tells about the design of the antenna and its dimensions, materials used, etc. Section III gives the results and discussion produced for the proposed design, and section 4 concludes the research work and the future needs that must be addressed.

II. ANTENNA CHARACTERISTICS

A. *Design of the antenna*

The design of the proposed antenna has been explained in this section. Generally, a microstrip patch antenna consists of four parts: the patch, ground plane, substrate and feeding transmission line.

The dimensions of an antenna are (79.5x76.12) mm. The bottom ground plane and the upper patch are made of copper because of their excellent electrical and radiation properties and ease of availability. Its thickness is 0.035 mm and has a dielectric value of 1.68. The substrate material of the microstrip patch antenna used for simulation is Polyamide, whose thickness is 0.1 mm and has a dielectric constant of 2.4.

The impedance matching is achieved when proper feeding is given to the patch. One of the techniques employed to achieve impedance matching is the Insert feed. It is given to the patch to increase the bandwidth, improve the return loss, and obtain the optimum gain and impedance matching.

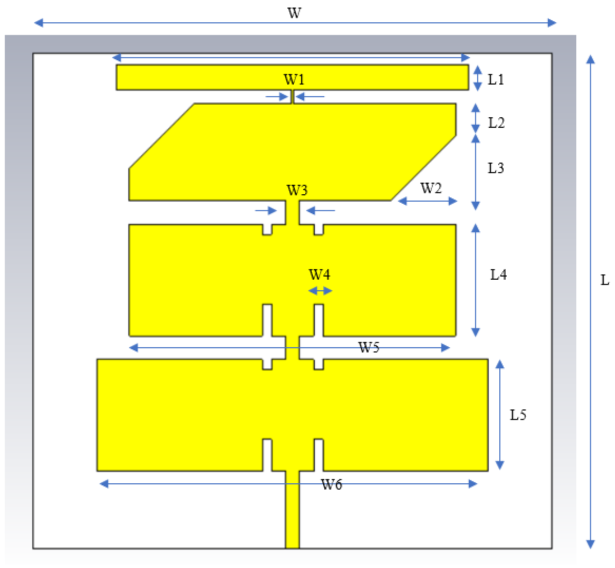


Fig .1. CST Design model of the resultant antenna

The dimensions of the designed antenna is given in Table I. The front side is given in Fig .1. and the back side (ground) is fully covered.[14]

TABLE I. DIMENSIONS OF THE DESIGN

Character	**Dimensions (mm)**
W	79.5
L	76.12
W1	0.25
W2	10
W3	2
W4	1.38
W5	50
W6	60
L1	4
L2	5
L3	10
L4	17.11
L5	17.11

III. RESULTS AND DISCUSSIONS

Before analyzing the results, a few basic terminologies required to understand the antenna design are discussed [15]

1. Gain – The antenna can direct the electromagnetic energy from the antenna. It is represented as the ratio of power radiated in one direction to the power radiated by an isotropic antenna.
2. Operating Frequency– Pertains to the spectrum of frequencies for which the antenna is engineered. It is a crucial factor that determines the performance and suitability of an antenna for a particular application. In this design, there is a center frequency at which there is maximum performance.
3. Bandwidth is generally represented as the difference between upper and lower frequency limits. Here, it is calculated from -10dB points on both the left and right sides of the center frequency.
4. Radiation Pattern – This parameter describes the spatial distribution of electromagnetic energy radiated in three dimensions.
    - Azimuthal Plane – The radiation pattern produced in the horizontal plane. This illustrates how the antenna radiated in the horizontal direction with the antenna axis as a reference.
    - Elevation Plane – In this, the antenna's main axis is aligned vertically, allowing the antenna's radiation characteristics in the vertical direction.
5. VSWR – It is an essential parameter for examining the impedance matching of antennas. It is defined as the ratio of maximum to minimum voltage across the transmission line. It measures the extent of power that bounces back towards the load due to impedance mismatch. Ideally, the value of VSWR should be around 1-3. A higher VSWR value leads to poor impedance matching and higher power loss.
6. Surface Current refers to the movement of electrical charges along the conductor's surface instead of flowing through the volume.
7. E-field and H-field patterns – The electric field pattern represents how the electric field strength is spatially around the antenna. The H-field pattern is

essential for understanding how electromagnetic waves are induced to produce magnetic fields.

From the above understanding, the results are depicted below-

The frequency dip in the S-parameter analysis is produced at 3.1325 GHz with a reflection coefficient of –19.947, which means the energy reflected is high[16]. This is an essential key point to be noted. The S-parameter analysis is depicted in Fig .2.

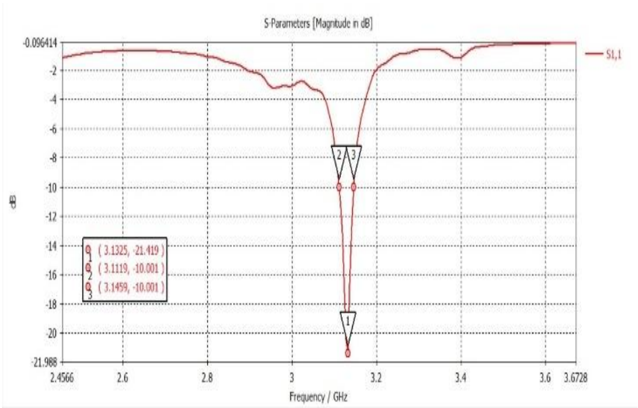


Fig .2. S-Parameter analysis and reflection coefficient calculation

The bandwidth acquired for this design is 33.5MHz, which is less for 5G communication. This is given in Fig .3.

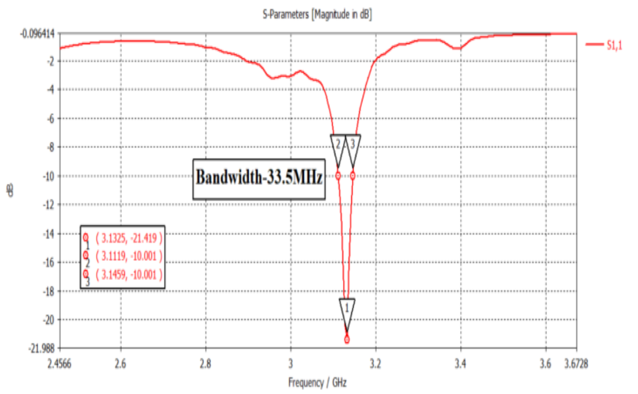


Fig .3. Bandwidth calculation

The Voltage Standing Wave Ratio (VSWR) at 3.1278GHz comes to around 1.2253, which is in its ideal range. This is given in Fig .4.

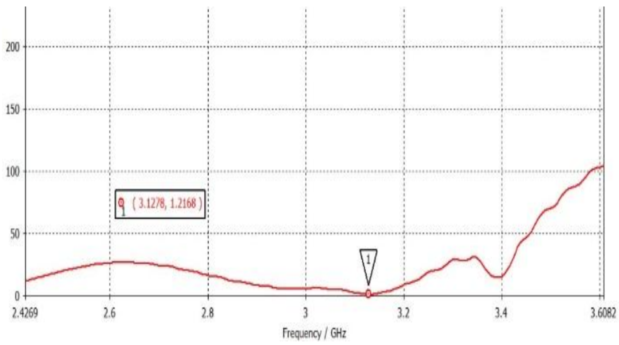


Fig .4. VSWR analysis

The Electric field and Magnetic field patterns are given in figures Fig .5. and Fig .6. They depict that the fields pass through the entire structure.

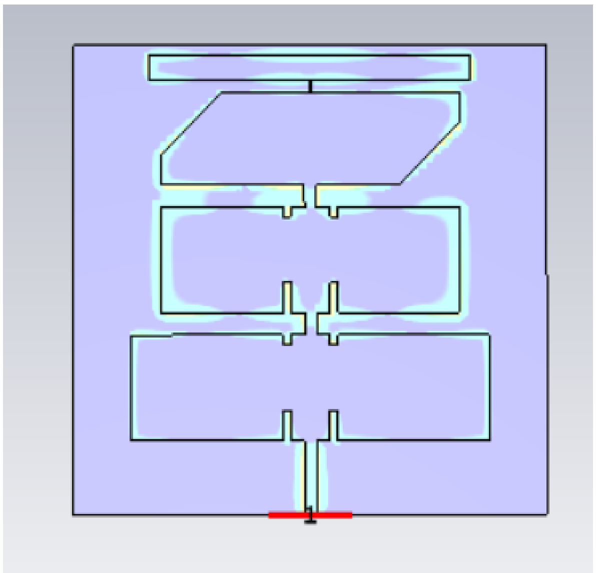


Fig .5. E-field radiation across the design

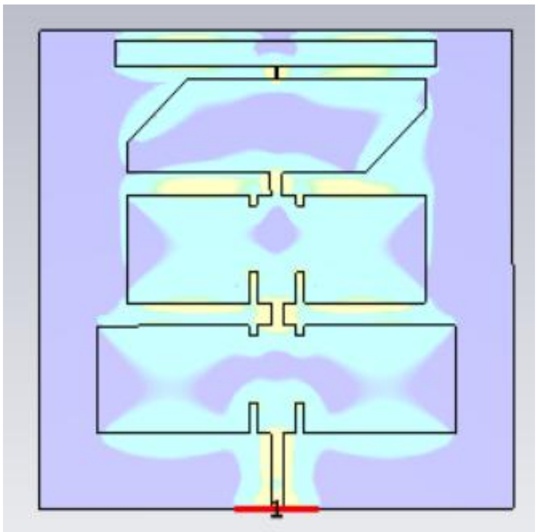
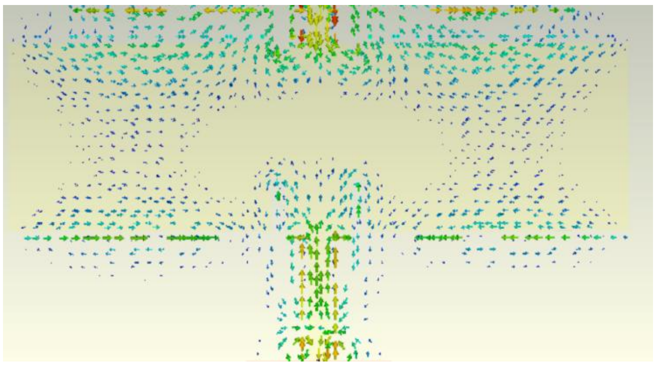


Fig .6. H-Field radiation across the design

The surface current across the patches and the transmission lines are given in Fig .7. The direction of current flow in the patches is outward at the patch and circulated throughout.



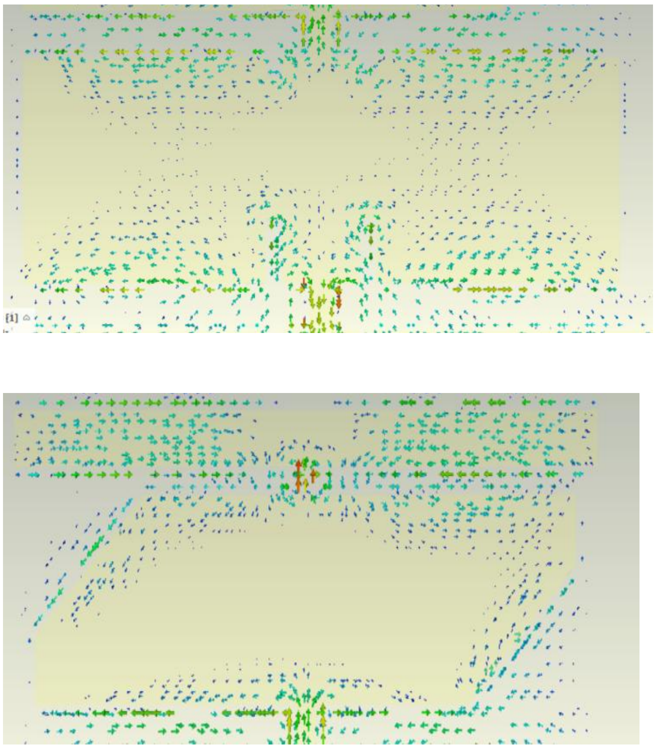


Fig .7. Surface current acquired at 3.1278GHz

The far-field pattern at 3.1278GHz is given in Fig .8., Fig .9. and Fig .10. Respectively.

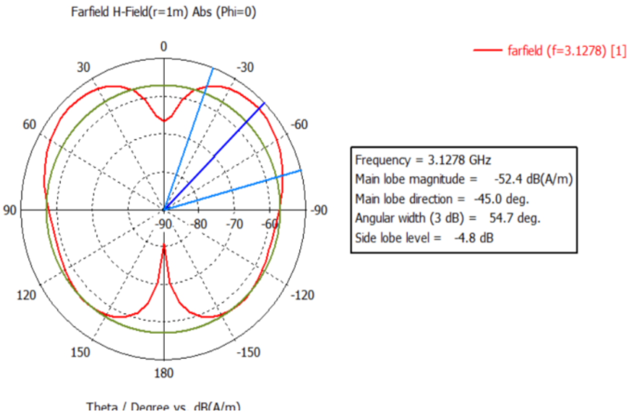


Fig .8. H-Field radiation across the design

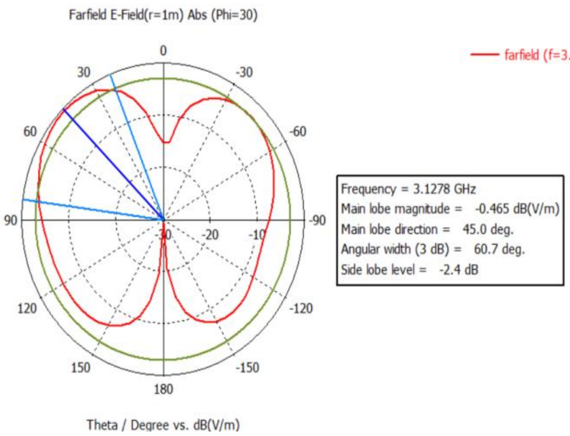


Fig .9. E-field radiation pattern across the design

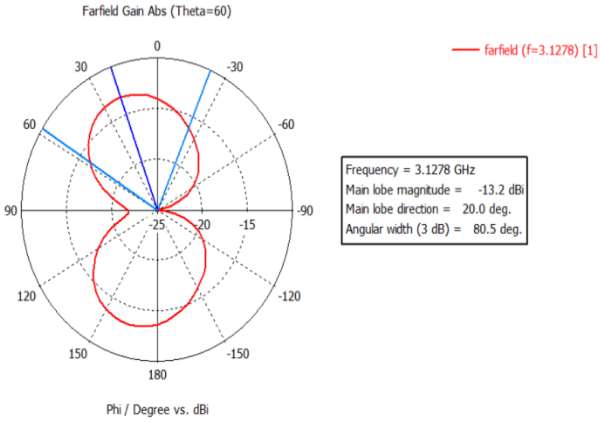


Fig .10. Far-field radiation across the design

IV. CONCLUSION

In this paper, the conformal antenna is designed to operate at Sub-6 GHz 5G bands in UAV applications. The performance of the proposed antenna was analyzed using various metrics to achieve reliable coverage at the mid-band of 5G. The reflection coefficient found is -19.947 at 3.1325GHz. The operating bandwidth of the proposed design is 33.8MHz. The surface current metrics analysis shows the current flow is good in the radiating patch. The proposed design's E-field and H-field patterns metrics show that the antenna can effectively radiate to free space. Further. The proposed antenna design will be modified to support the GNSS band for UAV application along with sub-GHz 5Gband

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