Design of Microstrip Patch Antenna for Air Traffic Control System

Kommu Vaishnavi[1], Dr. R. Sandhya[2]

[1]M.E Student, Department of Electronics and Communication Engineering, Osmania University, Hyderabad, India
[2]Associate Professor, Department of Electronics and Communication Engineering, Osmania University, Hyderabad, India

Abstract
These days, there are lot of aircraft accidents, and communication between the pilot and air traffic control (ATC) is essential to prevent them. When it comes to aviation communication systems, the 117–137 MHz range is where the VHF and ground-based augmentation systems (GBAS) operate. This research work's major purpose is to design and construct a low profile microstrip patch antenna that reduces the size, cost, and mass of the VHF antenna while simultaneously facilitating VHF Air to Ground (A/G) communication. VHF A/G Communications handles the communication and information sharing between the ATC and the aircraft. Additionally, VHF A/G communication is used to provide navigational and weather information. High Frequency Structure Simulator (HFSS) is used to design and simulate the antenna. In this case, the substrate, FR4 epoxy, is utilized to create the antenna which is of the size 350 mm x 170 mm. The Meander line approach is used to minimize the antenna's dimension. This design uses a single stub and microstrip line feed to provide optimal antenna impedance matching, and a hexagonal ring-shaped defective ground system (DGS) to improve bandwidth impedance. The achieved antenna's operating frequency is 145 MHz, and its reflection coefficient is 13.7 dB, which supports A/G communication in the specified frequency range.

Keywords: Ground-based augmentation systems (GBAS), Very- high frequency (VHF), Air to Ground (A/G) communication, Defective ground system (DGS), Air Traffic control (ATC), microstrip patch antenna, and meander line approach.

1.Introduction

The significance of antennas in air traffic control (ATC) systems is discussed in this study, with a focus on how they allow pilots and ground stations to communicate reliably. The demand for reliable, long-range, and effective communication systems has increased dramatically with the growth in aviation traffic. Conventional Very High Frequency (VHF) communication antennas are frequently large and costly, particularly when utilized in the 117–137 MHz range. Compact, low-profile options like microstrip patch antennas are becoming more popular in an effort to increase efficiency and integrate with contemporary avionics.[1] The Existing VHF antennas in air traffic communication systems are bulky and often suffer from limited gain and bandwidth, which restricts effective communication across wide areas.
The 117–137 MHz VHF band is used for aeronautical communication systems. It is anticipated that GBAS communication service activities will assist various approach, landing, departure, and surface

operations[2]. The limitations of current VHF antennas are big size, expensive, and poor frequency performance in terms of gain and bandwidth. Reliable communication is hampered by these problems during critical flight phases like takeoff and landing. The goal is to create a compact, reasonably priced antenna that resonates at 145 MHz, which is a typical frequency for approach control in Indian airports, in order to get over these obstacles.To provide minimal signal loss and effective radiation, the antenna must have a reflection coefficient (return loss), which indicates good impedance matching at the target frequency.[4] Despite their inherent drawbacks, such as low gain and restricted bandwidth, microstrip patch antennas (MPAs), which are renowned for their small size and compatibility with printed circuit technologies, are thought to be appropriate for this application. Defected Ground Structures (DGS) in a hexagonal ring pattern to improve gain and bandwidth, microstrip line feed with stub matching for better impedance matching, and the meander line method for size reduction are some of the novel techniques used in this work. These enhancements are intended to guarantee that the antenna operates efficiently while staying small and appropriate for actual aircraft settings. The construction and materials, such the FR4 epoxy substrate, are selected for their affordability and usefulness. The ultimate goal of the research work is to close the gap between theoretical antenna design and practical aviation requirements. Also, to enhance ATC systems' safety, coordination, and communication dependability by creating a low-profile, highly effective antenna specifically designed for the VHF band. The design is feasible for incorporation into contemporary aircraft infrastructure since it not only satisfies performance standards but also takes environmental considerations and fabrication limitations into account.

2. Literature Review

To ensure flight safety, pilots and air traffic controllers must communicate reliably. Because of their high gain and vertical polarization, traditional antennas like whip and monopole antennas were frequently utilized in previous systems. They cannot, however, be included into contemporary lightweight aircraft and unmanned aerial vehicles due to their size and weight [1].Microstrip patch antennas (MPAs) have become a promising substitute for these issues because of their low profile, simplicity in production, and suitability for printed circuit boards. Using substrates like FR4 and ARLON, researchers have investigated a variety of configurations, such as dual-band, omnidirectional, and programmable systems. Nevertheless, a large number of these antennas are not vertically polarized or small enough for VHF air-to-ground (A/G) applications [2].In order to decrease antenna size without compromising resonance, sophisticated methods like the meander line approach have been put forth. Although they frequently depart from the ideal 117–137 MHz band utilized in aviation A/G communication, frequency reconfigurable MPAs with integrated PIN diodes and inductors have been created to work in the 135–174 MHz range [3], [4]. The lack of vertical polarization and VHF band support makes ultra-wideband (UWB) antennas with octahedral forms and small design unsuitable for surface penetration radar [3].Gain enhancement through the use of metamaterials, reactive impedance matching circuits, and electromagnetic band-gap (EBG) structures has been the subject of other research. For instance, a low-profile VHF dual-band printed antenna operating at 150 and 450 MHz was constructed with reactive matching [5]. Nevertheless, these designs frequently fail to satisfy the precise VHF A/G communication specifications. All things considered, the literature emphasizes the trend toward small, high-performing MPAs while simultaneously highlighting the necessity of optimized designs made especially for ATC applications in the 117–137 MHz band.

3. Antenna Design

To design the desired Antenna targeting the 117–137 MHz region, the antenna's design is focused on providing effective Very High Frequency (VHF) air-to-ground (A/G) communication for air traffic control (ATC) systems. In order to enable this, a small and light microstrip patch antenna (MPA) was created to replace large, conventional antennas while still ensuring adequate gain, impedance matching, and acceptable radiation efficiency.FR4 Epoxy was chosen as the substrate material for the antenna's design. The substrate thickness (h) of FR4 is 1.6 mm, and its relative dielectric constant (εr) is 4.4. These features enable size reduction in the VHF band while maintaining a respectable level of efficiency and bandwidth. The substrate's overall dimensions is 350 mm x 170 mm provide enough room for ground modifications and compact patch designs.

The antenna uses the meander line approach, which involves bending a typical monopole or patch back and forth to fit a longer electrical channel into a smaller physical space, in order to achieve downsizing. The objective is to decrease the physical height or length of the antenna without sacrificing the resonant frequency.

First, we compute the guided wavelength,

$$L_{\text{elec}} = \frac{\lambda_g}{4}$$

λ_g is the guided wavelength

L_{elec} Electrical length of the Meander line

The effective dielectric constant is given by:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}}$$

Where, W is the patch width.

εr = 4.4 (relative dielectric constant)

h =1.6 (Thickness of the Substrate)

To achieve miniaturization using a meander line with N bends, the total electrical length of the antenna remains nearly the same, but the conductor is folded. This results in a compact structure:

$L_{\text{meander}} = N.\frac{\lambda g}{4N}$

N= number of bends in meander structure (6)

In this work, a 6-bend (N = 6) meander structure is implemented, reducing the antenna’s length substantially while still resonating at the desired frequency (145 MHz). A microstrip line feed is used to excite the antenna, and a single stub is added to ensure proper impedance matching. This ensures that the input impedance of the antenna matches the standard 50-ohm transmission line, which minimizes signal reflection and power loss. The stub acts as a reactive element and can be adjusted to cancel out the imaginary part of the antenna impedance.

To enhance gain and bandwidth, a Defected Ground Structure (DGS) is incorporated. This involves etching specific patterns (hexagonal ring shapes) in the ground plane, which alters current distribution and electromagnetic fields. Three DGS units are used in the ground plane. The DGS introduces a band-stop effect, improves radiation efficiency, and suppresses harmonics, resulting in better antenna performance without increasing size. The Optimized Dimensions for designing of Antenna is formulated in the below Table 1.

Parameters	**Value(in mm)**
Length of Substrate(Ls)	350.0
Width of Substrate(Ws)	170.0
Length of Patch(Lp)	261.3
Width of Patch(Wp)	140
Length of Feed(Lf)	47.4
Width of Feed(Wf)	3.2
Length of Stub(Lt)	11.8
Width of Stub(Wt)	4.0
Hexagon Inner Radius(RinH)	15.0
Hexagon Outer Radius(RoutH)	20.0
Spacing (Lpp)	18.3

Table 1: Dimensions of the Antenna

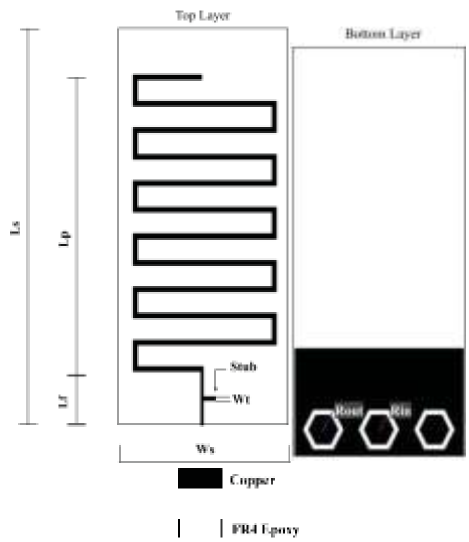

Figure 1: Antenna Design

4.Simulation Results

The Proposed Antenna was simulated using HFSS. It is found to be having an operating frequency of 145 MHz for a Return loss of 13.74 dB. The Simulated results are as follows,

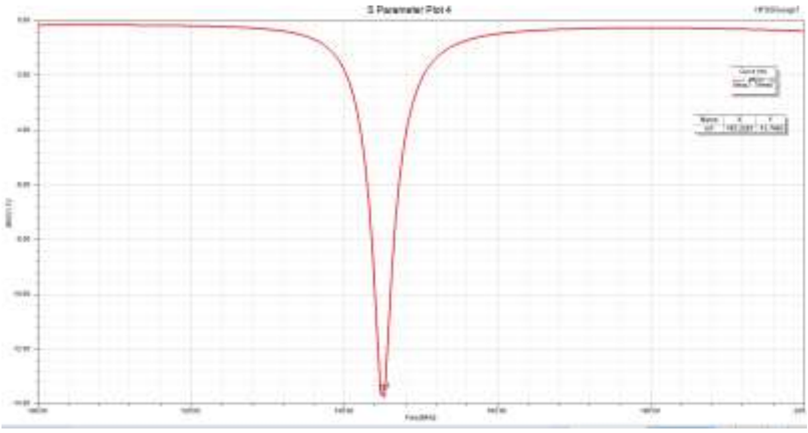

Figure 2: S11 Plot

The proposed microstrip patch antenna's bidirectional radiation pattern at 127.6 MHz is depicted in Gain Plot 1. Both the primary (φ = 0°) and perpendicular (φ = 90°) planes of the polar plot display the distribution of gains.

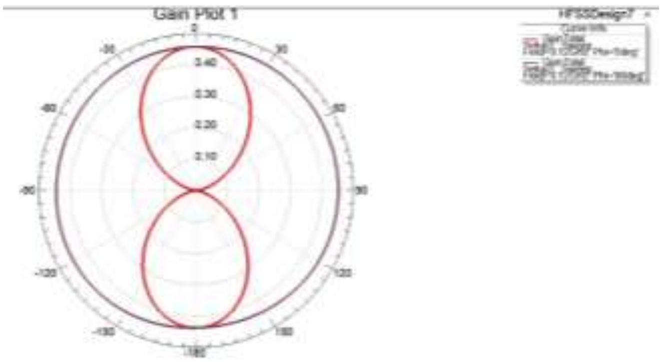

Figure 3: Radiation Pattern in Elevation Plane

With symmetric radiation lobes and a maximum gain of roughly 0.4 dB, the antenna is appropriate for efficient ground-to-air communication in air traffic control systems.

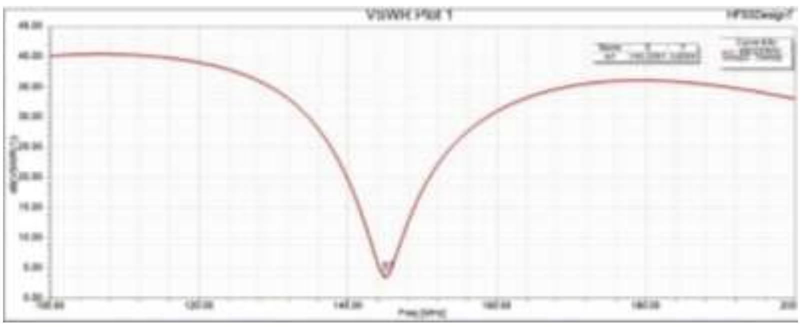

Figure 4: VSWR

The impedance matching properties of the suggested microstrip patch antenna are displayed on the Voltage Standing Wave Ratio (VSWR) plot between 100 MHz and 200 MHz. The antenna's resonance frequency is 145.2261 MHz, as indicated by the low VSWR value of 3.62 that was recorded at that frequency. Better impedance matching between the antenna and the transmission line is indicated by a reduced VSWR. In most practical situations, a value below 2 is deemed acceptable, even though the optimal VSWR value is near 1.Moderate impedance mismatch is indicated by the slightly higher obtained value of 3.62.

5.Measured Results

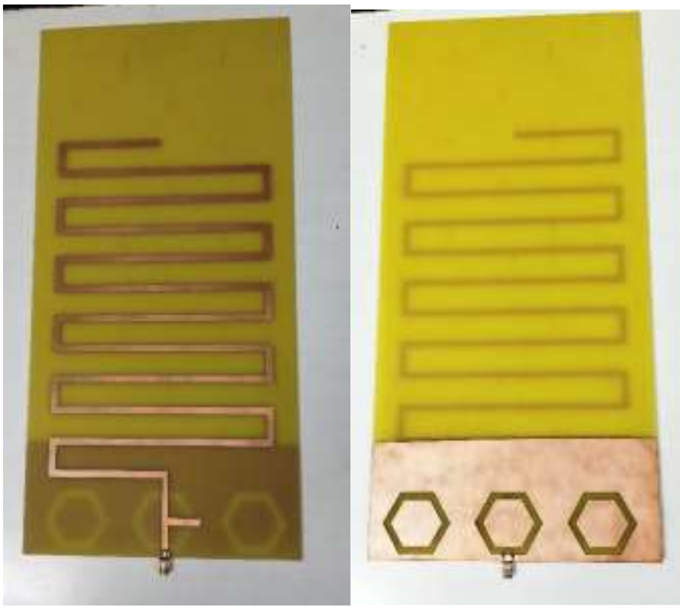

Figure 5: Fabricated Antenna

The meander line monopole patch, which is folded in a serpentine pattern to decrease the physical length while preserving the electrical resonance at 145 MHz, is visible in the top view of the constructed antenna. At the bottom of the patch, you can clearly see the single stub and microstrip feed line, which enhance power transfer and impedance matching. Compactness is guaranteed by the layout, making it perfect for aircraft applications.

Figure 6: Return Loss Measurement of the Fabricated Antenna

The performance of the manufactured microstrip patch antenna was verified by testing with a network analyzer. Excellent signal transmission with little reflection is demonstrated by the return loss value of -20.46 dB at 113 MHz. This attests to the antenna's appropriateness for aviation systems' air-to-ground (A/G) communication.

6. Conclusion

The design and development of a compact microstrip patch antenna for VHF air-to-ground (A/G) communication has successfully met the main objective of improving ATC communication systems. Using HFSS simulation, the suggested antenna produced a resonant at 145 MHz frequency with a gain of 4.89 dB, VSWR of 3.62, and return loss of -13.74 dB, suggesting dependable operation for aviation communication during approach control. The radiation pattern was bidirectional, as expected, ensuring adequate coverage in both the azimuth and elevation axes.The produced antenna showed a slight frequency shift to 113 MHz but an outstanding return loss of -20.46 dB when evaluated with a network analyzer showing efficient signal transmission and impedance matching. This variation, which takes place within the VHF band (117–137 MHz) utilized for ATC, is due to practical factors such as substrate variation and production tolerances. The new design achieves resonance at 127.3 MHz with a return loss of 25.7 dB, demonstrating comparable and reliable performance through the use of similar enhancing techniques such meander line design, hexagonal DGS, and stub matching. To sum up, the antenna offers a discrete, efficient, and cost-effective means of enhancing pilot-ATC communication in the VHF band, and both measured and simulated results validate its suitability for integration into modern aviation infrastructure.

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