Design of Quad feed end-fire microstrip patch antenna for Airborne Systems

V Gnanalakshmi¹, Rahul Raaj², V Suresh Kumar³

¹Assistant Professor, Electronics and Communication Engineering, Mepco Schlenk Engineering College, Sivakasi, Tamilnadu, India.
²,³ UG Student, Electronics and Communication Engineering, Mepco Schlenk Engineering College, Sivakasi, Tamilnadu, India.

v.gnanalakshmi@mepcoeng.ac.in, rahulraajaiyavu@gmail.com, suresh181299@gmail.com

Abstract. To design a quad feed end-fire microstrip patch antenna for airborne systems. Basically these type of antennas are most helpful for avoiding mid-air collisions between aircraft. The microstrip patch antenna is very small in size and it is less in weight. Due to small size and less weight, it offers an easy design and fabrication process. The microstrip patch antenna has radiating patch on one side and ground on the other side. They operate at microwave frequencies. The low profile structure of microstrip antenna offers its wide use in wireless communication. They are used as communication antenna on missiles. Traffic alert and Collision Avoidance System (TCAS) is an airborne system which is utilized to provide the service as last defense equipment for avoiding mid-air collisions between the aircraft. 1.03 GHz and 1.09 GHz are the transmitting and receiving frequencies of the existing TCAS antenna respectively. In airborne systems, low aerodynamic drag is required. FR4 epoxy is chosen as the substrate material whose dielectric constant is 4.4. 1.06GHz is chosen as the design frequency, since it is centre frequency between 1.03GHz and 1.09GHz. Microstrip patch antenna always radiates in the broadside direction which is along elevation plane. Due to metallic cap, microstrip patch antenna can also radiate in the end fire radiation which is along the azimuth plane. The ground plane must have very large dimensions than the patch. This microstrip patch antenna working at UHF (Ultra High Frequency) band is designed and simulated using ANSYS HFSS (High Frequency Structure Stimulator).

Keywords: Quad feed, Patch antenna, TCAS, Microwave frequency, Radiation Pattern, Bandwidth

1. Introduction

Traffic alert and Collision Avoidance System is an airborne system which is utilized to provide the service as last defense equipment for avoiding mid-air collisions between the aircraft [1-3]. 1.03 GHz and 1.09 GHz are the transmitting and receiving frequencies of the existing TCAS antenna respectively. According to radiation characteristics, antennas are classified into two types. One is broadside antennas, and the other is end-fire antennas. A broadside antenna always radiates in perpendicular direction with respect to the plane of the antenna. In this category, some well-known topologies are monopole antenna, half-wavelength slotted antenna, and patch antenna. An end-fire planar antenna has radiation pattern with the maximum of radiation in the azimuth plane of the antenna [4]. The radiation characteristics of the end-fire antenna depend on the antenna structure, through which the surface wave propagates, and its
magnitude. These types of antennas are Yagi antenna, helix antenna with end-fire mode and tapered slot antenna. Today, microstrip antennas have found wide application in the wireless communication field because of their attractive features such as low weight, low profile, small size and easy manufacture [5]. There is a fact that microstrip antenna has intrinsically narrow bandwidth. Much research has been done to increase its bandwidth, such as employing a multi-layer structure with aperture coupling and adding parasitic elements. In many practical cases, microstrip antennas are required not only to be wideband but also to have an end-fire radiation pattern [6]. However, most previous researches of microstrip antennas mainly paid attention to the impedance bandwidth of antennas, but ignored the radiation pattern to a certain extent. Very few attempts were made to achieve an end-fire radiation pattern from microstrip antenna. The antennas having end-fire radiation are widely preferable in many applications for their characteristics such as simplified structure, easy fabrication, cost effectiveness, and low aerodynamic profile. Especially in airborne electronic system, there is a restriction on the antenna orientation as it should not obstruct the airflow during flight. Hence, end-fire antenna is suitable for being used in these applications [7]. The organization of the work as follows: Section 2 discusses the proposed antenna design. Section 3 discusses the design of quad feed antenna. Section 4 discusses about simulation results and finally section 5 discusses about the conclusion of our work.

2. Literature Survey
Debajit et al [3] focuses on the design of an end-fire unit element microstrip antenna for TCAS of civil aircraft. This paper explains the concept of making an single patch single feed antenna, dual patch single feed antenna, and dual patch dual feed antenna using FR4 epoxy substrate. Comparison of three antennas are done to analyse better performing antenna.
Debajit et al [2] the concept of making an dual patch dual feed antenna, Penta patch Penta feed antenna array using FR4 epoxy substrate. The antennas are simulated using CST Studio Suite tool. For the measurement and testing purpose, Agilent E5071C Vector Network Analyzer (VNA) is used. Performance comparison is done between these two antenna. The proposed microstrip antenna array provides a better performance like high gain, good directivity and narrow beamwidth as compared to that of existing monopole TCAS antenna.
Debajit et al [1] proposed the concept of making a quad patch quad feed end fire antenna using FR4 epoxy substrate. It provides a solution to reduce the threat of mid-air collisions between civil aircraft. In airborne system, end fire antenna is very much essential. The gain of the antenna obtained is 3.5 dB.

3. Proposed Antenna Design
The proposed antenna consists of totally four patches. Each patch consists of one coaxial feed, shorting pin and triangular shaped metallic cap. Coaxial feed is used to improve the bandwidth and it can be placed any desired position inside the patch. In coaxial feeding, the inner conductor of the coaxial is attached to the radiation patch [8], while the outer conductor is attached to the ground. In this design total four shorting pins are used. Shorting pin which is also known as inductive posts. It is made up of copper which is used to tune the frequency of the microstrip patch antenna. Shorting pin is placed between the patch and ground (above the patch and below the ground). A triangular shaped metallic cap which is made of copper foil is used in this design. In this antenna, there are four metallic cap are used. Microstrip patch antenna always radiates in the broadside direction which is along elevation plane. Due to the presence of metallic cap, microstrip patch antenna can also radiate in the end fire radiation which is along the azimuth plane. Here the material of the patch is copper. The dimensions of the patch are calculated using design equations which are given in equations 1, 2, 3 and 4. Length of the patch is obtained as 71.95 mm and the width of the patch is obtained as 88.1 mm. Gap between four patches is 78.1mm. The distance between substrate and each patch is 1mm. Figure 1 shows the design of quad feed microstrip patch antenna. It shows all the four patches along with four slots and metallic caps.
Figure 1. Model of quad patch quad feed antenna

The distance between substrate and each patch is 1mm. Copper is used as the material for the ground. Ground is placed below the substrate. The dimension of the ground is same as the dimension of the substrate. FR-4epoxy is used as the material for the substrate. The thickness of the substrate is 4mm. Here the four patches were placed above the substrate. The dimension of the substrate is 224 mm * 224mm. The distance between coaxial feed and the patch is 24.45 mm. The distance between shorting pin and the patch is 10.95 mm. The radius of the shorting pin is 0.1mm. This paper presents a designing technique for the quad feed end-fire microstrip antenna. The proposed quad-feed microstrip end-fire antenna would be expected to have a great potential usage for TCAS application in terms of advanced avionics standards such as design simplicity, lightweight and high performance.

3.1 Microstrip patch antenna design equations

The microstrip patch antenna design equations are given below [9]

Length of patch is given by

\[
L = \frac{c}{2f/\varepsilon_{r\text{eff}}} - 2\Delta L
\]  

(1)

where,

\[
\varepsilon_{r\text{eff}} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2} \left( 1 + 12 \frac{h}{w} \right)^{-1}
\]  

(2)

\[
\frac{\Delta L}{h} = 0.412 \frac{(\varepsilon_{r\text{eff}}+0.3)(\varepsilon_{r\text{eff}}+0.264)}{(\varepsilon_{r\text{eff}}-0.258)(\varepsilon_{r\text{eff}}+0.8)}
\]  

(3)

Width of patch,

\[
w = \frac{c}{2f/\sqrt{\varepsilon_r+1}}
\]  

(4)
Table 1. Design specifications of proposed antenna

| Design parameters | Material   | Dimension            | Qty |
|-------------------|------------|----------------------|-----|
| Patch             | copper     | 71.95mm × 88.1mm     | 4   |
| Substrate         | FR4 epoxy  | 224mm × 224mm        | 1   |
| Ground            | copper     | 224mm × 224mm        | 1   |
| Shorting pin      | copper     | 0.1mm (radius)       | 4   |
| Metallic cap      | copper     | 100mm (height)       | 4   |

Table 2. Design specifications of the coaxial feed

| Feed parameters  | Dimension | Material  |
|------------------|-----------|-----------|
| Feed external    | 6 mm      | Pec       |
| Feed internal    | 3.5 mm    | Pec       |
| Feed patch       | 5 mm      | Pec       |
| Blindage         | 3.5 mm    | Polyester |

4. Design of Quad Feed Antenna

4.1 Design procedure
Quad feed antenna is designed by choosing FR-4 EPOXY as the substrate material. Copper is used as patch. The feeding method used here is coaxial line. The proposed antenna design has been designed and simulated using ANSYS HFSS software. The step-by-step procedure for designing antenna is given below.

The steps are:
- Creating a model or geometry
- Assignment of boundaries
- Assignment of excitations
- Setting up the solution
- Solve
- Post-processing the results

The first step in designing antenna is creating a model. Using the designed values for antenna, model can be created and the next step is assigning the boundaries to the antenna structure. The open model in HFSS can be created by assigning the radiation boundaries. While simulating an antenna, the radiation boundary should be positioned in such a way, that it is quarter the wavelength away from the surface of radiation. Assignment of boundary to the antenna structure is much essential as it have direct impact on the result provided by the HFSS software. Figure 2 shows the boundary assignment to the 2D sheets. Then the next step is the excitation of ports. The excitations or ports needs 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 depends on the assignment of excitations or ports. Figure 3 shows the excitation assignment to coaxial feed. After this step, setting of solution and solving for this antenna is done. Figure 4 shows the dialog box showing validation of the proposed antenna design. Figure 5 shows the 3 dimensional view of quad feed microstrip patch antenna and Figure 6 shows the two dimensional view of the designed antenna.
Figure 2. Boundary assignment to the 2D sheets

Figure 3. Excitation assignments to the coaxial feed
Figure 4. Dialog box showing the above steps validation

Figure 5. 3D view of Quad feed antenna

Figure 6. 2D view of Quad feed antenna
5. Simulation Results and Discussions
In this section, results obtained for the proposed antenna are discussed. Various parameters like return loss, VSWR, Gain, radiation pattern are calculated.

5.1 Return Loss
Figure 7 shows the return loss of the proposed antenna. The dip indicates a return loss of -22.016 and the antenna resonates at 1.06GHz. Return loss is the power loss in the signal that is reflected or returned in a transmission line or optical fibre by discontinuity. Return loss is the measure of how well devices or lines are matched.

![Figure 7. Return loss of Quad feed antenna](image)

5.2 VSWR
Figure 8 shows the VSWR of the proposed antenna. The Voltage Standing Wave Ratio is the measure of loss at the feeder because of mismatch. It normally ranges between 0 to infinite. For practical antennas the value should be less than 2 then the antenna is said to be matched. The VSWR obtained by our proposed antenna is 1.3 at 1.06 GHz.

![Figure 8. VSWR of Quad feed antenna](image)
5.3 Gain

In real time the gain of the antenna should be high. They are highly directional. The maximum directive gain provided by single patch antenna is 6-9 dB. This proposed antenna has the appreciable gain of 5.4 dB for the frequency of 1.06GHz. Figure 9 shows the gain plot of proposed antenna.

5.4 Radiation pattern

Graphical representation of the relative field strength that the antenna transmits or receives is called radiation pattern. It is indicated with side lobes and back lobes. Each supplier/user of antenna has different requirements or standards and also different formats for plotting. An antenna’s radiation pattern can be defined as the locus of all points in which power emitted per unit surface is equal. Figure 10 shows the Radiation pattern of Quad feed antenna.

5.5 Directivity

Directivity of an antenna is given by the ratio of the maximum intensity of radiation to the average intensity of radiation. Maximum intensity of radiation means power per unit solid angle and average intensity of radiation means average over a sphere. Figure 11 shows the directivity plot of Quad feed antenna.
5.6 Gain Optimization

In order to obtain better gain value, the shorting pin radius value is varied from 2 mm to 0.1 mm. Table 3 shows the performance of proposed Quad feed antenna by varying radius of shorting pin. As radius of shorting pin is reduced, the gain is getting increased and the proposed antenna reaches the desired center frequency. The gain value obtained for this designed antenna is 5.4 dB, return loss obtained is -22.0168 dB and the center frequency obtained at 1.0603 GHz.

| Radius of shorting pin (mm) | Centre Frequency (GHz) | Return loss | VSWR | Gain (dB) |
|----------------------------|------------------------|-------------|------|-----------|
| 2                          | 1.106                  | -22         | 1.2630 | 5.2       |
| 1.5                        | 1.093                  | -28.3629    | 0.6636 | 5.3       |
| 0.5                        | 1.0734                 | -28.4072    | 0.6602 | 5.4       |
| 0.1                        | 1.0603                 | -22.0168    | 1.3801 | 5.4       |

6. Conclusion and Future Work

A quad feed quad patch antenna has been designed and analyzed using FR-4 EPOXY substrate with the copper as a patch. The resonant frequencies obtained for the proposed structure is 1.06GHz. This proposed antenna has a return loss of -22.016 and gain of 5.4 dB. The VSWR obtained by our proposed antenna is 1.3 at 1.06GHz. Thus the parameters of antenna such as return loss, gain, radiation pattern, directivity and voltage standing wave ratio (VSWR) has been analyzed and simulated using high frequency structure simulator (ANSYS HFSS). The proposed prototype model of the antenna exhibits an improved better performance in terms of high gain, good directivity and narrow beamwidth as compared to that of existing monopole TCAS antenna. The proposed triangular shaped metallic director and the metamaterial lens based radome improve the directive radiation along the azimuth plane. The future work of this proposed contribution can be done for enhancing the bandwidth and gain than the proposed one.

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