Design of a Microstrip Multi-Patch End-Fired Antenna for Collision Avoiding System of Aircraft

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***Abstract*—In airborne systems, where low aerodynamic drag is urgently required, an end-fire antenna is suitable to be used. Traffic alert and Collision Avoidance System (TCAS) is an airborne electronic system that is designed as the last defense equipment for avoiding mid-air collisions of two aircraft. An effort to develop such an antenna, using microstrip elements, is described in this paper. Here, a Dual Patch Dual Feed Microstrip Antenna is presented which radiates in the end-fire direction. Thereafter, a Quad Patch Multi-Feed Microstrip Antenna is proposed and it is designed in such a way that it can radiate the whole 360^0 surveillance region of the aircraft. For designing these antenna models, CST Microwave Studio (MWS) is used here as the EM tool. From the simulation results, various antenna characteristics have been studied. Thereafter, these antenna prototype models have been fabricated and tested. Quite good agreement is achieved between the simulated and the measured results.**

***Index Terms*—End–fired antenna, TCAS, microstrip antenna, return loss, gain, beamwidth, side-lobe.**

I. Introduction

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. An end-fire planar antenna has radiation pattern with the maximum of radiation in the azimuth plane of the antenna. 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 [1], helix antenna with end-fire mode [2], and tapered slot antenna [3]. Throughout many years, the antennas having end-fire radiation are widely preferable in various applications for their characteristics such as simplified structure, easy fabrication, cost effectiveness, and low aerodynamic profile. Specially 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 [4].

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.The basic property of a microstrip antenna is to radiate in the broadside direction and it has intrinsically narrow bandwidth. Much research has been done to increase its bandwidth. In many practical cases, microstrip antennas are required not only to be wideband but also to have an end-fire radiation pattern. However, most previous studies 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. In this paper, an attempt is made to establish the concept that a microstrip antenna with simple modified configuration can radiate in a end-fire direction just like those conventional end-fired antennas.

This paper focuses on the designing of an end-fired microstrip antenna for TCAS system of civil aircraft. For surveillance of any surrounding aircraft, TCAS interrogates at a consistent rate, at around once per every second, and it utilizes a recipient to distinguish all the responds for those transmitting signals which are coming from all the transponders of close-by aircraft. TCAS consists of a Mode S/TCAS Control Panel, one Mode S Transponder, the TCAS Computer, Antennas, Traffic and Resolution Advisory Displays and an Aural Annunciator [5]. In the existing system of TCAS, 4 monopole stubs are the directional antenna, which are oriented at 0^0, 90^0, 180^0 and 270^0 with respect to the vertical axis. While interrogation occurs in Mode S and C, 1.03 GHz RF signal is transmitted by the antenna through the four monopole stubs. During the signal reception, all those radiating stubs detect the available 1.09 GHz RF signals.

Section 2 of this paper explains the design methodology of the proposed antennas, which are Dual Patch Dual Feed Microstrip Antenna (DPDFMA) and Penta Patch Multi-Feed Microstrip Antenna (PPMFMA). Section 3 deals with the simulation and measurement results of these proposed antenna models. The discussions and summary of the results are also included in this section. The conclusion part of this paper is briefly described in Section 4.

II. Design Configuration and Analysis

First, a Dual Patch Dual Feed Microstrip Antenna is proposed in this paper. Thereafter, a Penta Patch Multi-Feed Microstrip Antenna is also proposed here. The proposed antenna models are designed and simulated in CST MWS tool. Here, Chemical Etching process is used to fabricate all these antennas. FR4 Epoxy is chosen as the substrate material whose dielectric constant (ϵ_r) is 4.4. Though FR4 Epoxy is a lossy material, it is used here, because this material is easily available in the market and very much cost effective. 1.06 GHz is chosen as the design frequency, since it is center frequency between 1.03 GHz and 1.09 GHz. The dimensions of all these proposed antennas are calculated using the formulas available in the literature [6].

A. *Dual Patch Dual Feed Microstrip Antenna*

Figure 1 shows the Simulated and Schematic Model of Dual Patch Dual Feed Microstrip Antenna. This proposed antenna consists of two copper patches, which are designed as radiators. These two patches are abbreviated as patch 1 and patch 2. One inductive post/shorting pin of copper is drilled inside FR4 substrate and under the second patch. The second patch has two identical slots that are in opposite position with each other. The fabricated antenna model is shown in Fig. 2.

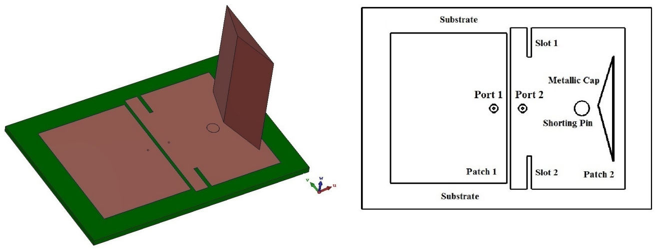


Fig. 1: Simulated and schematic model of DPDFMA.

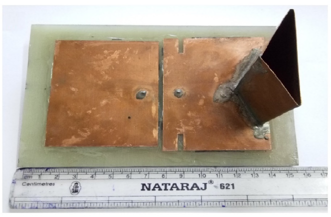


Fig. 2: Fabricated model of DPDFMA.

For achieving proper resonating frequency, fine tuning is required. Hence, the shorting pin diameter and the slot length can be adjusted as per requirement. Here, shorting pin and slots can be treated as the tuning parameters. Conventional coaxial feeding technique is used here through which those two patches are excited. In this proposed antenna, both the patches have been excited simultaneously. As per the design methodology, port in patch 1 is meant for 1.03 GHz and port in patch 2 is meant for 1.09 GHz. A metallic cap of triangular shape is designed here and it is made of thin copper foil. This structure is placed above patch 2 by soldering it with the patch. The vector components of the electric fields in this metallic cap are oriented in such a way that the maximum resultant electric fields can be obtained from the front side of the structure. To have minimum back-lobe and proper radiation along the azimuth plane, the metallic cap is used.

This proposed antenna element only radiates in 0^0 direction of the azimuth plane which is along the u axis of the antenna structure as shown in Fig. 1. Thus, the antenna structure has been modified and implemented in such a way so that it's radiation can cover the whole 360^0 region of the azimuth plane. Hence, the Penta Patch Multi-Feed Microstrip Antenna is now proposed.

B. *Penta Patch Multi-Feed Microstrip Antenna*

Figure 3 shows the proposed antenna. This proposed antenna consists of five radiating patches and the center patch is treated as the common radiator while the remaining four patches are behaved as the primary radiators. The fabricated antenna model is shown in Fig. 4.

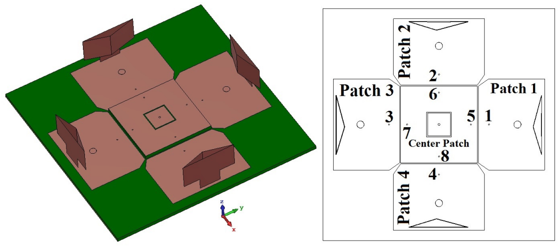


Fig. 3: Simulated and schematic model of PPMFMA.

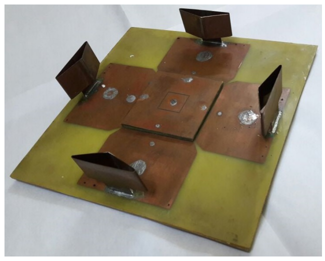


Fig. 4: Fabricated model of PPMFMA.

To steer the beam in all directions, 4 separate elements of DPDFMA can be oriented at 0^0, 90^0, 180^0 and 270^0. But for that case, the overall structure will be large and it will not remain compact. Hence, this compact antenna model is proposed. If the antenna structure is being behaved as a cavity model, then it's size should be remained similar with all aspects and that causes proper resonating frequencies. But here, the size of the antenna is considerably reduced and hence the cavity size should be also reduced. So, for proper size of the cavity, the thickness of the structure is increased. Hence, an additional 4 mm. layer of the similar substrate is incorporated at the upper level of the main substrate. The center patch is designed on that extended 4 mm. layer of substrate. As a result, the effective height of the substrate area under the center patch becomes 8 mm., while the substrate height remains 4 mm. in the rest of the antenna part.

In this antenna structure, five shorting pins are used and these are drilled into the substrate and under the five patches separately. Center patch is also having one square-shaped ring type slot. In this antenna, the center patch is designed for 1.03 GHz while patch 1, 2, 3 and 4 are designed for 1.09 GHz. Here also, four triangular shaped metallic caps have been used. The height of the metallic cap was 75 mm. in case of

DPDFMA. But in this proposed antenna, the height of the metallic caps have been made considerably lower (40 mm.) through the use of top-loaded elements [7]. This modification considerably improves the air drag performance of the antenna structure.

Here, to excite all these 5 radiating patches individually, total eight coaxial feeds are used in this proposed antenna. An equal split 1:8 RF Power Divider has been utilized to feed this multi-port antenna. In this power divider, there is no phase difference between all the 8 output ports. The numbering of ports and patches in this antenna have been illustrated in Fig. 3. With the excitations of proper ports, the radiating beam will be simultaneously steered in the azimuth plane with 45^0 step in rotation. Hence, to steer the whole 360^0 region, total eight number of combinations for ports excitation are sufficient. In each combination, two or four antenna ports will be excited and all the remaining ports will be terminated by 50 Ω matched terminator.

III. Results and Discussions

The proposed antenna is simulated, fabricated and tested for the validation of the design technology. Vector Network Analyzer (Agilent E5071C) has been used for the antenna testing purpose. The radiation patterns of these proposed antennas have been measured in a Tapered Anechoic Chamber with 10^0 step of rotation in the positioner. A horn antenna with double-ridge structure has been used as a reference antenna during antenna gain measurement. The antenna will be placed at the body of the aircraft and the whole body of the aircraft is itself a ground plane. Hence during the radiation pattern and antenna gain measurement, the proposed antenna is placed over a large metallic ground plane of size 10 m . x 10 m. for realizing the presence of the aircraft body upto some extent.

A. Simulation and Measurement Results of DPDFMA

The simulated & measured return losses of the Dual Patch Dual Feed Microstrip Antenna are shown in Fig. 5. It can be observed that S_{11} is around 57 dB at 1.03 GHz, and S_{22} is around 20 dB at 1.095 GHz. From the measured return loss plot, it is shown that S_{11} is around 30 dB at 1.035 GHz, and S_{22} is 18 dB at 1.09 GHz. Here, the measured return loss is in good agreement with the simulated results, though there are a few disagreements due to measuring environment and fixation of the SMA connectors which are not taken care of during simulation.

The simulated & measured power patterns of the antenna in XY elevation plane for 1.03 GHz and for 1.09 GHz are shown in Fig. 6. From Fig. 6, it is observed that the antenna radiates maximum at around 0^0 of the XY azimuth plane which shows that this antenna provides end-fire radiation at 1.03 GHz and 1.09 GHz. Here, the simulated and measured power level is varying around 10 dBW to -15 dBW.

Figure 7 shows the simulated & measured peak gains of the proposed antenna at $\varphi = 0^0$ in XY plane. It is shown that at $\varphi = 0^0$ in XY plane, the simulated antenna gain is around 6.2 dB at 1.03 GHz and around 6.5 dB at 1.09 GHz. The measured antenna gain is around 5.5 dB at 1.03 GHz and around 6.7 dB at 1.09 GHz. The simulated & measured radiation efficiencies of the proposed antenna are shown in Fig. 8. It is observed that the simulated radiation efficiency is around 54% at 1.03 GHz and around 47% at 1.09 GHz, while the measured radiation efficiency is around 46% at 1.03 GHz and around 53% at 1.09 GHz.

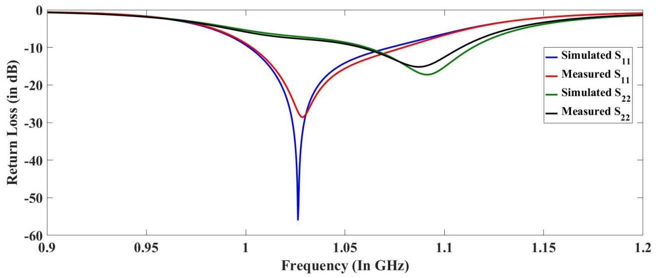


Fig. 5: Simulated and measured return loss of DPDFMA.

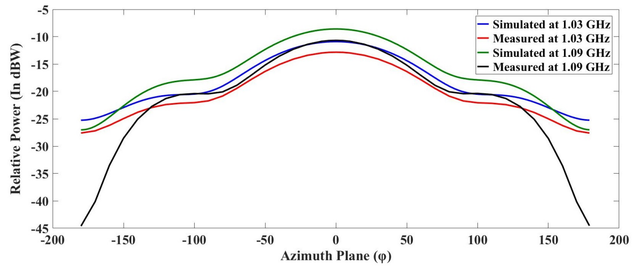


Fig. 6: Simulated and measured power patterns of DPDFMA.

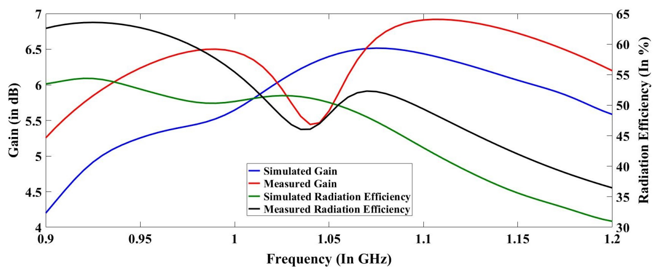


Fig. 7: Gain and radiation efficiency plot of PPMFMA.

B. Simulation and Measurement Results of PPMFMA

The simulated & measured return losses of the Penta Patch Multi-Feed Microstrip Antenna are shown in Fig. 8. From the simulated return loss plot of the antenna, it can be observed that S_{11}, S_{22}, S_{33} and S_{44} is around -55 dB at 1.03 GHz. Similarly, the simulated S_{55}, S_{66}, S_{77} and S_{88} is around -25 dB at 1.09 GHz. Again, from the measured return loss plot of the antenna, it can be seen that S_{11}, S_{22}, S_{33} and S_{44} is around -37 dB at 1.028 GHz. Similarly, the measured S_{55}, S_{66}, S_{77} and S_{88} is around -22 dB at 1.095 GHz.

At 1.03 GHz, the simulated radiation patterns of this proposed antenna for all the port exciting combinations are shown in Fig. 9a and in Figure 9b. Figure 10a and Fig. 10b illustrate

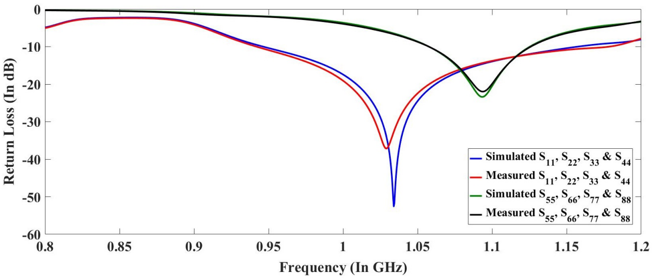
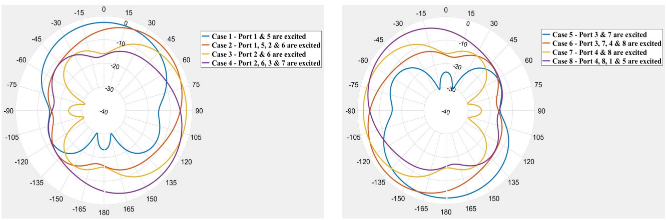


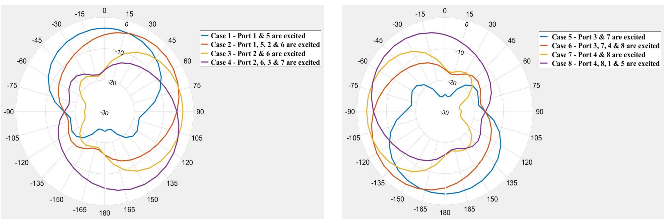
Fig. 8: Simulated and measured return loss of PPMFMA.

the measured radiation patterns for the same. For 1.09 GHz, the simulated radiation patterns of the antenna have been shown in Fig. 11a and in Fig. 11b respectively. Figure 12a and Fig. 12b show the measured radiation patterns of the antenna at 1.09 GHz.



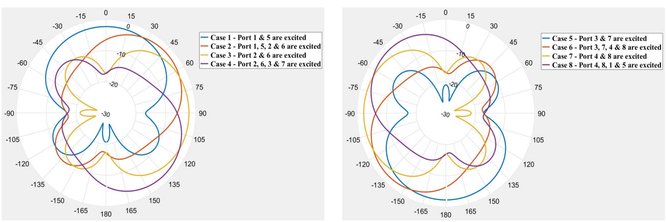
(a) (b)

Fig. 9: Simulated radiation patterns of PPMFMA at 1.03 GHz - (a) case 1 to case 4 and, (b) case 5 to case 8.



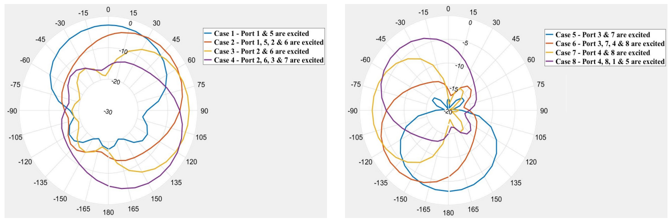
(a) (b)

Fig. 10: Measured radiation patterns of PPMFMA at 1.03 GHz - (a) case 1 to case 4 and, (b) case 5 to case 8.



(a) (b)

Fig. 11: Simulated radiation patterns of PPMFMA at 1.09 GHz - (a) case 1 to case 4 and, (b) case 5 to case 8.



(a) (b)

Fig. 12: Measured radiation patterns of PPMFMA at 1.09 GHz - (a) case 1 to case 4 and, (b) case 5 to case 8.

For all these cases, the simulated and measured power level is around -2.2 dBW. From these plots, it can be seen that for Case 1 to 8, the antenna radiates maximum at around $\varphi = 0^0$, $\varphi = +45^0$, $\varphi = +90^0$, $\varphi = +135^0$, $\varphi = +180^0$, $\varphi = -135^0$, $\varphi = -90^0$ and $\varphi = -45^0$ of the XY azimuth plane respectively. Hence, with the excitations of proper port combinations, the radiation beam of this proposed antenna can be fully steered along the whole azimuth plane.

For all the cases, Fig. 13 shows the simulated & measured peak gain of the proposed antenna. It is observed that the simulated antenna gain is around 8.2 dB at 1.03 GHz and around 7.9 dB at 1.09 GHz for case 1, 3, 5 and 7. The measured antenna gain is around 8 dB at 1.028 GHz and around 7.7 dB at 1.095 GHz for the same. Again for case 2, 4, 6 and 8, the simulated gain of the antenna is around 7.8 dB at 1.03 GHz and around 7.4 dB at 1.09 GHz. In these cases, the measured gain is around 7.5 dB at 1.028 GHz and around 7.1 dB at 1.095 GHz.

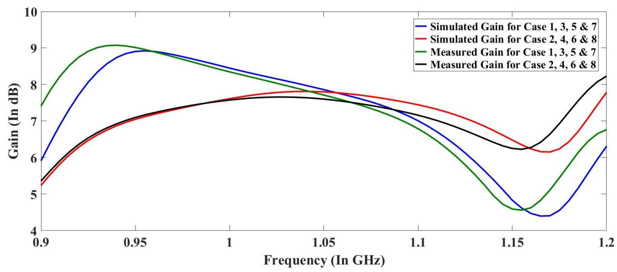


Fig. 13: Gain vs frequency plot of PPMFMA.

Figure 14 shows the simulated & measured radiation efficiency of the proposed antenna for case 1 to 8. It is observed that the simulated antenna radiation efficiency is around 70% at 1.03 GHz and around 67% at 1.09 GHz for case 1, 3, 5 and 7. The measured antenna radiation efficiency is around 68% at 1.028 GHz and around 65% at 1.095 GHz for the same. Again for case 2, 4, 6 and 8, the simulated radiation efficiency of the antenna is around 71% at 1.03 GHz and around 69% at 1.09 GHz. In these cases, the measured radiation efficiency is around 69% at 1.028 GHz and around 66% at 1.095 GHz.

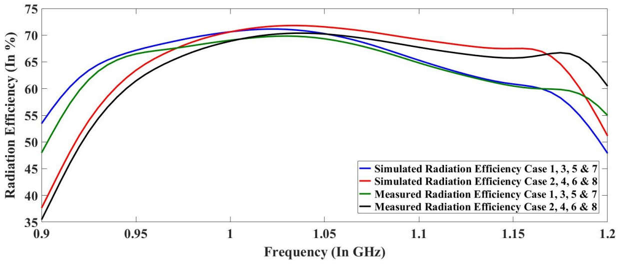


Fig. 14: Radiation efficiency vs frequency plot of PPMFMA.

C. Comparison in Performance between the Existing TCAS Antenna and the Proposed Antenna Model

Table I summarizes all the measurement results of the proposed Penta Patch Multi-Feed Microstrip Antenna. This table also helps to compare between this proposed and the monopole TCAS antenna [8]. From Table I, it can be observed that the proposed microstrip end-fired antenna can perform much better in comparison with the present TCAS antenna in terms of frequency sensitivity, desired end-fire radiation pattern, gain, beamwidth and side-lobe level. Hence, this prototype antenna model could be a better product for this application.

TABLE I: Comparison of the existing TCAS antenna with the proposed antenna.

Parameters	**Proposed Antenna (PPMFMA)**	**Existing TCAS Antenna**
Operating Frequencies (f_1 & f_2) in GHz	1.028 & 1.095	1.03 & 1.09
Return Loss (at f_1 & at f_2) in dB	-37 & -22	-15
VSWR (at f_1 & at f_2)	1.11 & 1.39	1 to 1.5
Co & Cross Pol. Level in dBW	-2.2 & below -40	-4 & around -20
Gain (at f_1 & at f_2) in dB	8 & 7.7	3.5
Beamwidth (at f_1 & at f_2)	54^0 & 55^0	More than 100^0
Side-Lobe (at f_1 & at f_2) in dB	-12.6 & -12.6	-7.5
Radiation Efficiency (at f_1 & at f_2)	69% & 66%	-

IV. Conclusions

In this paper a designing methodology for end-fired microstrip antenna has been presented, and hence it can be used in many airborne systems like TCAS. The proposed prototype model of the antenna provides a much better performance in terms of gain, directivity and 3-dB beamwidth with comparison to the present TCAS antenna. Here, it is shown that how the antenna can radiate towards the 360^0 surveillance region of the aircraft with proper antenna feeding technique. The ongoing research focus is on the development of a switchable feeding network and it will be designed in such a way that the input power will be fed to to the proper antenna ports with various switching conditions. Hence, the radiating beam can be shifted in the whole azimuth plane by just controlling few RF switches. The proposed antenna is very compact in size and weights around only 550 grams. This antenna is also cost effective since FR4 epoxy substrate is used here. Therefore, in terms of high performance and design simplicity, this proposed Penta Patch Multi-Feed End-Fired Microstrip Antenna will be expected to match with certain requirements of the present scenario in the avionics field.

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