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Comparative Analyzes of Antenna Designs for Applications in Stealth Technologies

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Abstract:

In this research UWB Antennas are designed, demonstrated and compared for stealth applications. Many-methods are applied on designs to realize RCS reduction. The RCS has been reduced in the whole frequency band on account of size miniaturization. Moreover the monostatic RCS of modified antenna has been reduced for both X and Y-polarized incident waves but maximum reduction in RCS of horizontal polarized wave is more than 25dBsm at 11.8GHz. The outcomes demonstrate that the proposed design provides a good prospect for the requirement of stealth technologies.

Keywords: *Impedance matching; Radar Cross section Reduction (RCSR); Miniaturization*

1. Introduction

Antenna is an ingredient of radar system. It is a major tool to detect and locate objects. Since the development of radar has been, in a variety of military and civilian system plays a vital role. In terms of civil, thunder to be used for a sort of navigation, such as terrain avoidance, air traffic control avoidance, etc; In addition, a variety of military radar platform, can carry out tasks such as detection, surveillance and attack [2]. When the enemy radar is effectively avoided, our military target battlefield viability is able to ascend and safeguard our various military missions was carried out smoothly. Therefore, radar cross section and its control have a vital importance in the academic and military engineering fields from all over the world. The radar antenna is widely utilized for modern military operations. The radar acts as a dynamic measure of survival of military systems in hostilities and animosities. In low observable platforms, RCS reduction is very important subject in avoiding sensitive targets from the detection of the hostile radar. Reduced Radar Cross Section (RCS) is the most fundamental parameter in stealth designs of aircrafts and watercrafts [1, 2].

The detection of friendly objects by hostile radar can be lingered on and the fighting ability of hostile and inimical radar can be enfeebled. Thus the competence of friendly objects can be ameliorated. The radar low observability has been usually achieved through reducing the radar cross-section (RCS). Hence, the antenna scattering is analyzed carefully as it is the principal contributor to the entire RCS of stealthy technologies. Antenna, being a dominant scatter can usually generate strong RCS which handicaps the antenna designs with low RCS [3, 4].

There has been a broad study on the printed UWB antennas in recent times. They are fascinating for their configuration advantages. Besides this, they have tremendous application values in stealth platforms [1]. The ultra wide band antenna is a fundamental constituent in building up the UWB technology. These antennas have been opening a way to wireless communication system and radar technology [6-9].

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Printed Circular Disc Monopole Antenna (PCDMA) is realized to be good candidates for UWB applications because they are simple in geometry, easier in manufacturing. Moreover they have broad band features and Omni directional radiation pattern for higher frequencies and bidirectional pattern for lower frequencies. However, the metallic coverage of the portable patches is often large, which cause to enhance their RCS. The frequency band under consideration for UWB antennas is so wide; hence it is highly challenging to consider RCS reduction in the whole band [1, 10].

According to the principles of surface current distributions on the patch of the designed antenna, the metallic region of minimum current is reduced. Hence, RCS of proposed design will be reduced, while its radiation performance maintained the same as the referenced design [6]. Despite, in such examines the RCS reduction wasn't achieved in entire operating frequency band.

In order to overcome these limitations, a planar design with reduced RCS is presented in this paper. This proposed design is based on UWB Printed Circular Disc Monopole Antenna (PCDMA) to validate the efficacy of designing techniques [1]. In this study, first we have designed a referenced PCDMA; secondly its circular patch has been modified in to an octagonal patch which makes the size miniaturizations as to attribute for RCS reduction. The basic equation relating to delectability and invisibility of RADAR targets is as follows:

$$R_{\max} = \sqrt[4]{\frac{P_t G A_e \sigma}{(4\pi)^2 S_{\min}}}$$

In above equation; $R_{\max}$ is the maximum detection range, P_t the radiating power, G and A_e the gain and the effective area of the radiating and receiving antennas, σ is the RCS of the target and $S_{\min}$ the minimum detectable signal. Thus, for given radar parameters, the maximum detection range is proportional to the 4th root of the target RCS, hence in this rational we have decreased the size of radiating patch, which ultimately reduces RCS i.e. $R_{\max} \propto \sqrt[4]{\sigma}$

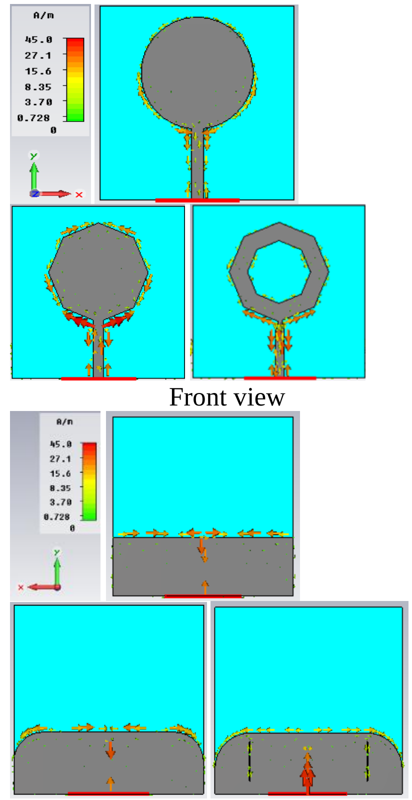
Moreover, we did some parametric study on the simulated models. By increasing value of dielectric make S11 bad but RCS improves. The slots on the ground and octagonal radiating patch contribute in RCS reduction. Afterwards, the surface current distributions of the designs were analyzed and the region of minimum current amplitude is subtracted to balance the impedance matching and reduces the RCS as well. Therefore, in this rational RCS reduction of the modified antenna has been achieved. Hence, the delectability of radars decreased thus makes object invisible for the hostile radar [6, 16]. Moreover; two antennas are designed and demonstrated in steps to clarify the advantage of proposed antenna**.**

2. ANTENNA DESIGN AND RCS REDUCTION PRINCIPLE

This section comprises of parametric analysis to make antenna optimized for RCS reduction operations. By doing so some important parameters of suitable values are chosen for designing the prototype as to validate the fabricated model.

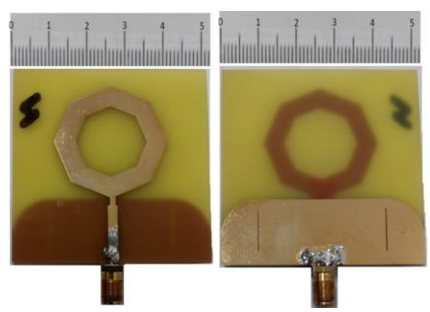
The referenced and proposed antennas are demonstrated in this section as shown in Fig.1 and Fig.2. In order to present the advantages in RCSR of the modified antenna, both the antennas are taken to be of the same ground plane and substrate. Antenna designing parameters focuses on the consistency in reflection coefficient and reduction in RCS of suggested model to an optimum level. These antennas are printed on FR-4 square substrate of permittivity constant $\epsilon r = 4.6$. The height of substrate is 1.6mm. The source line and the ground are printed oppositely to the substrate. The ground slots of width 3mm and length 11mm are capable of changing surface currents of the designed model in accordance with Faradays laws of electromagnetic induction [12, 13]. Thus the scattering field counteract because of phase reversal of 180^{o} [6, 14]. Therefore, in such a rationale, slits on the ground serves as an impedance matching in an electrical devices for easy flow of current. The patch of the proposed antenna is designed as an octagon. The sides of octagonal patches are 11.48 mm in length, while the radius of circular patch of reference antenna is 15 mm. The overall, decrease in the size of radiating patch of aimed antenna has been reduced RCS to a most favorable level.

The PCDMA was studied in [1], as shown in Fig.2. In this paper, PCDMA is preferred as a referenced antenna for its balanced radiation performance and proper scattering characteristics. It is well known that the circular radiating patch leads the antenna good performance, but its large metallic area give rise a large RCS [2, 6]. In this research large area distorts the aim of stealth. In order to achieve RCS reduction, the surface current distribution of the referenced antenna was determined [1]. The radiation characteristics of the UWB antennas are based on the distribution of surface currents over the metallic patches. Fig.1 shows the surface current distributions of referenced and modified antennas. The method of reducing patch coverage is different for different type of antennas. The currents are distributed unequally. While, at the centre of the patch current distributions are out of resonance so has minimum magnitude. But in this research, after examining the surface current distributions of referenced and the modified antennas, the area where current is minimum has been reduced as shown in Fig. 1. Despite being the area of small surface current is reduced, so the structural mode RCS will be reduced accordingly [6]. Thus, the total RCS has been reduced, while the S_{11} parameter of the proposed design will be maintained the same [1, 6]. The assigned frequency of this prototype covers S-band (2 GHz - 4 GHz) for satellite, radio and cellular phones, C-band (4 GHz - 8 GHz) for satellite and microwave relay, X-band (8 GHz -12 GHz) for Radar and Ku-band (12 GHz-18 GHz) for Satellite TV and police Radar.



Back view

Figure 1: Antenna design steps & surface current distributions



(I) Front view (II) Back view

Fig.2 Fabricated proposed Model

3. RESULTS AND DISCUSSION

The detailed discussion of the results of the both the antennas are given in this section.

3.1. RETURN LOSS (S_{11}):

The most commonly referred parameter relating with the antenna operation is return loss [7]. The S_{11} diagram of refereed and aimed designs is depicted in Fig.3 (a, b). The black curve shows S_{11} of referenced antenna, while the red curve represents S_{11} of octagonal patch on it.

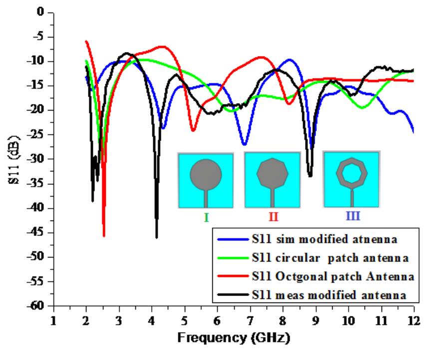


Fig.3 (a) S_{11} Comparisons of three antennas

However, the simulated return loss (S_{11}) is below -10 dB which give good efficacy on the modification of designed antenna in the whole operating frequency band and depicted by red curve as shown in Fig3 (a). It is clear in blue curve that at frequency of 7 GHz S_{11} has been improved dramatically. As the width of feed line increases antenna radiates most effectively at lower frequencies but scattering degrades for higher frequencies as depicted in Fig3 (b). If width of feed line increases, the receiving and radiating power of antenna increases consequently. It has been shown that the simulated and measured S_{11} graphs of the modified antenna are nearly consistent. But slight incoherency in the measured return loss is reasonable, which is caused by improper welding of the wave guide port with feed line. In Fig.3 (b), the return loss curves of three antennas (I, II and III) are contracted together as to clarify the consequence.

The simulated reflection coefficient S_{11} of the modified design at frequency of 2.5 GHz - 18 GHz with different widths of feed line is presented in Fig.3. It has been observed that almost all the curves are below -10 dB but the most wanted performance of design is achieved at width of 1.05mm.

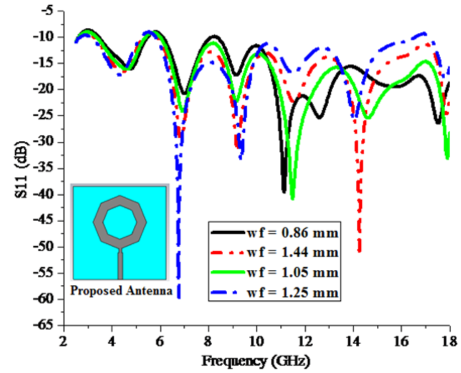


Fig.3 (b) Effect of microstrip feed line on S11

3.2. RADIATION PATTERN

The radiation pattern is a graphical representation (in polar or Cartesian coordinates) of the spatial distribution of radiation from an antenna as a function of angle [7]. The simulated radiation pattern of designed and reference antennas has consistency, which indicates that the alterations in geometry of designed model did not affect on the overall scattering characteristics of antenna. The radiation pattern is normal to the antenna axis across UWB frequency band and has stable Omni directional behaviour. In addition to this for lower frequencies radiation pattern looks '8'or bi-directional. In bi-directional patches main & back loops has same radiation strength, while side lobs are negligible. If antenna radiates more in one direction then it must radiate less in other directions as to validate law of conservation of energy. At frequency of 2 GHz main lobe magnitude is 10.5dBv/m in horizontal direction and in vertical direction main lobe strength is 15.7dBv/m. While at frequency of 4 GHz the radiation intensity has magnitude of 14.4 dB v/m and in vertical direction it is 15.1dBv/m. The modified antenna looks planar monopole [7, 15].

The radiation behaviour of the designed antenna was measured in the far filed an Echoic Chamber with SATIMO at Star Lab 6E in UESTC as shown in Fig.5.Afterwards, the radiation pattern is depicted and contracted at θ = 90⁰ in xy-plane, see Fig7. The simulated and measured radiation pattern has slight incoherency due to some distortions on the measured curves caused by the feed connector. Even then, their software results show that the radiation representations of both models are nearly identical.

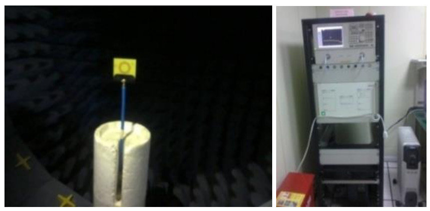


Fig.4. Designed antenna radiates in echoic chamber

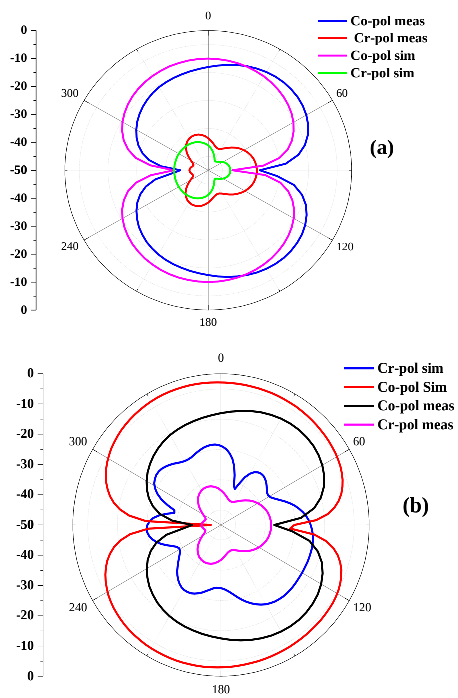


Fig.5. Sim: & meas co-pol and cross pol: radiation representation of cited antenna at θ= 90º in xy-plane for frequencies (a) 2 GHz (b) 4 GHz

4. RCS

RCS is a measure of how target is able of being detected by radar antenna. To find a low RCS antenna, the effect of different radiating elements was analyzed by using CST microwave simulator. The feed termination has vital importance in studying the RCS reduction because it controls the scattering characteristics of antenna [1, 17].The linearly polarized monostatic RCS values of antenna connected with matched load of 50Ω were studied [7].

It has been observed that the octagonal patch with octagon aperture has optimal performance and improved RCS due to its small radiating elements [11]. Hereby, the RCS of modified antenna is reduced due to the reduction in structural mode RCS [3, 6]. Hence, octagon patch is used as radiating element in this prototype.

Moreover, the antennas are terminated with short-circuit load and open circuit load then RCS curves are calculated and compared as expressed in Fig.6 [1]. Compared with the cited patch, the aimed design has merits on the RCS reduction in the whole operating frequency band [12, 20].

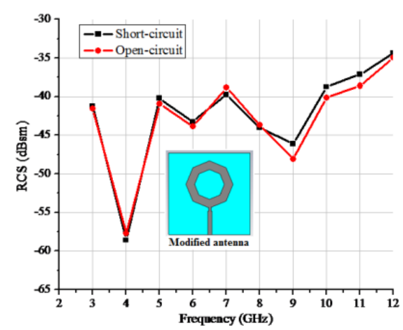


Fig.6 Variation of RCS values verses frequency in the proposed antenna

In this part the polarization of incident field; whether parallel or perpendicular to the micro strip feed lines have been specified. The RCS of proposed antenna is simulated for both polarizations and their reductions are shown for both over the entire band. The incident and received electric fields are parallel to X –axis. The monostatic RCS of proposed model for both X and Y -polarized incident and received waves are depicted over the entire frequency band as shown in Fig.7 However, compared with the planar octagonal-shaped UWB antenna see Fig.17 and Fig.18 in [17,19]; the modified design has rewards on RCS reduction in the operating frequency band. In addition, the RCS has been reduced more than 25dBsm at frequency of 11.8 GHz in the modified design as shown in Fig.7

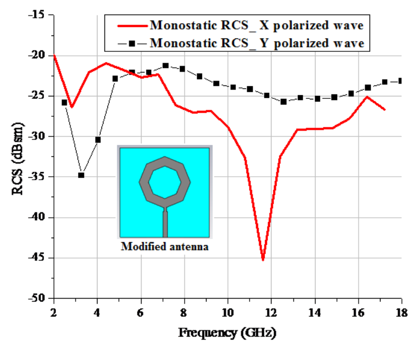


Fig.7. Monostatic RCS of proposed antenna for x & y-polarized waves

In the second case the antennas are terminated with short-circuit load (port is connected with ground plane PEC) and open circuit load (port is not connected) then RCS curves are calculated as shown in Fig.7. However, compared with the referenced patch in [1], the modified design has advantages on the RCS reduction over whole frequency band.

5. Conclusion

In this study antennas are designed for RCS reduction in stealth technology. The S_{11} less than -10 dB of the designed model have been accomplished in the operational frequencies ranges from 2 GHz to 18 GHz. The results show that the return loss S_{11} of referenced and suggested antennas is almost the same.

Moreover, the simulated radiation performance of both the antennas is nearly consistent and stable. The fabricated antenna has lower RCS than the referenced patches in the entire operational frequency bandwidth which is favorable for the prototype. The optimized outcomes have been supported through fabricated model and found coherency in the antenna parameters. The novelty of the design is that the RCS has been reduced in the whole operating frequency band. Hence, the proposed design can be used as a UWB antenna for the necessity and control of RCS in stealth technologies

AUTHOR CONTRIBUTION

All the authors contributed equally in various sections of the research paper.

DATA AVAILABILTY STATEMENT

Data generated during the current study are available from the corresponding author on reasonable request.

CONFLICT OF INTEREST

Authors of this paper declare no conflict of interest.

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