Progress In Electromagnetics Research Letters, Vol. 1, 211–220, 2008

MICROSTRIP ANTENNA USING GROUND-CUT SLOTS FOR LOW RCS WITH SIZE MINIATURIZATION TECHNIQUES

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Abstract—The techniques of ground-cut slots and miniaturization are applied in the design of microstrip antenna which reduces the resonance frequency and size of antenna and achieves the Radar Cross Section (RCS) reduction. Compared with the rectangular patch antenna working at the same frequency, the designed antenna realizes the RCS reduction in the whole frequency band of 2–8 GHz. And the RCS can be reduced 2–4 dB at its working frequency. The RCS peaks are efficiently controlled to get a smooth curve while the gain loss is only approximately 0.9 dB, which assures the radiation performance. The measured results of radiation performance accord with the simulation results and it implies that this method is feasible.

1. INTRODUCTION

For stealth platform, antennas on it are one of the main contributions to the total Radar Cross Section (RCS). So the RCS reduction of antenna is now an important topic for the current stealth technologies. Antenna is a special scatter, which must assure the radiation and receiving of radar waves [1–3]. Regular stealth methods are not valid for direct use on antenna, which makes it very difficult to design antenna with good radiation performance and low RCS. Microstrip patch antennas have been found wide used on aircraft because they are lightweight, conformal, relatively easy and inexpensive to fabricate. In fact, Microstrip patch antenna is a resonant structure with high Q typically. One of the main disadvantages of the patch, however, is its small bandwidth. This resonant character introduces another characteristic of the patch which may be undesirable for the certain application: large radar cross section (RCS) at the resonant frequencies [4, 5].

Although it is supposed to reduce the RCS of microstrip patch antenna arrays in most practical applications, the RCS of patch arrays at resonance is much larger than their respective cross-sectional areas because of the RCS of single microstrip patch [6]. So it is necessary to obtain a single microstrip patch antenna with low RCS first. There are many methods currently available to reduce the RCS of single microstrip patch antennas. In contrast, research on the RCS reduction of array is reported little. Researchers have devised several methods to reduce the RCS of single microstrip patch. Distributed loading has been used to suppress the patch RCS while having a minimal effect at the operational frequency of the patch [7]. By controlling the bias voltage across a varactor diode that is mounted between the patch and ground plane, the scattering response of the antenna can be tuned to minimize the RCS at threatened frequencies [8]. The RCS peaks of a microstrip patch antenna printed on a ferrite substrate can be shifted by changing the magnetic bias field with little effect upon the radiation property of microstrip antennas [9]. Additionally, the application of meshed patch antennas to the RCS reduction of microstrip antennas has been investigated yet being at the cost of the gain and bandwidth of the antenna [10]. In conclusion, the RCS reduction of single microstrip patch, which is a problem that has not yet been satisfactorily solved, requires further research.

To reduce the RCS of antenna, changing the shape of patch which minimizes the patch and making slots in the ground plane are proposed in this letter. With the radiation performance almost maintained, a low RCS antenna is designed.

2. THE THEORY OF RCS REDUCTION

The total scattering field of antennas constitutes structural scattering and antenna-mode scattering. When the feed port is match loaded, the scattering is structural scattering. If not, part of the received energy is reradiated, which is antenna mode scattering [11].

The source of structural scattering field of microstrip antenna is the inducing current. In this letter, the novel shape of patch has changed the direction of the inducing current, so the scattering field counteract because of the different phase. The structural scattering field of microstrip antenna is reduced. In addition, the structural scattering field is related to the physical parameter of antenna, minimize the patch can also reduce the structural scattering field of antenna [12].

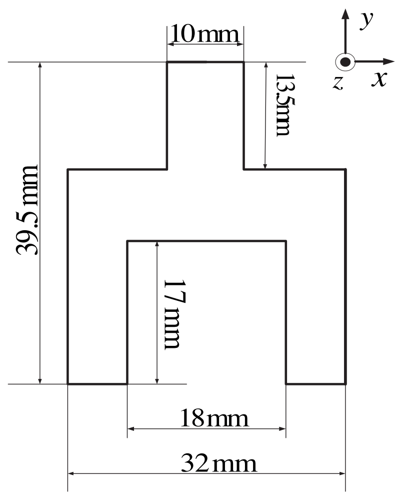


Figure 1. Configuration of the proposed patch.

The techniques of slots-cutting can change the radiation and impedance property of microstrip antenna, which has been used in broad up the bandwidth of antenna [13–15]. Considering the radiation and scattering property, we design the patch with slots in the ground plane as shown in Fig. 2. In additional, the size of ground plane can also affect the scattering property of antenna, so the ground plane should be designed as small as possible on the premise that the construction and radiation property of antenna remain.

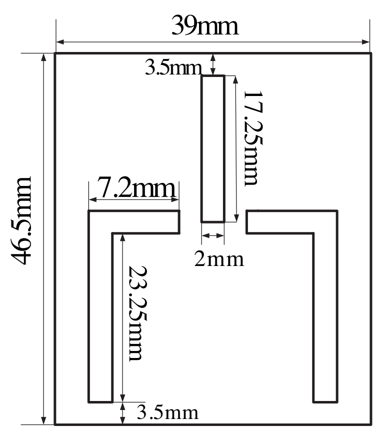
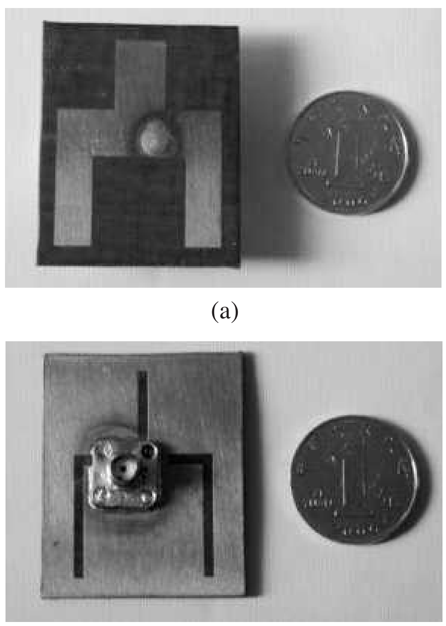


Figure 2. Configuration of the proposed ground plane.

3. ANTENNA CONFIGURATION AND RESULTS

The techniques of ground-cut slots and miniaturization are applied in the design of microstrip antenna, and we will get a patch antenna with low RCS. The antenna substrate is 2 mm thick and with the relative permittivity $\varepsilon_r = 2.6$. Antenna is fed by coaxial line with 50 ohm in the position of (3.7, 0, 0). The working frequency of the antenna is 2.29 GHz. The configuration of patch and size of slots in the ground plane are shown in Figs. 1 and 2, and Fig. 3(a) and (b) give the pictures of patch and ground plane. For comparative purpose, a rectangular patch antenna with the same resonant frequency is also designed as the standard antenna. The size of rectangular patch antenna is $37 \times 47.4\,\text{mm}^2$, and the thickness and the relative permittivity of the dielectric substrate are the same with those of the proposed antenna. It can be seen that the area of this novel patch is 62.3% smaller than the rectangular patch antenna.



(a)

(b)

Figure 3. Photographs of the proposed antenna.

The simulated and measured S11 of two antennas are compared in Fig. 4. The resonant frequency of the standard antenna and the proposed antenna is 2.29 GHz. Compared with two antennas,

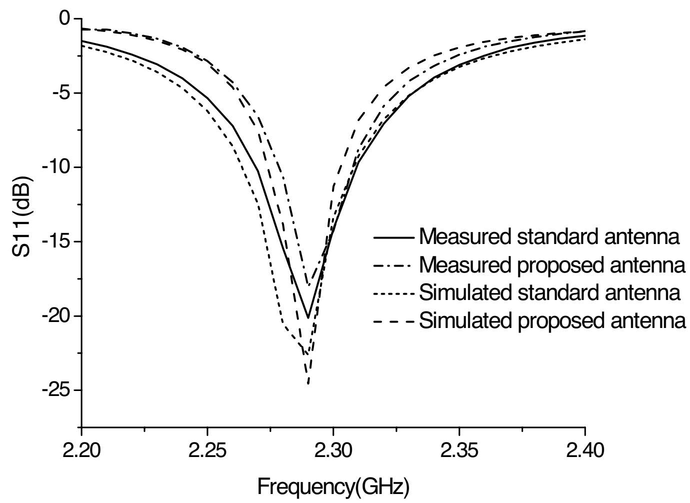
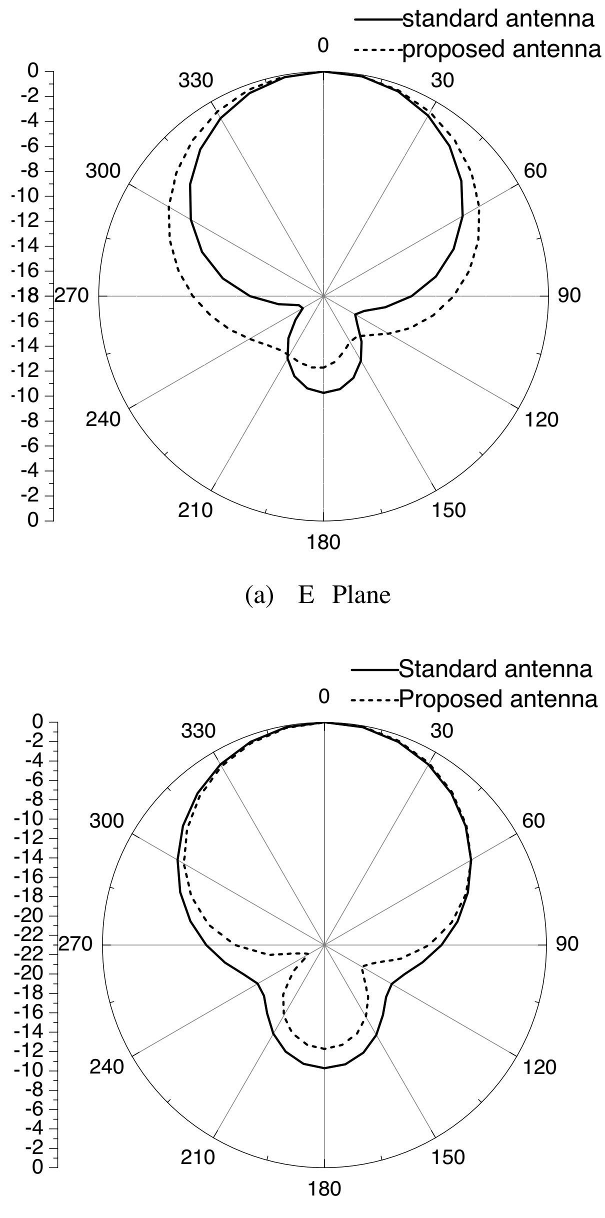


Figure 4. Simulated and measured S11 of two antennas.

the simulated bandwidth has a loss of 0.7%. There is a frequency shift, which may be caused by the fabrication error. The measured bandwidth loss is almost the same with the simulated results.

The simulated and measured radiation patterns of $\varphi = 0°$ and $\varphi = 90°$ of two antennas are shown in Fig. 5 and Fig. 6. The simulated gain at the resonant frequency decreases from 6.65 dB to 5.72 dB. The measured gain of the proposed antenna has a loss of 0.5 dB, which is better than simulated results. From the simulated results, we can see that back lobe of the proposed antenna become smaller than the standard antenna. The miniaturization brings little changes to the radiation ability.

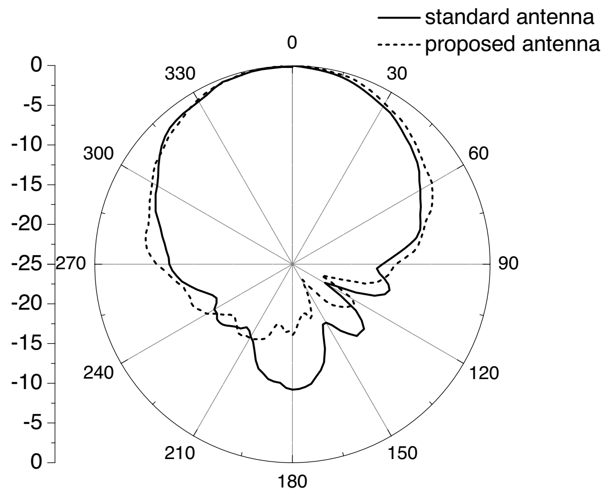
The comparisons of RCS between the standard antenna and the proposed antenna are given in Fig. 7. The incidence angles are $\theta = 60°$, $\varphi = 45°$, $\theta = 60°$, $\varphi = 90°$ and $\theta = 60°$, $\varphi = 0°$ respectively. From Fig. 7(a) we can see that the RCS peaks of the rectangular patch with incidence angle $\theta = 60°$, $\varphi = 45°$ get some reduction. The RCS received 2–4 dB reduction at its working frequency. The RCS reduction for the frequency band 4–8 GHz is also very apparent. The RCS curve becomes smoothly and the peaks are all less than -30 dB. Fig. 7(b) is the results with incident angle $\theta = 60°$, $\varphi = 0°$, several larger peaks have a reduction of about 10 dB. Fig. 7(c) shows that the RCS of two antennas with incident angle $\theta = 60°$, $\varphi = 90°$. We can see that the RCS has a reduction of about 12 dB at 2.29 GHz. The loss of bandwidth and gain of antenna are accepted for the RCS reduction effect.



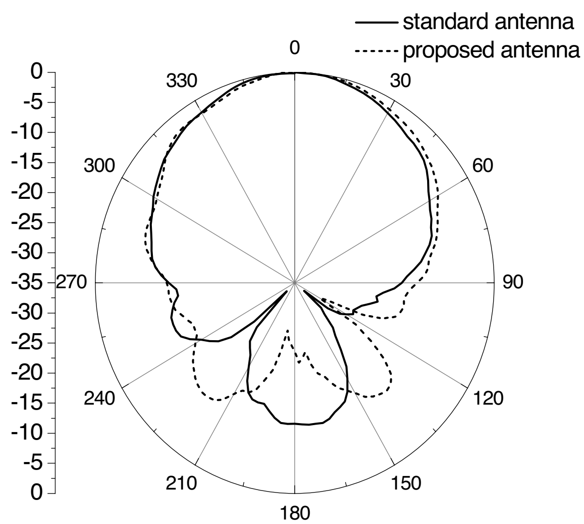
(a) E Plane

(b) H Plane

Figure 5. Simulated radiation patterns of two antennas.

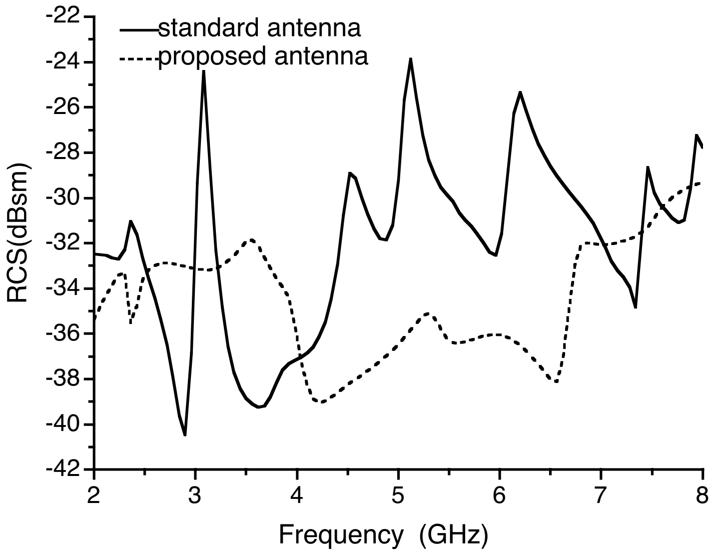


(a) E Plane

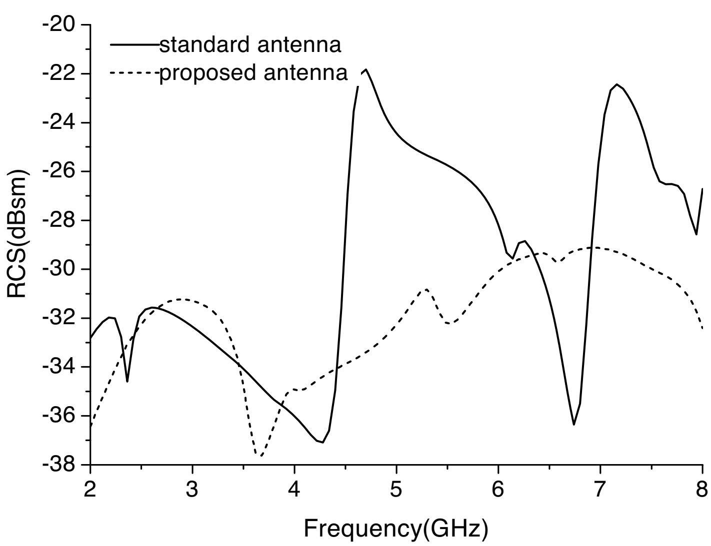


(b) H Plane

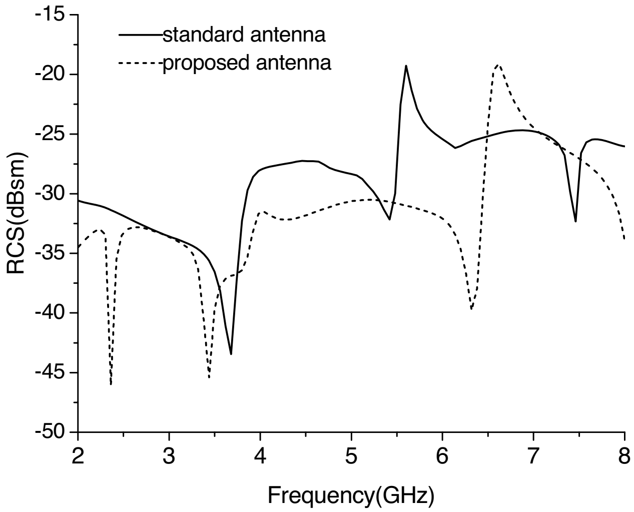
Figure 6. Measured radiation patterns of two antennas.


standard antenna
proposed antenna
RCS(dBsm)
Frequency (GHz)
-22
-24
-26
-28
-30
-32
-34
-36
-38
-40
-42
2
3
4
5
6
7
8

(a)


standard antenna
proposed antenna
RCS(dBsm)
Frequency(GHz)
-20
-22
-24
-26
-28
-30
-32
-34
-36
-38
2
3
4
5
6
7
8

(b)



(c)

Figure 7. Simulated RCS of two antennas. (a) $\theta = 60°$, $\varphi = 45°$, (b) $\theta = 60°$, $\varphi = 0°$, (c) $\theta = 60°$, $\varphi = 90°$.

4. CONCLUSION

The RCS reduction mechanism of microstrip antenna using ground-cut slots and miniaturization techniques is analyzed in the paper, and microstrip antenna with low RCS and good radiation ability is designed and measured. Considering the machining precision and measure error, the proposed method works when there is little influence of the radiation ability. The proposed antenna can be conveniently used as microstrip antennas where low RCS property is required.

REFERENCES

1. Sayem, A. M. and M. Ali, "Characteristics of a microstrip-fed miniature printed hilbert slot antenna," *Progress In Electromagnetics Research*, PIER 56, 1–18, 2006.
2. Yousefzadeh, N., C. Ghobadi, and M. Kamyab, "Consideration of mutual coupling in a microstrip patch array using fractal elements," *Progress In Electromagnetics Research*, PIER 66, 41–49, 2006.

3. Donelli, M., S. Caorsi, F. DeNatale, M. Pastorino, and A. Massa, "Linear antenna synthesis with a hybrid genetic algorithm," *Progress In Electromagnetics Research*, PIER 49, 1–22, 2004.
4. Newman, H., "Scattering from a microstrip patch," *IEEE Transaction on Antenna and Propagation*, Vol. AP-35, No. 3, 245–251, March 1987.
5. Pozar, D. M., "Radiation and scattering from a microstrip patch on a uniaxial substrate," *IEEE Transaction on Antenna and Propagation*, Vol. AP-35, No. 6, 613–621, June 1987.
6. King, A. S., "Scattering from a finite array of microstrip patches," *IEEE Transaction on Antenna and Propagation*, Vol. AP-40, No. 7, 770–774, 1992.
7. Volakis, J. L., A. Alexanian, and J. M. Lin, "Broadband RCS reduction of rectangular patch by using distributed loading," *Electron Lett.*, Vol. 28, No. 25, 2322–2323, 1992.
8. Aberle, J. T., M. Chu, and C. R. Birtcher, "Scattering and radiation properties of varactor-tuned microstrip antennas," *Antennas Propagat. Soc. Int. Symp. Dig.*, Vol. 4, 2229–2232, 1992.
9. Pozar, D. M., "Radiation and scattering characteristics of microstrip antennas on normally biased ferrite substrates," *IEEE Trans. Antennas Propagation*, Vol. AP-40, No. 9, 1084–1092, 1992.
10. Wu, B.-I., W. Wang, J. Pacheco, X. Chen, T. M. Grzegorczyk, and J. A. Kong, "A study of using metamaterials as antenna substrate to enhance gain," *Progress In Electromagnetics Research*, PIER 51, 295–328, 2005.
11. Liu, Y., S. Gong, H. Guo, and D. Fu, "Fractal microstrip patch antenna for antenna RCS reduction," *Acta Electronica Sinica*, Vol. 32, 1530–1531, 2004.
12. He, X., S. Gong, Y. Ji, and Q. Liu, "Meshed microstrip patch antennas with low RCS," *Microwave and Optical Technology Letters*, Vol. 46, 117–120, 2006.
13. Wan, J. X. and C.-H. Liang, "A fast analysis of scattering from microstrip antennas over a wide band," *Progress In Electromagnetics Research*, PIER 50, 187–208, 2005.
14. Saed, M. A., "Broadband cpw-few planar slot antennas with various tuning stubs," *Progress In Electromagnetics Research*, PIER 66, 199–212, 2006.
15. Eldek, A. A., A. Z. Elsherbeni, and C. E. Smith, "Rectangular slot antenna with patch stub for ultra wideband applications and phased array systems," *Progress In Electromagnetics Research*, Vol. 53, 227–237, 2005.