A Wide-Beam Antenna Based on Missile Telemetry System

Lizhong Song [1] and Xiuwen Tian [2]

[1] College of Information Science and Engineering
Harbin Institute of Technology at Weihai, Weihai, 264209, China
songlz@hit.edu.cn

[2] College of Information Science and Engineering
Harbin Institute of Technology at Weihai, Weihai, 264209, China
hittxw@163.com

Abstract **─** This paper presents an antenna system with multiple patches and multiple layer substrates for missile telemetry application. The antenna is comprised by a driven microstrip line, which is printed on the bottom layer dielectric substrate, and two parasitic patch radiators which are printed on the upper dielectric substrate. The microstrip line is excited by a coaxial probe directly, and the two parasitic patches are excited by the coupling energy. In order to broaden the beam width of the microstrip antenna, two parasitic patch radiators with different sizes are printed on the upper dielectric substrate. The width of the microstrip line is linearly varied to obtain a wide impedance-matching bandwidth. This antenna is simulated and optimized by using the full wave electromagnetic simulation technique. The simulated results show that the voltage standing wave ratio (VSWR) is less than 1.9 between 2.15GHz and 2.17GHz. At 2.16GHz, the VSWR of port is 1.29 and the 3dB beam widths of radiation patterns at E planes and H planes were more than 89.2 degrees. The proposed antenna is processed and measured. The measured results show that the proposed antenna achieves the expected radiation performance and validates the effectiveness of the antenna design. The antenna scheme studied in this paper is suitable for missile telemetry system. The research results have laid a technical foundation for its practical engineering application.

Index Terms **─** Gain, missile telemetry system, radiation pattern, telemetry antenna, wide angle coverage.

I. INTRODUCTION

Microstrip antenna has many advantages, such as easy processing, small size, light weight, simple manufacturing process, easy to realize conformal and so on. Because the microstrip antenna is easily printed on the circuit board, the microstrip antenna can be produced in large quantities. The above-mentioned advantages make them suitable for numerous applications [1-2]. Microstrip antenna arrays have been used for missile telemetry system. With the development of microwave technology, the requirements for the application of microstrip antenna arrays are becoming ever more demanding now. Due to the need for target tracking, the telemetry system needs a wider working beam. Therefore, it is of great practical significance to design an antenna unit with wide coverage range suitable for missile telemetry system. However, the inherent constraints of the microstrip antenna are the narrow bandwidth and beam width. Microstrip antennas have narrow beam width, which is typically 1–5% [3]. The wide band microstrip antenna has been a main issue of research in this field since the 1970s [4-5].

A lot of methods to broaden bandwidth in practical engineering have been proposed, and the general techniques include multi-resonators, stacked electromagnetically coupled and aperture-coupled patches, parasitic patch, ferrite substrates, et al. For example, the broadband impedance monopoles with finite ground planes have been reported in reference [6]. The reference [7] expanded the range of radiation by increasing the area of the dielectric substrate. A microstrip antenna, which is composed of a composite dielectric plate, was proposed in reference [8]. In order to broad antenna beam width, the teference [9] expanded the conductive wall around the patch antenna, and narrowed the antenna radiation aperture, and reducing antenna gain. In order to increase the beam width, Tang added three dimensions to microstrip circularly polarized antenna and the gain has decreased by 1.7dB [10]. Wu loaded the electric dipole around the circular polarized microstrip antenna to broaden the radiation beam of the antenna [11]. Shi used a single arm tapered gradient spiral antenna and 8 vertical electric dipole sub columns to widen the beam [12]. Pan proposed a method to broaden the beam width by loading the metal ring above the circular polarized microstrip antenna [13]. Luk used complementary characteristics of magnetic electric dipole radiation

Submitted On: July 27, 2018
Accepted On: December 25, 2018

pattern to design a wide beam circularly polarized antenna which works in 1.6-2.47GHz [14]. Park used cross electric dipole and magnetic electric dipole to design a circularly polarized antenna which wideband is 1.39-1.82GHz [15]. In literature [16], a cross dipole circular polarized antenna with a reflective cavity in 1.1-1.6GHz was designed, which was mainly used in GPS. In literature [17], a circular polarized patch antenna, which can realize the axis ratio wide beam, was designed by using two pairs of parallel dipoles.

In this paper, the research and development of the printed antenna for the missile telemetry system application is presented. A specific antenna scheme with wide space coverage based on missile telemetry system was designed. The antenna solved the application problem in the practical engineering and met the practical engineering requirements.

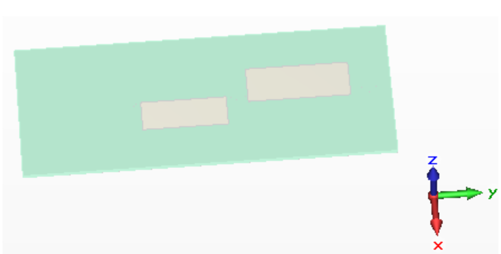
II. ANTENNA STRUCTURE

The model of the wide beam microstrip antenna is shown in Fig. 1.

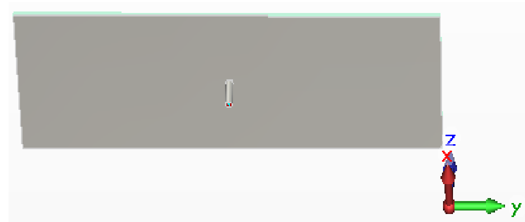
The antenna comprises a driven microstrip line radiator with two parasitic patch radiators. The antenna structure consists of two dielectric substrates which have the same relative dielectric constant; the microstrip line printed on the bottom substrate, and two parasitic patch radiators printed on the upper dielectric substrates.

The wide beam microstrip antenna of removing the substrate of the wide beam microstrip antenna is presented in Fig. 2 (a). The microstrip line is excited by a coaxial probe directly, and the two parasitic patches are excited by the coupling energy. Figure 2 (b) is the top view of the upper substrate. Two dielectric substrates with different sizes can be used to broaden the antenna beam width. Figure 2 (c) shows the top view of the bottom substrate. The width of the microstrip line is linear variety to obtain a wide impedance-matching bandwidth. Two dielectric substrates are a common FR4 material. The thickness of the two dielectric substrates are 1mm. The thickness of microstrip line and two parasitic patches are 0.036mm.

This paper uses the full wave electromagnetic simulation software (CST) to build the antenna. The radiation performance of the antenna is calculated and optimized by the full wave electromagnetic simulation software.

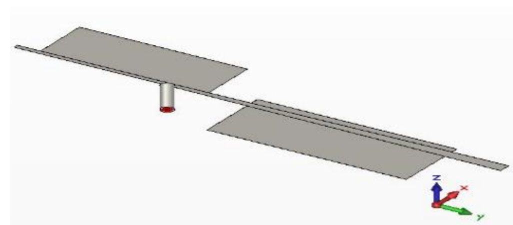


(a) The overhead view of the antenna

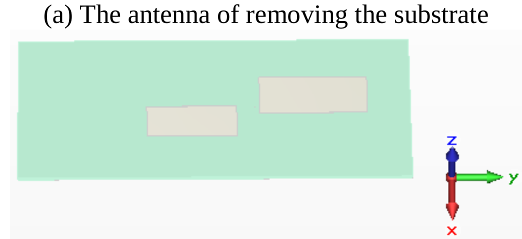


(b) The invert view of the antenna

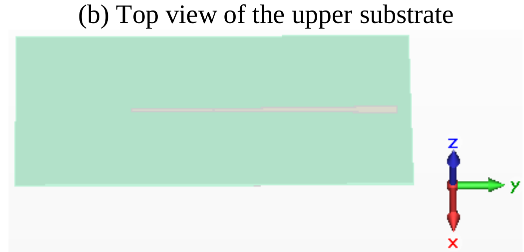
Fig. 1. The model of the antenna.



(a) The antenna of removing the substrate



(b) Top view of the upper substrate



(c) Top view of the bottom substrate

Fig. 2. Configuration of the proposed wide beam microstrip antenna.

The sizes of the proposed antenna structure on both sides of dielectric substrate are presented in Figs. 3 (a), (b) respectively.

The sizes of the parasitic patch radiators can be approximated by the formula:

$$W\_Patch = \frac{c}{2f}\left(\frac{\varepsilon_r + 1}{2}\right)^{\frac{-1}{2}}, \tag{1}$$

$$L\_Patch = \frac{c}{2f\sqrt{\varepsilon_e}} - 2\Delta l, \tag{2}$$

$$\Delta l = 0.412h\frac{(\varepsilon_e + 0.3)(a/h + 0.264)}{(\varepsilon_e + 0.258)(a/h + 0.8)}. \tag{3}$$

In formula (1) and (2), W_P is the width of the parasitic patch radiators, L_P is the length of the parasitic patch radiators.

We can calculate the sizes of the microstrip line from the formula:

$$Z_0 = \frac{120\pi}{2\sqrt{2\pi}\sqrt{\varepsilon_r + 1}} \ln\left\{1 + \frac{4h}{w'}\left[\frac{14 + 8/\varepsilon_r}{11}\frac{4h}{w'} \sqrt{\left(\frac{14 + 8/\varepsilon_r}{11}\right)^2 \left(\frac{4h}{w'}\right)^2 + \frac{1 + 1/\varepsilon_r}{2}\pi^2}\right]\right\}, \quad (4)$$

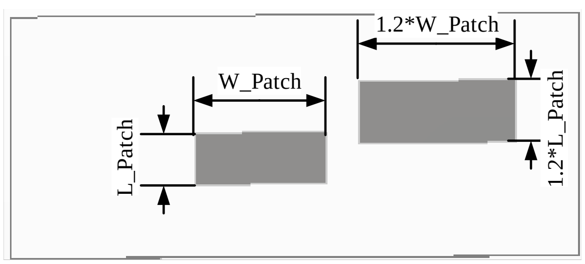
Where:

$$w' = w + \Delta w', \quad (5)$$

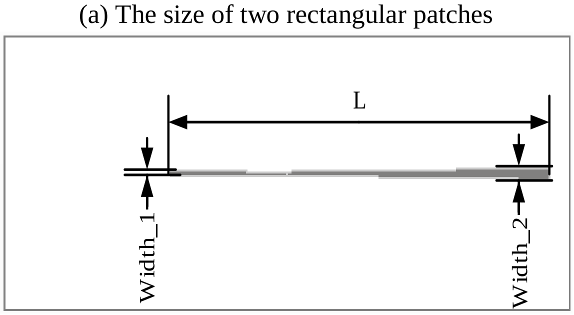
$$\Delta w' = \Delta w\left(\frac{1 + 1/\varepsilon_r}{2}\right), \quad (6)$$

$$\frac{\Delta w}{L} = \frac{1}{\pi}\ln\left[\frac{4e}{(t/h)^2 + \left(\frac{1/\pi}{w/t + 1.1}\right)^2}\right]. \quad (7)$$

In formula (7), Z_0 is the impedance of the microstrip line, t is the thickness of the microstrip line, w is the width of the microstrip line, L is the length of the microstrip line.



(a) The size of two rectangular patches



(b) The length and width of the microstrip line

Fig. 3. The engineering drawing of wide beam antenna.

According to the formula (1), (2), (3), (4), (5), (6), (7), we can get the initial value of the parasitic patch radiators and the microstrip line. Then, the final sizes can be obtained through the full wave electromagnetic simulation and optimization. The dimensions of the designed antenna are showed at Table 1.

Table 1: The dimensions of the designed antenna

Parameters	Sizes	Units
L_patch	26	mm
W_patch	66.5	mm
L	195	mm
Wdith_1	5	mm
Wdith_2	2	mm

III. SIMULATIONAND ANALYSIS

This paper uses the full wave electromagnetic simulation software (CST) to build the antenna. All the simulated results are obtained from CST. The voltage standing wave ratio (VSWR) of the port1 is shown in Fig. 4. As illustrated in Fig. 4, at 2.15GHz, 2.16GHz, and 2.17GHz, the VSWR of the port1 is about 1.68, 1.29, and 1.64, respectively. The VSWR is less than 1.7 within the range of 2.15GHz~2.17GHz. The impedance-matching bandwidth of port1 is not wide. Adjusting the sizes of those parameters, including microstrip line and two parasitic patch, can obtain a wide impedance-matching bandwidth. The simulated VSWR of port1 is suitable for practical application.

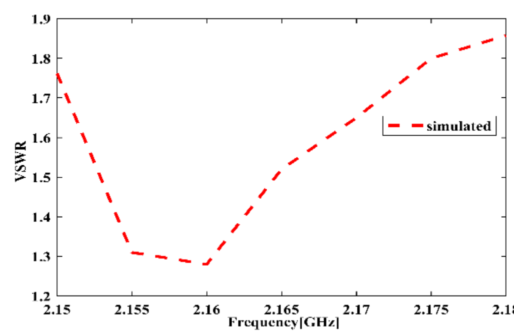
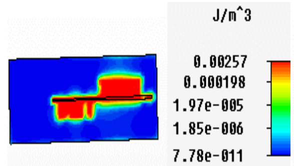


Fig. 4. Simulated VSWR of port1.

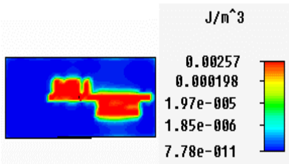
Figure 5 shows the electric energy density of the proposed antenna at 2.15 GHz, 2.16GHz and 2.17 GHz. Electric Energy distribution and current transmission path are presented clearly in Fig. 5.

Figure 5 shows that the electric energy density is higher on the microstrip line, two parasitic patches and coaxial probe. The current, through coaxial probe, flow into the microstrip line. The microstrip line radiates energy to space. The two parasitic patches are excited by the coupling energy. Hence, the two parasitic patches have higher electric energy density, and radiate energy into space.

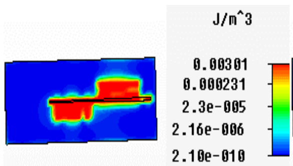
The simulated radiation patterns of the wide beam antenna at 2.15GHz, 2.16GHz and 2.17GHz are shown in Fig. 6, Fig. 7 and Fig. 8 respectively. At each frequency point, the radiation pattern of the port1 on the xoz plan and the yoz plan is given respectively.



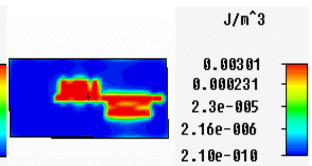
(a) The positive structure at 2.15 GHz



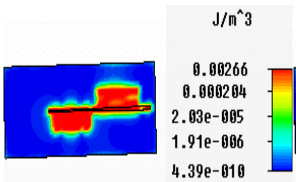
(b) The reverse structure at 2.15 GHz



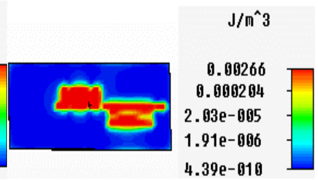
(c) The positive structure at 2.16GHz



(d) The reverse structure at 2.16GHz



(e) The positive structure at 2.17GHz



(f) The reverse structure at 2.17GHz

Fig. 5. Simulated electric energy density of port1.

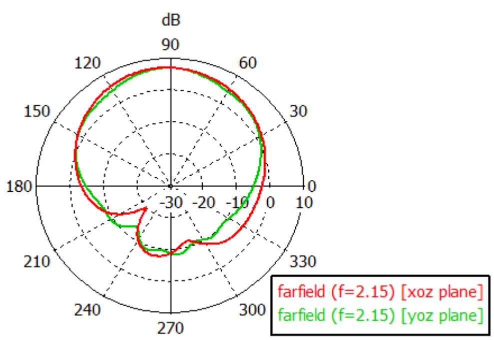


Fig. 6. The radiation pattern at 2.15GHz.

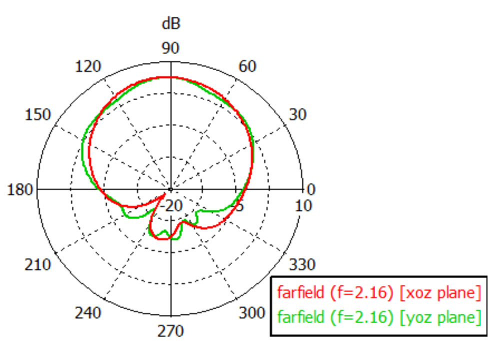


Fig. 7. The radiation pattern at 2.16GHz.

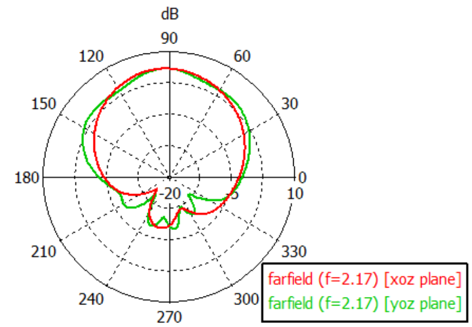
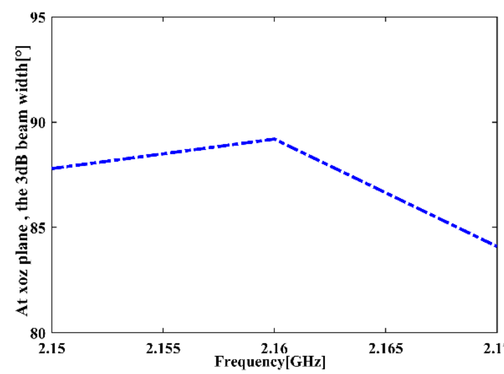
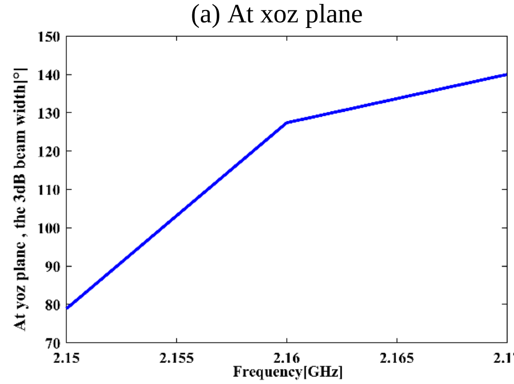


Fig. 8. The radiation pattern at 2.17GHz.

According to the simulated radiation patterns, it can be observed that the radiation pattern of the antenna port1 is more regular at xoz plane and yoz plane. The radiation gain of the antenna port1 is greater than 4.8dB. The 3dB beam width is more than 78.9°. At 2.15GHz, the 3dB beam width of the xoz plane and the yoz plane is 87.8° and 78.9° respectively. At 2.16GHz, the 3dB beam width of the xoz plane and the yoz plane is 89.2° and 127.4° respectively. At 2.17GHz, the 3dB beam width of the xoz plane and the yoz plane is 84.1° and 140° respectively.



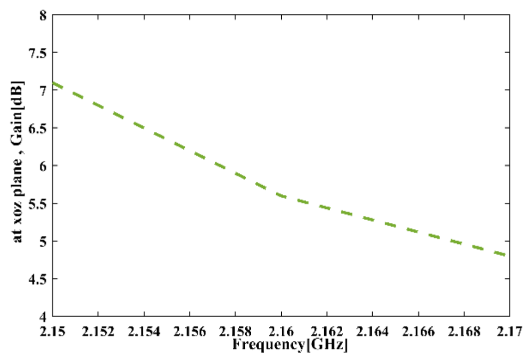
(a) At xoz plane



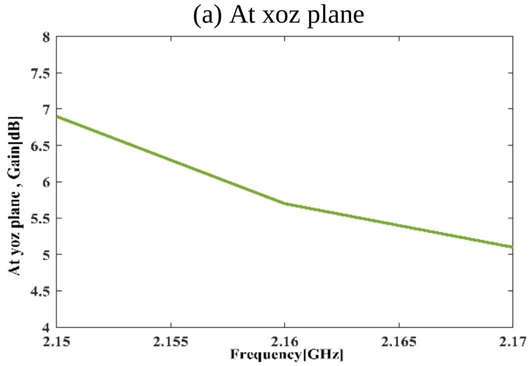
(b) At yoz plane

Fig. 9. The curve of antenna beam width with frequency.

The curve of antenna beam width with frequency variation at xoz plane and at yoz plane are shown in Fig. 9. The simulated results present that the 3dB beam width of the proposed antenna is between 84.1°and 89.2° at the xoz plane. The 3dB beam width of the proposed antenna is linear increasing with frequency at 2.15~2.16GHz and linear decreasing with frequency at 2.16~2.17GHz. At yoz plane, the 3dB beam width is between 78.9°and 140°. At 2.16~2.17GHz, Fig. 8 shows that the 3dB beam width at yoz plane is better than the 3dB beam width at xoz plane. The 3dB beam width is more than 78.9° at 2.15~2.17GHz. The simulated results indicate that the proposed antenna, at 2.17GHz, can obtain 140° at yoz plane and 84.1° at xoz plane. Therefore, the proposed antenna has a wider beam width performance. The designed antenna can obtain a wider beam width by adjusting the sizes of two parasitic patch.



(a) At xoz plane

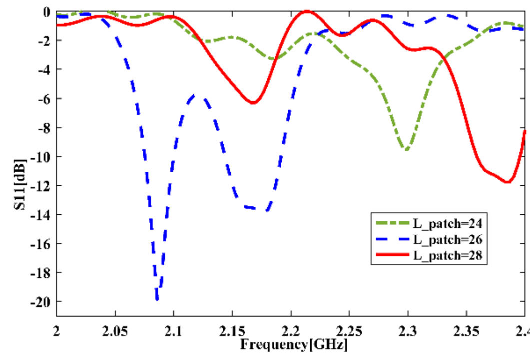


(b) At yoz plane

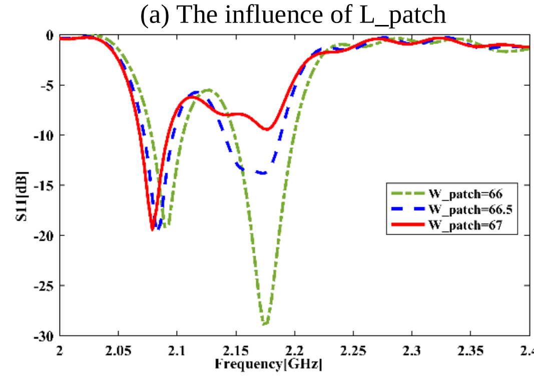
Fig. 10. The curve of antenna gain with frequency.

Figure 10 (a) shows that the gain, at 2.15~2.17GHz, is between 4.8dB and 7.1dB and decreasing with frequency at xoz plane. Figure 10 (b) reveals that the gain, at 2.15~2.17GHz, is between 5.1dB and 6.9dB and is linear decreasing at yoz plane. At yoz plane, the gain is decreasing with 3dB beam width increasing. Figure 9 presents that the gain, both xoz plane and yoz plane, is maximum at 2.15GHz.

In this section, the influence of several key parameters on the performance of the antenna circuit are discussed. Figure 11 reveals that the size of rectangular patch has large influence on the resonant frequency.



(a) The influence of L_patch



(b) The influence of W_patch

Fig. 11. The influence of the size of the parasitic patch radiation reflection coefficients.

As shown in Fig. 11 (a), with the increase of the length of the rectangular patch(L_patch), the resonant frequency moves toward the low frequency, and the return wave loss (S11) is gradually decreasing. When the L_patch is more than 26mm, the return wave loss (S11) increases, and the waveform becomes worse. In Fig. 11 (b), with the increase of the width of the rectangular patch(W_patch), the resonant frequency slightly moves toward the low frequency, and the return wave loss (S11) gradually decrease. When the L_patch is 66mm, the return wave loss (S11) has a better performance. But, when the L_patch is 66.5mm, S11 becomes worse. The simulated results present that a wide impedance-matching bandwidth can obtain by altering the size of two parasitic patches radiator.

IV. FABRICATION AND MEASUREDRESULTS

According to the proposed antenna structure and size, the wide beam antenna was fabricated and its prototype photo is shown in Fig. 12.

The measured results are given in Fig. 13. The VSWR is less than 1.9 at 2.15~2.18GHz. The measured VSWR meet the design requirement, and are closed to the simulated VSWR.

Fig. 12. Fabricated wide beam antenna.

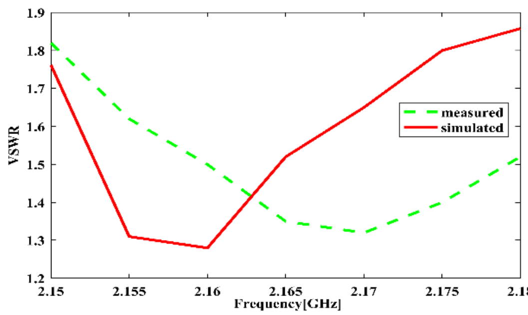
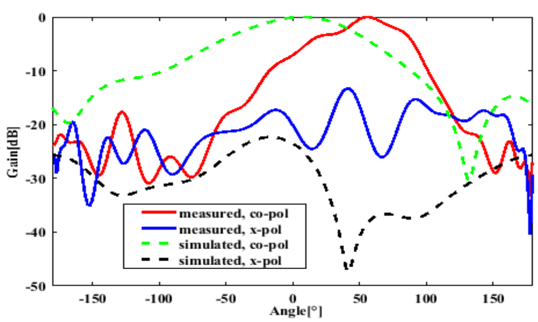
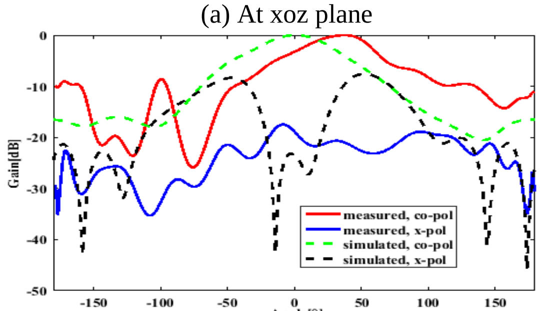


Fig. 13. The measured VSWR of the fabricated wide beam antenna.

The measured and simulated patterns of the co-polarisation and cross-polarisation 3dB beamwidths, at E-plane and H-plane, are presented in Figs. 14, 15 and 16, respectively.

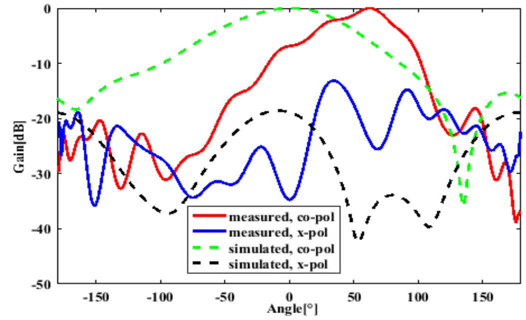


(a) At xoz plane

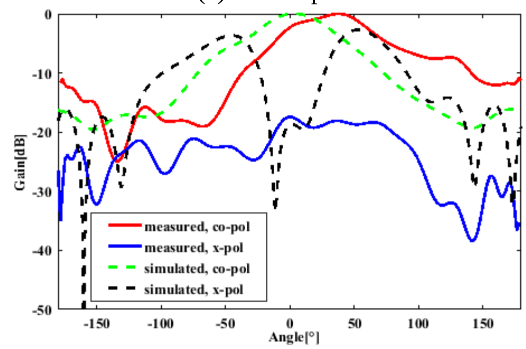


(b) At yoz plane

Fig. 14. The radiation pattern at 2.15GHz.

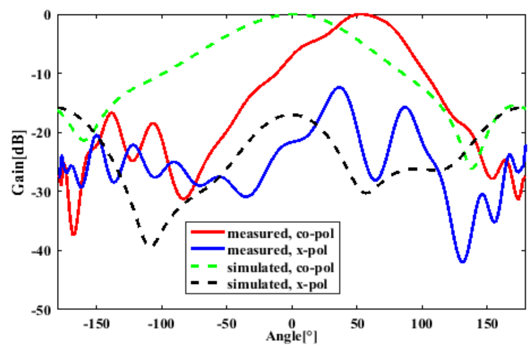


(a) At xoz plane

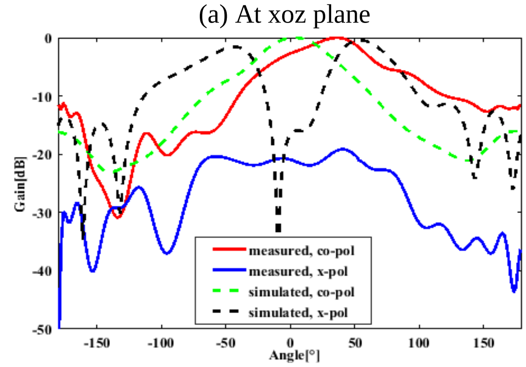


(b) At yoz plane

Fig. 15. The radiation pattern at 2.16GHz.



(a) At xoz plane



(b) At yoz plane

Fig. 16. The radiation pattern at 2.17GHz.

The antenna measured patterns are not as smooth as the simulations. The other environmental noise may influence the patterns. At 2.15GHz, the measured co-polarisation 3 dB beamwidths of xoz plane and yoz plane are 52°and 75°, while the simulated results are 61.9° and 87.7°, respectively. At 2.16GHz, the measured co-polarisation 3dB beamwidths of E-plane and H-plane are 67° and 56°, while the simulated results are 127.4° and 89.7° respectively. At 2.17GHz, the measured co-polarisation 3dB beamwidths of E-plane and H-plane are 67° and 56°, while the simulated results are 75° and 50.9°, respectively. Thus, the proposed antenna has a good wider beam radiation performance, which is high enough to be applied to missile telemetry system. In order to meet the needs of the missile telemetry system, the antenna with wide beam and big efficiency was designed. Both the measurement and simulation results meet the requirements of the missile telemetry system.

V. CONCLUSION

As the requirement for information acquisition is increasing, the missile telemetry system requires a wider beam coverage range. Therefore, it is of practical significance to develop a wide beam antenna element which is suitable for practical engineering applications. A new way to achieve wider bandwidth and broad beam width of microstrip antennas based on the two parasitic patch radiators with different sizes and microstrip line radiator is proposed. The structure of the proposed antenna is based on a two-layer dielectric substrates. The microstrip line is excited by a coaxial probe directly, and the two parasitic patches are excited by the coupling energy. The width of the microstrip line is linearly varied to obtain a wide impedance-matching bandwidth. The sizes of the parasitic patches can be adjusted to increase the beam width of the proposed antenna. The proposed antenna in this paper is suitable for the missile telemetry system, and is very convenient to be applied to practical engineering. In this paper, the stricture of the proposed antenna and the simulated and measured results are discussed in detail. The measured results show that the proposed antenna meets the requirements of missile telemetry system in VSWR, the co-polarisation and cross-polarisation 3 dB beam widths and gain. Thus, the proposed antenna has a good wider beam radiation performance, which is high enough to be applied to missile telemetry system. For some specific engineering project, this paper designed a missile antenna system. In order to meet the requirements of the missile telemetry system, the printed antenna with wide beam was designed. Both the measurement and simulation results meet the requirements of the missile telemetry system.

ACKNOWLEDGMENT

This work is sponsored by the National Natural Science Foundation of China (Grant No. 61571154), the Science Foundation of Aeronautics of China (Grant No. 20160177005).

REFERENCES

[1] K. R. Carver and J. W. Mink, “Microstrip antenna technology” *IEEE Transactions on Antennas & Propagation* [J], AP-29, pp. 2-24, 1981.

[2] R. J. Mailloux, et al, “Microstrip array technology,” *IEEE Transactions on Antennas & Propagation*, AP-29, pp. 25-37, 1981.

[3] G. Kumar and K. P. Ray, *Broadband Microstrip Antennas*. Artech House, Boston, MA and London, pp. 18-23, 2003.

[4] A. G. Derneryd, “Microstrip disc antenna covers multiple frequency,” *Microware Technology [J]*, pp. 77-79, 1978.

[5] K. P. Ray, “Broadband, dual-frequency and compact microstrip antennas,” *Ph.D. Thesis*, Indian Institute of Technology, Bombay, India, 1999.

[6] Z. N. Chen, et al., “Planar antennas,” *IEEE Antennas and Propagation Magazine*, vol. 7, no. 6, pp. 63-73, 2006.

[7] H. D. He, “A novel wide beam circular polarization antenna microstrip-dielectric antenna,” *Telecommunication Engineering [J]*, pp. 381-384, 2003.

[8] S. Chattopadhyay, J. Y. Siddiqui, and D. Guha, “Rectangular microstrip patch on a composite dielectric substrate for high-gain wide-beam radiation patterns,” *IEEE Transactions on Antennas & Propagation [J]*, vol. 57, no. 10, pp. 3325-3328, 2009.

[9] C. W. Su, S. K. Huang, and C. H. Lee, “CP microstrip antenna with wide beam width for GPS band application,” *Electronics Letters [J]*, vol. 43, no. 20, pp. 1062-1063, 2007.

[10] C. L. Tang, J. Y. Chiou, and K. L. Wong, “Beamwidth enhancement of a circularly polarized microstrip antenna mounted on a three-dimensional ground structure,” *Microwave & Optical Technology Letters [J]*, vol. 32, no. 32, pp. 149-153, 2002.

[11] C. Wu, L. Han, F. Yang, et al., “Broad beam width circular polarization antenna: Microstrip monopole antenna,” *Electronics Letters [J]*, vol. 48, no. 19, pp. 1162-1163, 2012.

[12] L. Shi and J. Li, “A compact broadband circularly polarized composite antenna with wide beam width,” *Microwave & Optical Technology Letters [J]*, vol. 50, no. 11, pp. 2973-2975, 2008.

[13] Z. K. Pan, W. X. Lin, and Q. X. Chu, “Compact wide-beam circularly-polarized microstrip antenna with a parasitic ring for CNSS application,” *IEEE Transactions on Antennas and Propagation [J]*, vol. 62, no. 5, pp. 2847-2850, 2014.

[14] M. J. Li and K. M. Luk, “Wideband magneto-electric dipole antennas with dual polarization and circular polarization,” *IEEE Antennas and Propagation Magazine [J]*, vol. 57, no. 1, pp. 110-119, 2015.

[15] S. X. Ta and I. Park, “Crossed dipole loaded with

magneto-electric dipole for wideband and wide-beam circularly polarized radiation," *IEEE Antennas and Wireless Propagation Letters [J]*, vol. 14, pp. 358-361, 2015.

[16] Y. F. Wei, B. H. Sun, C. Shi, et al., "Method for broadening the beamwidths of crossed dipole for wideband marine GPS applications," *Progress in Electromagnetics Research Letters [J]*, vol. 12, pp. 31-40, 2009.

[17] Y. Luo, Q. X. Chu, and L. Zhu, "A low-profile wide-beam-width circularly-polarized antenna via two Pairs of parallel dipoles in a square contour," *IEEE Transactions on Antennas & Propagation [J]*, vol. 63, no. 3, pp. 931-936, 2015.

Lizhong Song was born in 1975. He received master degree and Ph.D. degree from Harbin Institute of Technology in 2001 and 2005, respectively. He is a Professor and Doctoral Supervisor of Harbin Institute of Technology. He focuses his academic interests on antenna design, wireless electromagnetic wave propagation, microwave technology and radar signal processing.

Xiuwen Tian received the B.E. degree in Electronic and Information Engineering from Harbin University of Science and Technology, China, in 2017. Currently, he is a master student in the College of Information Science and Engineering at Harbin Institute of Technology, China. His research interests include antenna design and microwave technology.