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Optimized Design of Helical Antenna with Parasitic Patch for L-band Satellite Communications

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Abstract—A new small, low-profile and light-weight helical antenna element was designed for L-band satellite communications. The novelty of the antenna is that its input impedance matching has been improved by adjusting the copper strip matching stub, while its circular polarization performance has been enhanced by changing the parasitic radiation patch loaded in the front of the antenna. The optimal antenna structure for INMARSAT application has been fabricated and measured. The proposed antenna can produce a gain of higher than 9 dB, a 3-dB axial ratio bandwidth of nearly 15%, and a $|S_{11}| < -15$ dB impedance bandwidth of nearly 19%. A good agreement between measurements and simulations is obtained. The proposed antenna is compact in size and easy to tune. It provides a promising antenna element for antenna array applications.

1. INTRODUCTION

Satellite communications are a natural outgrowth of modern technology and of the continuing demand for greater capacity and higher quality in communications [1]. Broadband satellite systems have long been in focus, but primarily at the Ku or Ka band. A new broadband satellite communication system called Broadband Global Area Network (BGAN) can complete the global coverage at the L-band. The BGAN is a communications system created to transmit broadband wireless voice, video and data communications almost anywhere on the earth's surface [2]. The system, developed by the International Maritime Satellite Organization (INMARSAT), consists of a constellation of geostationary satellites working in conjunction with portable, lightweight, surface-based terminals about the size of a laptop or so. The main motivation for our work was to obtain a wide-band and compact antenna to meet the demand for small satellite terminals.

Antennas with circular polarization radiation have found wide applications in satellite communications due to their insensitivity to the ionospheric polarization rotation. Axial-mode helical antennas [3, 4] which can provide circular polarization over a wide bandwidth without the need for a polarizer, have been known for a long time. In the past, the axial-mode helical antennas continued to appear in new designs and research papers. For example, a new set of data related to the optimum design of traditional helical antennas had been presented in [5], including the maximum gain, the axial ratio, the operating bandwidth, and the input impedance. In order to increase the axial ratio bandwidth of the antenna, elliptical helical antenna using parasitic helix was presented in [6]. In [7], an elliptical helical antenna with a variable pitch angle was presented in the pursuit of improved circular polarization as well as its directivity. But the antenna structure is large or complex in [6, 7]. In [8], Professor Nakano et al. calculated the helical arm length current distribution and introduced an extremely low-profile cylindrical helical antenna by the combination of low pitch and a small number of turns. In order to widen the angle coverage of the circular polarization radiation, a cavity wall was used in [9]. In [10], a robust and low-profile hemispherical helical antenna was studied which produces very pure circular polarization radiation over a broader angular range. But it doesn't mention impedance matching method

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in [8–10]. In [11], a conical helical antenna with high gain and low side-lobe level was presented and microstrip impedance transformer was used for the matching network design and optimization. And the impedance matching by modifying the helical arm near the feed point was also presented in [12].

In order to reduce the size and processing complexity and improve the performance of the antenna, a new small, low-profile and light-weight helical antenna element with matching stub and parasitic radiation patch has been proposed in this paper. The design goal is to obtain an antenna that has the best performance and minimum overall size. In addition, a parametric study of the proposed antenna is presented to provide the engineers with information for designing, modifying, and optimizing such an antenna. The optimal antenna structure has been implemented for L-band INMARSAT application, and the simulated results are validated by experimental data.

2. ANTENNA CONFIGURATION

The proposed antenna was composed of the cylindrical helix strip, the parasitic patch, the matching stub, the supported foam, and the ground plate. Sketch of the proposed antenna structure is shown in Fig. 1. The helix strip was made of copper foil wound on polyfoam (dielectric constant of 1.05) mounted on a copper ground plate. The diameter of the ground plate is 160 mm. Geometrical parameters of the helix strip are chosen as follows: radius of the helix strip $R_{helix} = 32\,\text{mm}$, width of the helix strip $W = 6\,\text{mm}$, pitch angle $\alpha = 5^\circ$, helical turns $N = 2.75$. A thin metal strip as a matching stub was supported by expanded polystyrene foam (dielectric constant of 1.3) of $R_{sub} = 45\,\text{mm}$ connecting the beginning of the helix proper as suggested in Fig. 1. The short vertical feed wire which penetrates the ground plate through a hole was connected to the matching stub of length $L_a = 32\,\text{mm}$ and width $L_b = 8\,\text{mm}$, and the height of the feed wire above the ground plane was $H_{sub} = 5\,\text{mm}$. In order to achieve much wider circular polarization bandwidth, a parasitic patch was introduced into the design of the helical antenna. The radius of the parasitic patch is at $R_{hat} = 32\,\text{mm}$ and the distance between the parasitic patch and the ground plate is at $H = 65\,\text{mm}$.

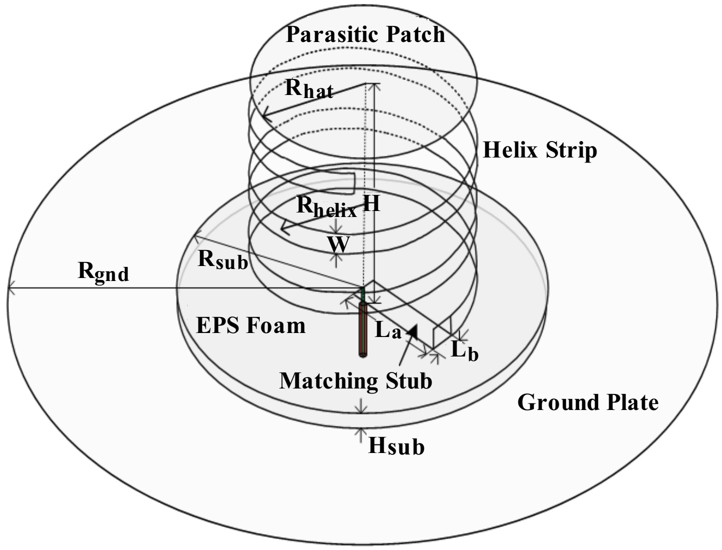

Figure 1. Antenna model configuration.

3. EXPERIMENTAL RESULTS

A prototype of the antenna has been fabricated and is shown in Fig. 2. The commercial simulation tool HFSS has been used in this study. After extensive simulations, it is found that the antenna input impedance can be easily adjusted to 50 Ohms by changing the matching stub as described in Fig. 1. The real part of the antenna impedance can be easily controlled by mainly changing the matching stub

Figure 2. The fabricated antenna prototype.

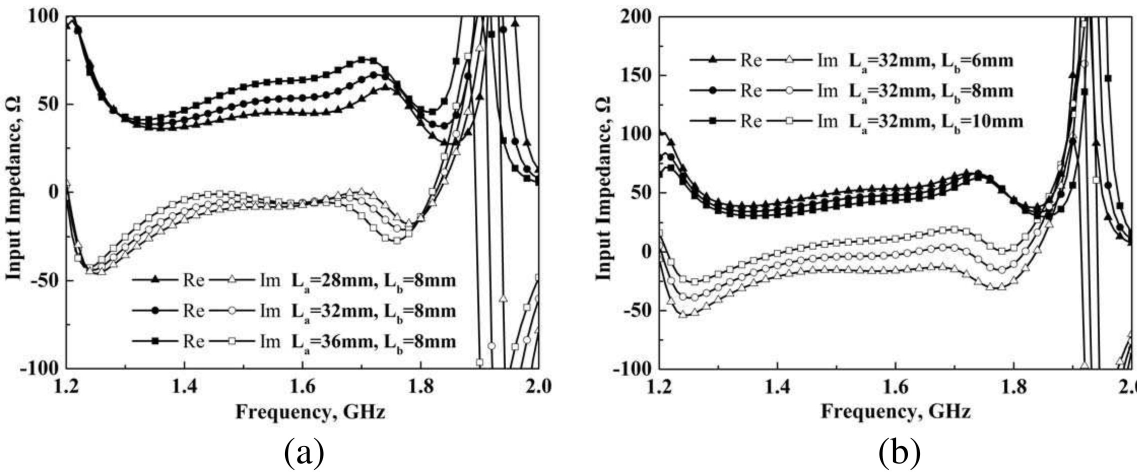

Figure 3. Input impedance as a function of the matching stub length and width. (a) Changing matching stub length L_a. (b) Changing matching stub width L_b.

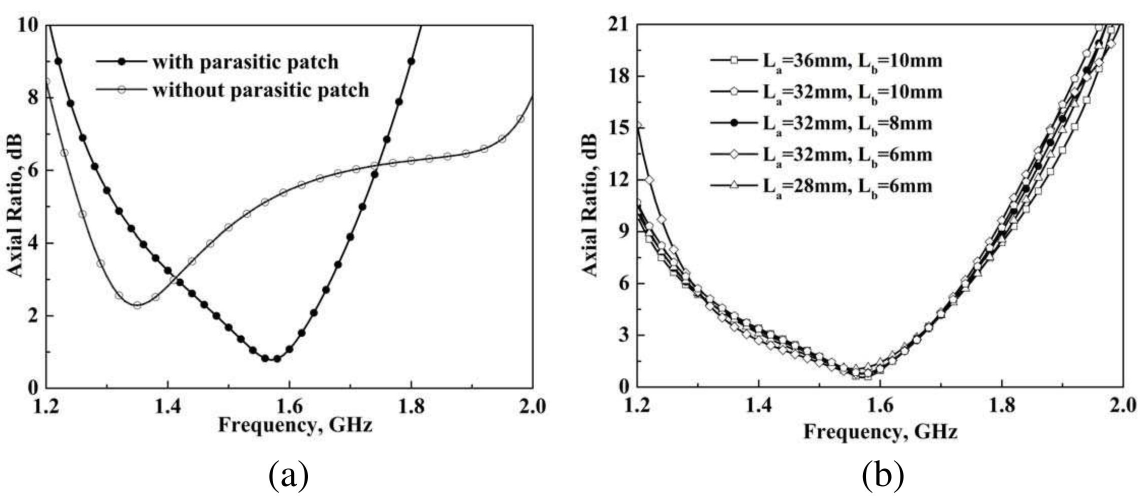

Figure 4. Simulated CP radiation axial ratio of the antenna. (a) Axial ratio variation with or without parasitic patch. (b) Axial ratio variation with different matching stub size.

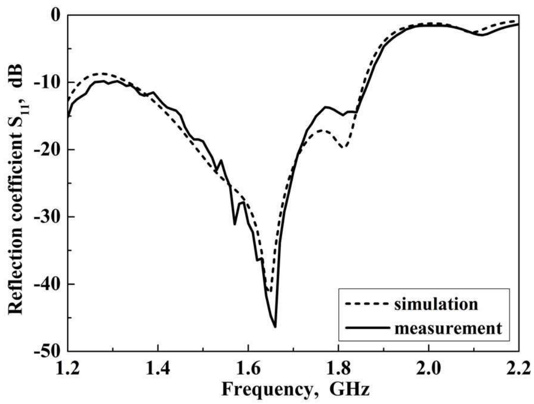

Figure 5. Measured and simulated reflection coefficients.

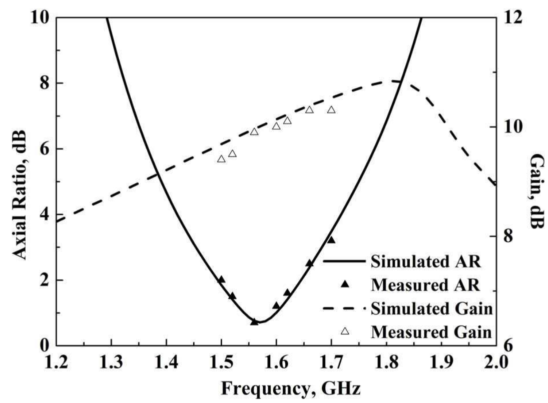

Figure 6. Simulated and measured axial ratio and gain.

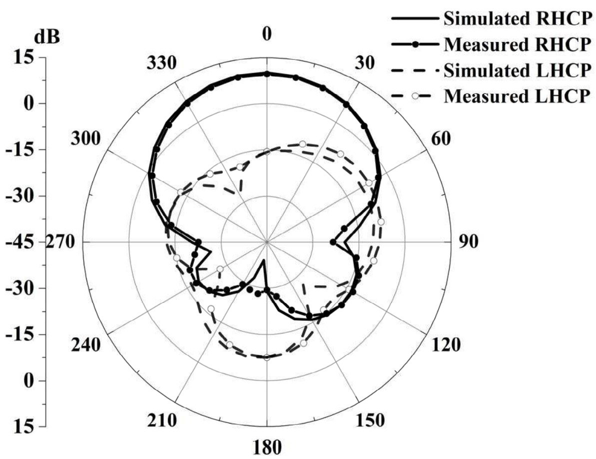

Figure 7. Simulated and measured radiation patterns at the center frequency 1.593 GHz.

length L_a, while the imaginary part of the antenna impedance can be adjusted by mainly changing the matching stub width L_b, which can be seen in Fig. 3. And also the loading of the parasitic patch can effectively improve antenna circular polarization (CP) radiation performance, as can be seen in Fig. 4. The axial ratio of the antenna without the parasitic patch is poor due to the low antenna height and few helical turns. Meanwhile, the CP characteristic is also not so sensitive to the changing of the matching stub size. It indicates that once the CP band is optimized, we can change the matching stub to adapt the impedance band with CP band. This feature can facilitate the tuning of the antenna.

The experimental and simulated reflection characteristics of the antenna measured using Agilent N5230A vector network analyzer and Ansys HFSS respectively are shown in Fig. 5. It can be seen that the measured results are found to reasonably agree with the simulated data. A good measured input impedance match characteristics of $|S_{11}| < -15\,\text{dB}$ in the range of $1.45 \sim 1.75\,\text{GHz}$ is obtained. There exists a little frequency offset between the measurements and simulations due to the assembly error.

Figure 6 shows the simulated and measured axial ratio and the power gain in the bore-sight direction. As can be seen from the figure, the simulated 3-dB axial ratio bandwidth is found to be nearly 15% and the lowest axial ratio is found to be 0.7 dB at 1580 MHz. The measured results show that a very stable power gain of about higher than 9 dB and axial ratio lower than 3 dB are found within the whole maritime satellite communication working band. The radiation patterns of both right-hand circularly-polarized (RHCP) and left-hand circularly-polarized (LHCP) at the center frequency are shown in Fig. 7. The measured patterns are in good agreement with the computed ones. The discrepancy between them can be mainly attributed to fabrication and measurement errors.

4. CONCLUSION

A new improved helical antenna design for INMARSAT application has been presented. The impedance matching and circular polarization properties have been substantially improved by introducing the copper strip matching stub and the parasitic radiation patch. The remarkable feature of the antenna is that it is very easy to design and tune with limited antenna height. Firstly, the circular polarization radiation performance of the antenna can be optimized by changing the parasitic radiation patch, and then the impedance bandwidth can be tuned to coincide with the axial ratio bandwidth by changing the copper strip matching stub. Good antenna characteristics are achieved in the entire INMARSAT working band. The antenna has the characteristics of light weight, low profile and easy tuning. These characteristics make this antenna especially suitable for small-size and high-gain antenna or antenna array design for L-band satellite communications.

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REFERENCES

1. Ilcev, S. D., *Global Mobile Satellite Communications: For Maritime, Land and Aeronautical Applications*, Springer, Berlin, 2005.
2. Wang, J.-L. and C.-S. Liu, "Development and application of INMARSAT satellite communication system," *Proceedings of International Conference on Instrumentation, Measurement, Computer, Communication and Control*, 619–621, Beijing, China, 2011.
3. Kraus, J. D., "Helical beam antennas," *Electronics*, Vol. 20, 109–111, 1947.
4. Nakano, H., Y. Samasa, and J. Yamauchi, "Axial mode helical antennas," *IEEE Transactions on Antennas and Propagation*, Vol. 34, No. 9, 489–509, 1986.
5. Djordfevic, A. R., A. G. Zajic, M. M. Llic, and G. L. Stuber, "Optimization of helical antennas," *IEEE Antennas and Propagation Magazine*, Vol. 48, 107–115, 2006.
6. Wu, Z.-H., W.-Q. Che, B. Fu, P.-Y. Lau, and E. K. N. Yung, "Axial mode elliptical helical antenna with parasitic wire for CP bandwidth enhancement," *IET Microw. Antennas Propag.*, Vol. 1, No. 4, 943–94, 2007.
7. Yang, F., P. Zhang, C.-J. Guo, and J.-D. Xu, "Axial mode elliptical helical antenna with variable pitch angle," *Electronics Letters*, Vol. 44, No. 9, 1103–1104, 2008.
8. Nakano, H., H. Takeda, T. Honma, H. Mimaki, and J. Yamauchi, "Extremely low-profile helix radiating a circularly polarized wave," *IEEE Transactions on Antennas and Propagation*, Vol. 39, No. 6, 754–757, 1991.
9. Nakano, H. and H. Mimaki, "Radiation from a short helical antenna backed by a cavity," *Electronics Letters*, Vol. 31, No. 8, 602–604, 1995.
10. Hui, H. T., K. Y. Chan, and E. K. N. Yung, "The low-profile hemispherical helical antenna with circular polarization radiation over a wide angular range," *IEEE Transactions on Antennas and Propagation*, Vol. 51, No. 6, 1415–1418, 2003.
11. Gharibi, H. and F. Hojjat-Kashani, "Design of a wideband monopulse antenna using four conical helix antennas," *Progress In Electromagnetics Research Letters*, Vol. 29, 25–33, 2012.
12. Nakano, H., K. Sato, H. Mimaki, and J. Yamauchi, "A long helical antenna wound on a dielectric rod," *Proceedings of ISAP*, POS-A-27, 965–968, 2004.