Progress In Electromagnetics Research, PIER 78, 321–328, 2008

MINIATURIZED CIRCULARLY-POLARIZED ANTENNA USING TAPERED MEANDER-LINE STRUCTURE

J.-F. Li, B.-H. Sun, H.-J. Zhou, and Q.-Z. Liu

National Key Laboratory of Antennas and Microwave Technology
Xidian University
Xi'an, Shaanxi, China

Abstract—A novel miniaturized circularly-polarized antenna is presented. By using tapered meander-line structure, the designed antenna has a size reduction rate of 96% compared with a traditional turnstile dipole antenna. The unequal lengths of the two meander-line dipoles are properly adjusted to achieve a circularly polarized radiation. Furthermore, the impedance matching is effectively realized by a lumped matching network. A prototype of the antenna with a size of $64 \times 64\,\mathrm{mm}^2$ has been implemented and tested. Good agreement is achieved between the simulated results and the measured results, which shows that the axial ratio is less than 3.0 dB and the VSWR less than 2.0:1 in the frequency range of 450 ± 1.5 MHz.

1. INTRODUCTION

Satellite communication has become one of the most important communication techniques with the rapid developing of the modern space technology. Portable terminals for satellite application are the current tendency [1, 2]. A suitable antenna for the portable terminals should be low cost, low profile, light weight and especially small size, whereas the bandwidth requirement is less critical. Traditional receiving antennas for satellite communication are turnstile dipole antenna (TDA) and microstrip antenna [1, 2]. Turnstile dipole antenna is commonly used for its simple structure and easy fabrication. However, when we design an antenna operating at the frequency of 450 MHz using a traditional TDA, the size of the antenna, according to the reference [1], is about $333 \times 333\,\mathrm{mm}^2$ $(0.5\lambda \times 0.5\lambda)$. It is difficult to be integrated into a portable device. For microstrip antennas, some techniques, such as making slots or using high dielectric constant substrates, can be used to reduce the antenna size [3]. In [3], more than 50% size reduction rate can be achieved, but it still cannot satisfy the system requirement (in our design, the size reduction rate is 96%). To realize such a miniaturization, high dielectric constant substrates ($\varepsilon_r = 38$, for example) has to be used. However, it results in the narrow bandwidths for its high Q factor and the low radiation efficiency [4].

TDA is commonly used in the satellite communication. In order to have a circularly-polarized wave, the two orthogonal dipoles must be fed with equal amplitudes and quadrature phase. There are two approaches to achieve the circular polarization [1]. One is using a quadrature hybrid equal-amplitude power divider. Another one is using unequal length of the two diploes which does not require an external polarizer. The former will enlarge the antenna's volume and weight, and the cost is also increased. So we choose the latter one.

In this paper, we present a miniaturized circularly-polarized antenna, which is a tapered meander-line turnstile dipole antenna. By using the tapered meander-line structure, the antenna has a size reduction rate of 96% compared with a traditional turnstile dipole antenna.

2. ANTENNA DESIGN

The configuration of proposed tapered meander-line turnstile dipole antenna is shown in Fig. 1(a). In this paper, the designed antenna is constructed on a substrate, with a relative permittivity of ε_r and thickness of h. The size of the substrate is $L \times W$. The substrate is only used as a supporter here, so it is not restrictive to select the thickness and relative permittivity of the substrate. In our design, we chose $\varepsilon_r = 2.65$ and $h = 1\,\text{mm}$. The printed planar antenna consists of two coplanar meander-line bow-tie dipoles placed alone the x- and y-axes. As illustrated in the Fig. 1(a), the angle of the bow-tie is α. The meander shape has been tuned to resonate at the frequency of 450 MHz. The width of the line and the interval between the lines are w and s, respectively. By properly adjusting the angle of the bow-tie (α) and the lengths of the two diploes, the circular polarization is achieved at the desired resonant frequency. The antenna is feed by a 50 Ω coaxial line through a matching network as shown in Fig. 1(b).

The length of the dipoles alone the x- and y-axes are L_x and L_y, respectively. As illustrated in [1], when we shorten a dipole below resonance, its impedance is capacitive and its current has positive phase relative to the resonant-length dipole, while the lengthened dipole has an inductive reactance and a negatively phased current. For traditional TDA, the lengths of the two dipoles are determined

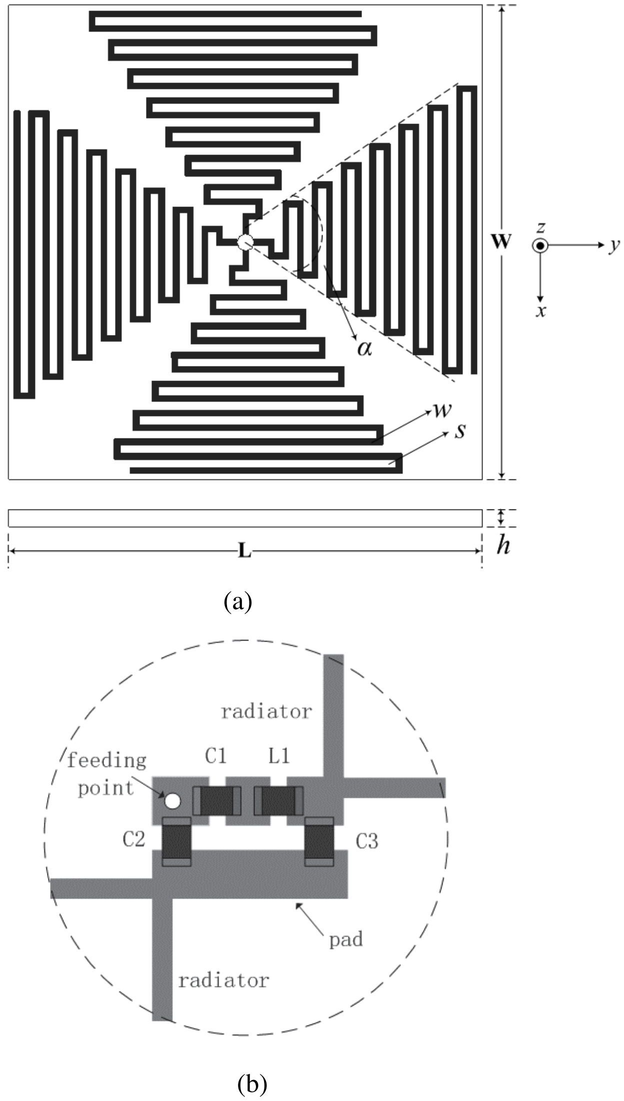

Figure 1. Geometry of the proposed antenna and the matching network. (a) Geometry of the proposed antenna and a coordinate system. Dimensions: $w = 0.8\,\text{mm}$, $s = 1.2\,\text{mm}$, $h = 1\,\text{mm}$, $\alpha = 80°$ substrate size $(W \times L) = 64 \times 64\,\text{mm}^2$ (b) Matching network at the center of the proposed antenna.

by a perturbation technique using the Q of the resonant circuit of the dipole. Q is related to the VSWR bandwidth:

$$BW = \frac{VSWR - 1}{Q\sqrt{VSWR}} \quad Q = \frac{VSWR - 1}{BW\sqrt{VSWR}} \tag{1}$$

The lengths of the two dipoles are derived in terms of the resonant length dipole, L_0.

$$L_x = \frac{L_0}{1 + 1/Q} \quad L_y = L_0\sqrt{1 + \frac{1}{Q}} \quad \text{(RHCP)} \tag{2}$$

The length of the traditional TDA L_0 at the resonant frequency of 450 MHz is about 333 mm which is too large to meet the requirements of the mobile satellite terminals in our design (the antenna size should be less than 64 mm). The tapered meander-line bow-tie structure can significantly miniaturize the antenna size [5–8]. By properly choosing of α and adjusting the length of the two dipoles, circular polarized radiation in the operation frequency band is obtained. In addition, the tapered structure leads to a wide impedance bandwidth [8–17]. Similar to the results in [8], the proposed tapered meander-line bow-tie structure has large input resistance than other bent antennas such as the general meander, the zigzag, and the sinusoidal, which make it easy to match.

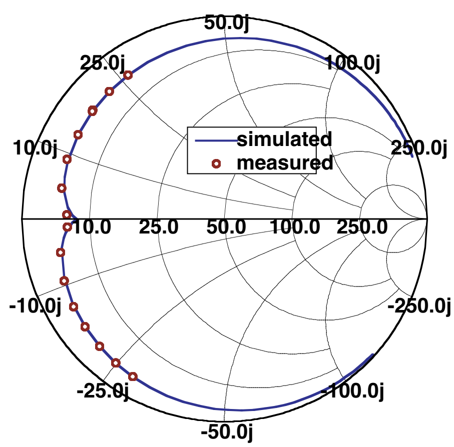

Figure 2. Measured and simulated input impedance for the antenna.

3. SIMULATED AND EXPERIMENTAL RESULTS

A prototype of the proposed tapered meander-line antenna with the optimal geometrical parameters as shown in Fig. 1(a) was constructed and measured. The proposed antenna is simulated and optimized using the MoM-based software IE3D and the measured results obtained with a HP 8753D network analyzer.

The impedance behavior of the proposed antenna is plotted in Fig. 2. From the results, it is clearly seen that the input impedance $Z_{in} = R_{in} + jX_{in}$ at the feed point is only about $7\,\Omega$ at the center frequency. Hence, the antenna radiation efficiency becomes very low. This is because of various losses, such as return loss,copper loss and ground effects. For an electrically small antenna, the impedance matching technique is necessary to reduce the return loss.

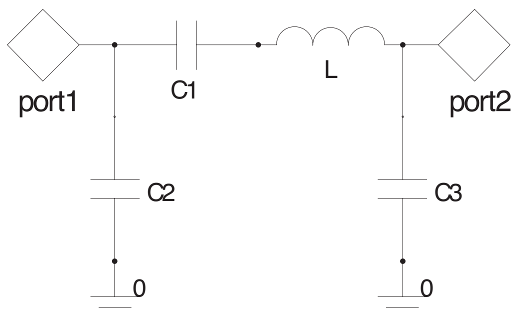

Figure 3. Matching network. Values: C1 = 32.8 pf, C2 = 6.9 pf, C3 = 18.1 pf, L = 10.0 nh.

In this paper, we select a π-type matching network . The schematic of the matching network is given in Fig. 3. The values of the lumped elements are optimized by the particle swarm optimization (PSO) [18]. The PSO is a global and stochastic optimization method, which has been widely used in electromagnetics. The optimized values of the lumped elements are also illustrated in Fig. 3. The actual matching network in our design is implemented using the TDK 0402 series chip capacitors and inductors. Both of the VSWRs of the antenna with and without the matching network are shown in Fig. 4. Experimental results show that the VSWR of the antenna with the matching circuit is less than 1.2:1 in the frequency bands 450 ± 2 MHz. By comparison, the VSWR of the antenna without the matching network is larger than 6.0:1, which shows that the VSWR is significantly improved.

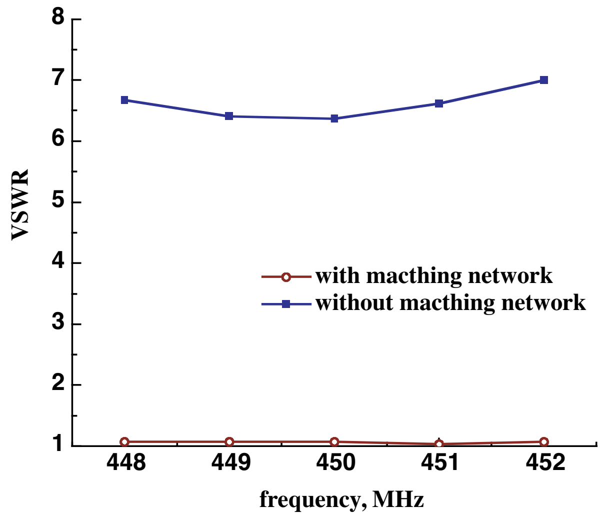

Figure 4. Measured VSWR with and without matching network.

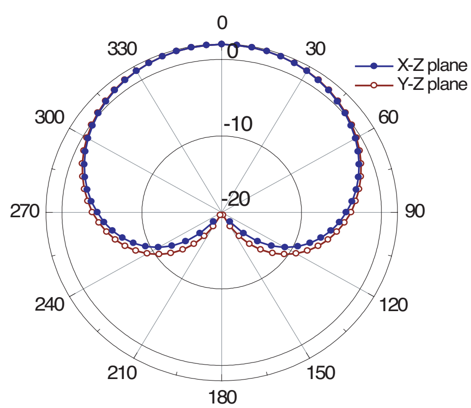

Figure 5. Measured far-field radiation patterns for the antenna.

The far-field radiation patterns in the two principal planes (X-Z plane and Y-Z plane) measured at the center frequency are plotted in Fig. 5. The 3 dB beamwidths of the antenna in both principal planes are about 130 degrees. In Fig. 6, the axial ratio in the broadside direction is presented. From this figure, we can see that good circularly-polarized radiation is obtained within the 3 dB axial ratio bandwidth. The antenna directivity is stable and large than 1 dB in the operation frequency band.

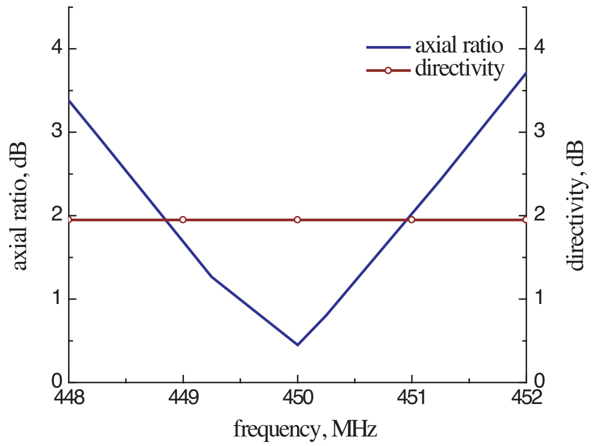

Figure 6. Measured axial ratio and directivity of the antenna.

4. CONCLUSION

In this paper, a novel miniature circularly polarized printed planar antenna is presented, which addresses the requirements for satellite communication applications. This meander-line bow-tie turnstile dipoles structure significantly reduces the overall dimensions of general turnstile dipole antenna by 96%. The VSWR is improved by the impedance matching technology. Good circular polarization is achieved by adjusting the unequal lengthens of the dipoles. Due to its compact size and easy fabrication, the antenna has widely and potential applications for the satellite communication systems.

REFERENCES

1. Milligan, T. A., *Modern Antenna Design*, 2nd edition, John Wiley & Sons, Inc., Hoboken, New Jersey, 2005.
2. Fujimoto, K. and J. R. James, *Mobile Antenna Systems Handbook*, 2nd edition, Artech House, Norwood, MA, 2001.
3. Wong, K. L., *Compact and Broadband Microstrip Antennas*, John Wiley & Sons, Inc., New York, 2002.
4. Bahl, I. J., P. Bhartia, A. Ittipiboon, and R. Garg, *Microstrip Antenna Design Handbook*, Artech House, 2001.
5. Wang, Y. J., C. K. Lee, and K. W. Jin, "On reducing the overall dimensions of a circular printed antenna," *Antennas and*

Propagation, Eleventh International Conference on (IEE Conf. Publ. No. 480), Vol. 1, 57–60, 2001.

6. Michishita, N. and Y. Yamada, "High efficiency achievement by material loading for a piled type small meander line antenna," *Antennas and Propagation Society International Symposium*, Vol. 1B, 492–495, 2005.
7. Wheeler, H. A., "Small antennas," *IEEE Transactions on Antennas and Propagation*, Vol. 23, No. 4, 462–469, 1975.
8. Ali, M. and S. S. Stuchly, "A meander-line bow-tie antenna," *Antennas and Propagation Society International Symposium, Digest*, Vol. 3, 1566–1569, 1996.
9. Shams, K. M. Z., M. Ali, and H. S. Hwang, "A planar inductively coupled bow-tie slot antenna for WLAN application," *Journal of Electromagnetic Waves and Applications*, Vol. 20, 861–871, 2006.
10. Chen, X. and K. Huang, "Wideband properties of fractal bowtie dipoles," *Journal of Electromagnetic Waves and Applications*, Vol. 20, No. 11, 1511–1518, 2006.
11. Gao, S. and A. Sambell, "A simple broadband printed antenna," *Progress In Electromagnetics Research*, PIER 60, 119–130, 2006.
12. Zhou, H. J., Q. Z. Liu, J. F. Li, and J. L. Guo, "A swallow-tailed wideband planar monopole antenna with semi-elliptical base," *Journal of Electromagnetic Waves and Applications*, Vol. 21, No. 9, 1257–1264, 2007.
13. Lin, Y. D. and S.-N. Tsai, "Coplanar waveguide-fed uniplanar bow-tie antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 45, No. 2, 305–306, 1997.
14. Soliman, E. A., S. Berbels, P. Delmotte, G. A. E. Vandenbosch, and E. Beyne, "Bow-tie slot antenna fed by CPW," *Electron Letters*, Vol. 35, 514–515, 1999.
15. Huang, J. F. and C.-W. Kuo, "CPW-fed bow-tie slot antenna," *Microwave Optical Technology Letters*, Vol. 19, No. 5, 358–360, 1998.
16. Miao, M., B. L. Ooi, and P. S. Kooi, "Broadband CPW-fed wide slot antenna," *Microwave Optical Technology Letters*, Vol. 25, No. 3, 206–211, 2000.
17. Qu, S. and C. Ruan, "Effect of round corners on bowtie antennas," *Progress In Electromagnetics Research*, PIER 57, 179–195, 2006.
18. Kennedy, J. and R. C. Eberhart, "Particle swarm optimization," *Proc. IEEE Int. Conf. Neural Networks IV*, 1942–1948, 1995.