Two Miniaturized Printed Dual-Band Spiral Antenna Designs for Satellite Communication Systems

Mohammed S. Binmelha, Chan H. See, Raed A. Abd-Alhameed,
M.S. Alkambashi Alkambashi, D. Zhou, Steve M.R. Jones, and P.S. Excell

Mobile Satellite Communications Research Centre, University of Bradford, Richmond Road, Bradford, West Yorkshire, BD7 1DP, UK
{ M.S.Bin-melha.chsee2.raaabd}@bradford.ac.uk

Abstract. Two novel reduced-size, printed spiral antennas are proposed for use in personal communications mobile terminals exploiting the ‘‘big low earth orbit’’ (Big-LEO) satellite system (uplink 1.61–1.63 GHz; downlink 2.48–2.5 GHz). The two proposed antenna give 3.12—6.25% bandwidth at lower resonant mode of 1600MHz, while at the higher resonant mode of 2450MHz a bandwidth of around 6% is obtained. The experimental and simulated return losses of the proposed antennas show good agreement. The computed and measured gains, and axial ratios are presented, showing that the performance of the proposed two antennas meets typical specifications for the intended applications.

Keywords: printed spiral antennas, bandwidth, return losses, axial ratios.

1 Introduction

Personal satellite communications systems provide global coverage, especially where there are no nearby terrestrial base stations [1,2]. The majority of systems currently in operation use the ‘big low earth orbit’ (Big-LEO) satellite system, such as ‘Globalstar’, which was chosen as a system for detailed study [1]. Handsets of this system require broad-beam radiation patterns with low-cross-polarization, circularly-polarized antennas to get acceptable link margins. These terminals use an uplink band at 1.61-1.6214GHz (L-band) and downlink band at 2.4835-2.5GHz (ISM/S-band).

Satellite mobile communications systems have been available for some years. The systems have experienced some commercial problems, particularly due to the unexpectedly rapid growth of terrestrial systems, but they still have a place in the overall range of wireless communication systems.

The size and appearance of the satellite handset quadrifilar helix antennas and their radomes presents a problem of image and convenience for a public used to the low-profile antennas of terrestrial systems [3-6], whilst the design must achieve specific antenna requirements appropriate for satellite communications.

Reducing the size of the antenna is not easy, since it requires us to have more directive gain than the lowest order (dipole) mode. This causes difficulties if its size is

P. Pillai, R. Shorey, and E. Ferro (Eds.): PSATS 2012, LNICST 52, pp. 81–86, 2013.

required to be less than about a half wavelength at the operating frequency, due to what is effectively a ‘law of physics’ for small antennas, the so-called Wheeler limit [7]. Some success in reducing the size of antennas has been achieved by coiling the wire elements, first into helices and later into spirals [8-13]. Understanding of traditional circular spirals is well advanced, but square designs are likely to fit more conveniently into practical products [8, 9].

Spiral antennas are particularly known for their ability to produce very wide band, almost perfectly circularly-polarized radiation over their full coverage region. As a result of this polarization characteristic and the ability to produce a broad zenith-directed pattern, spiral antennas are popular for use in satellite mobile communication handsets.

In this paper, the achieveable size of the Quadrifilar Square Spiral Antenna (QSSA) discussed in [8- 10] was significantly reduced by a new design of Dual-Arm Square Spiral Antenna (DASSA) on a thin dielectric substrate. This made the new antenna of a size that would be easily mountable on the top of a handheld terminal for use with a low-earth-orbit (LEO) personal satellite communications network. The present program of work has thus initiated a study of a square version of the dual spiral antenna (DASSA) that should satisfy the following design requirements: (i) hemispherical radiation pattern with elevation coverage from the zenith to a nominal minimum elevation angle (typically 10°and 20°); (ii)circular polarization with an axial ratio better than 5dB within the coverage angle; (iii)operational bandwidth to be covered with one antenna operating by itself, either with a single wide bandwidth or, with the assistance of a simple matching circuit, over the two sub-bands of interest; (iv) the size to be minimized by implementing the DASSA over dielectric substrates of high relative permittivity.

The new compact antenna design for handheld satellite mobile communication is investigated and discussed at L band (1.61-1.6214GHz), ISM S-band (2.4835-2.5GHz) and dual L-S bands. Two different antenna types are presented using two-arm spirals connected at the centre by a small rectangular patch and fed via a stripline from each end. Various stripline widths are studied. The inputs return loss and field patterns show quite reasonable results that satisfy the requirements of the communication strategy. The results in terms of the antenna size and radiation performance are addressed and compared to previous published data.

2 Antenna Design Concept and Geometry

The DASSA is an electrically small antenna providing circular polarization over a broad angular region. The antenna consists of two spirals equally spaced circumferentially (placed at 180° to each other) and fed by equal amplitude signals with 180°-phase difference between feeding sources. The DASSA can also be described as two orthogonal bifilar helix antennas fed in phase quadrature, (where a bifilar is a two-element helix antenna). The two spirals are fed at their ends, so that the feed lines in this case do not cause significant problems from the point of view of mutual coupling effects.

The desirable size for the DASSA will be that of the top of a typical personal handset; however, the initial design was made somewhat larger in order to prove the concept [8]: the work presented here uses a solid dielectric beneath the spirals to reduce the antenna size. All antennas were mounted on a thin dielectric substrate of $\varepsilon_r = 2.55$, tan $\delta = 0.0018$ and thickness of 1.524 mm. Fig.1 shows the geometry of the two proposed antennas for dual-band (L and ISM/S-band) operation. As can be seen, the two antenna sizes and the striplines width used for L and ISM/S bands are (16 × 12 mm^2 and 0.25mm) and (12.5 × 8.4mm^2 and 0.75mm) respectively. These two designs will give a variety of choices for antenna designer to further investigate the required antenna performance. Moreover, from the antenna sizes presented, the antennas can easily be mounted on top of a small area of the handset.

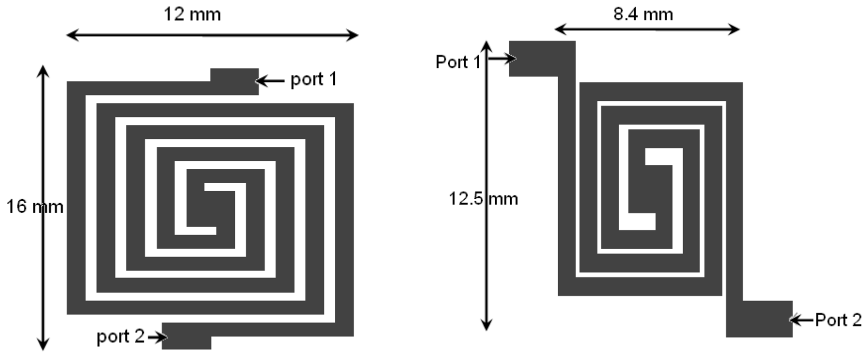

Fig. 1. The geometry of proposed dual-band printed antennas. (Left: Ant1 with stripline width 0.25 mm, Right: Ant2 with stripline width 0.75 mm.)

3 Results and Discussion

The simulated results of all antenna geometries shown in Fig. 1 were carried out using Agilent Advance Design System (ADS) — Momentum 2.5D EM solver [14]. To validate the simulated results, the practical prototypes of the antennas were constructed. Fig.2 and 3 illustrates the computed and experimental results of the two antennas. Two adjacent resonant frequencies in the range of return loss > 10 dB are observed, i.e., 1.61 and 2.485 MHz. 'Ant1' shows the measured impedance bandwidth of 6.25% at 1.6 GHz and 6% at 2.475 GHz whereas the 'Ant2' exhibits narrower bandwidth of 3.15% at 1.6 GHz and 6% at 2.525 GHz. These results confirm that the antennas completely satisfy the desired L frequency band (1.61-1.624 GHz) and ISM/S band (2.4835-2.5GHz) band respectively.

Fig.4 and 5 depicts the axial ratio of the proposed antennas for y-z plane ($\varphi = 90°$). As can be noticed, an axial ratio of less than 3dB over ±45°elevation angle for 'Ant1' whereas it is less than 4 dB over ±40°elevation angle for 'Ant2'. The measured gains for two proposed antenna are shown in Fig.6. The measured gains for both antennas varied between 1.25 and 2.25 dBi over the entire L band; and between 1.4 and 2.75 dBi over the ISM/S band. These results are quite promising and encouraging for practical deployment.

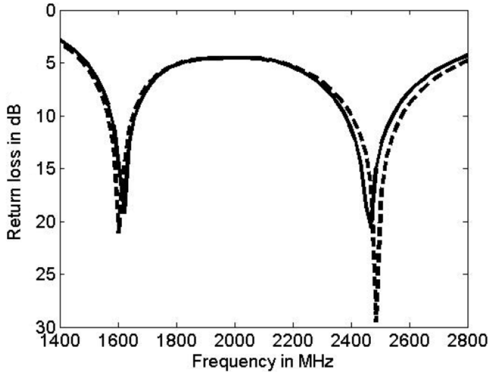

Fig. 2. Return loss of the proposed antenna (Ant1), where '———' simulated, --------- 'measured'

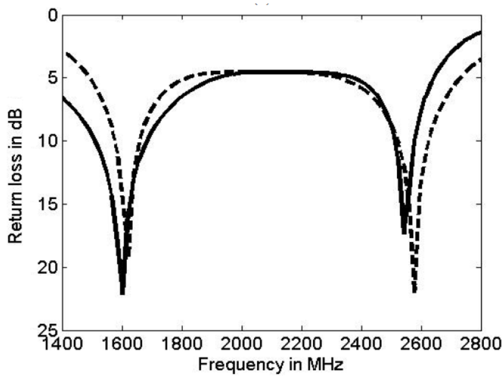

Fig. 3. Return loss of the proposed antenna (Ant2) , where '———' simulated, -------- 'measured'

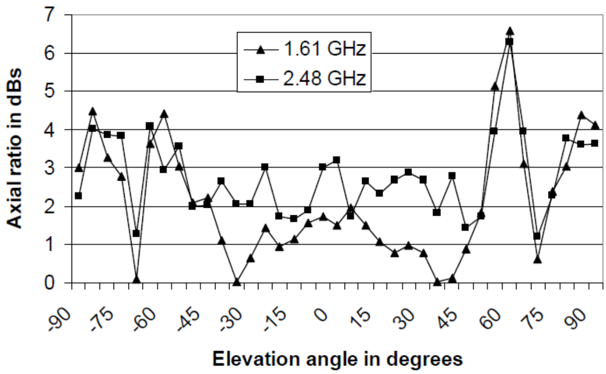

Fig. 4. Measured axial ratios for two operating frequencies versus elevation angle at φ = 90° for antenna (Ant1)

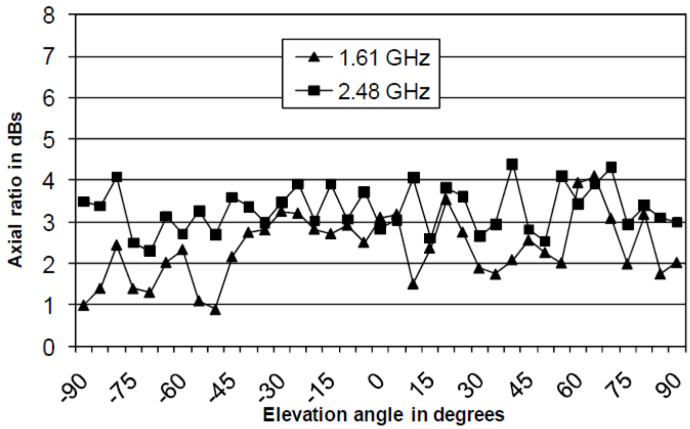

Fig. 5. Measured axial ratios for two operating frequencies versus elevation angle at φ = 90° for antenna (Ant2)

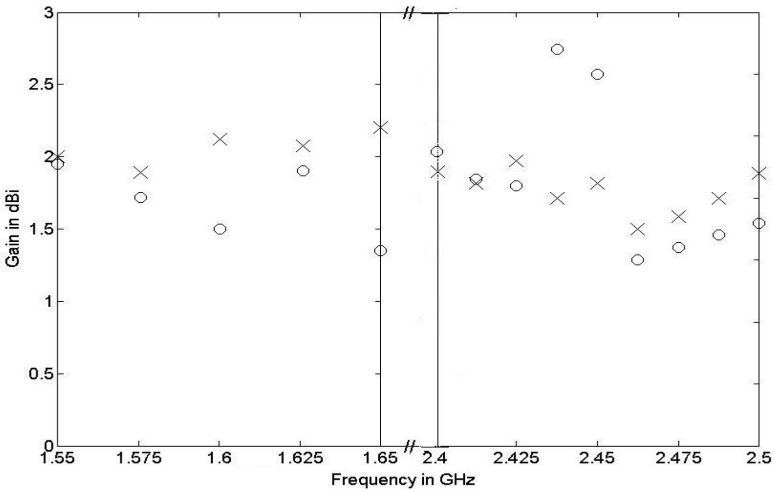

Fig. 6. Measured broadsight gains of the proposed dual-band antennas. (where xxxx is for Ant1 and ooo is for Ant2)

4 Conclusion

A new technique was discussed that reduced the antenna size for satellite-mobile handsets. Different stripline widths were introduced to achieve the frequency response and radiation performance required for Big LEO satellite mobile communications. Two different antenna geometries have been presented. The new designs were found to be very compact compared with four-square spirals on the same dielectric substrate described in previous studies. The larger antenna achieves a 6% impedance bandwidth in both bands, whilst the more compact design is limited to 3.15% in the lower band. The results in terms of the return loss are extremely promising and the field radiations are acceptable for both bands of interest, almost covering a ±45° range of elevation angles.

References

1. Dietrich, F.J., Metzen, P., Monte, P.: The globalstar cellular satellite system. IEEE Trans. Antennas and Propagation 46(6), 935–942 (1998)
2. Evans, J.V.: Satellite systems for personal communications. IEEE Antennas and Propagation Magazine 39(3), 7–20 (1997)
3. Daddish, S.M., Abd-Alhameed, R.A., Excell, P.S.: New Designs for Dual Band Antennas for Satellite-Mobile Communications Handsets. Applied Computational Electromagnetics Society Journal 15(3), 248–258 (2000)
4. Agius, A.A., Leach, S.M., Suvannapattana, P., Saunders, A.R.: Effects of the human head on the radiation pattern performance of the quadrifilar helix antenna. In: IEEE Int. Symp. On Antennas and Propagation, vol. 2, pp. 1114–1117 (1999)
5. Suvannapattana, P., Agius, A.A., Saunders, S.R.: Methods for minimizing quadrifilar helix antenna interactions with the human head. In: IEE Seminar on Electromagnetic Assessment and Antenna Design Relating to Health Implications of Mobile Phones, IEE Pub. No. 1999/043, pp. 11/1-11/4 (1999)
6. Ermutlu, M.E.: Modified quadrifilar helix antennas for mobile satellite communication. In: IEEE Conf. on Antennas and Propagation for Wireless Communications, pp. 141–144 (1999)
7. Wheeler, H.A.: Fundamental Limitations of Small Antennas. Proc. IRE 35, 1479–1484 (1947)
8. Khalil, K., Abd-Alhameed, R.A., Excell, P.S.: Dual–band quadrifilar square spiral antenna for satellite-mobile handsets. In: IEE International Conference on Antennas and Propagation, Exeter, vol. 1, pp. 186–189 (2003)
9. Zhou, D., Abd-Alhameed, R.A., See, C.H., Excell, P.S., Hu, Y.F., et al.: Quadrifilar Helical Antenna Design for Satellite-Mobile Handsets Using Genetic Algorithms. Microwave and Optical Technology Letters 51(11), 2668–2671 (2009)
10. Abd-Alhameed, R.A., Zhou, D., See, C.H., Excell, P.S.: Design of Dual-Band Quadrifilar Spiral Antennas For Satellite-Mobile Handsets. Microwave and Optical Technology Letters 52, 987–990 (2010)
11. Alazhari, K., Abd-Alhameed, R.A., Excell, P.S., Khalil, K.: New designs for single and dual band quadrifilar spiral antennas (QSA) for satellite-mobile handsets. In: IEE International Conference in Antennas and Propagation, Manchester, Manchester, vol. 2, pp. 750–753 (2001)
12. Nakano, H., Okuzawa, S., Ohishi, K., Mimaki, H., Yamauchi, J.: A Curl Antenna. IEEE Transactions on Antennas and Propagation 41(11), 1570–1575 (1993)
13. Colburn, J.S., Rahmat-Samii, Y.: Quadrifilar-Curl Antenna for the Big-LEO Mobile Satellite Service System. IEEE Antennas and Propagation Society International Symposium Digest 2, 1088–1091 (1996)
14. Momentum- 2.5D EM Simulator, Agilent Advance Design Systems, `http://www.home.agilent.com/agilent/`