International Journal of Microwave and Wireless Technologies, 2017, 9(1), 197–203.
doi:10.1017/S1759078715001117

RESEARCH PAPER

Total efficiency enhancement of X-band compact choke horn antenna with circular polarization and isoflux pattern

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This paper presents a solution to reduce the feed complexity and to improve the total efficiency of X-band compact choke horn antenna with circular polarization and isoflux pattern. This kind of antenna had been designed before by our laboratory for nanosatellite applications, but it required a 4-way divider with phase shifter which generates the insertion losses and therefore a lower realized gain (RG). Among several feeds, a uniform circular helix antenna has been used here, which produces a satisfying feed without too much damage for the axial ratio (AR) and the isoflux pattern over a 400 MHz radiation bandwidth (8.0–8.4 GHz). Theoretical and experimental results show an AR lower than 5 dB and a RG higher than 0 dB at the limit of coverage, i.e. 65° whatever the azimuth angle (φ).

Keywords: Nanosatellite application, Circular polarization, Compact choke horn, Isoflux pattern, Helix antenna

Received 20 April 2015; Revised 5 June 2015; Accepted 5 June 2015; first published online 29 June 2015

I. INTRODUCTION

For a few years, the choke horn has been used for downlink data-handling [1, 2]. This antenna should often have both isoflux radiation pattern and circular polarization. In the coming years, the development of nanosatellite applications pushes the scientific community to do research on the X-band compact antennas. Unfortunately, an isoflux pattern and a compact antenna are often incompatible. One solution is to make a tradeoff between isoflux pattern quality and antenna size [3]. The maximum antenna dimensions were a diameter of 90 mm and a height of 20 mm above the 3 U nanosatellite platform ($100 \times 100 \times 300\ \text{mm}^3$). We have already conceived a compact choke horn antenna. Excellent results with an axial ratio (AR) lower than 3 dB and a realized gain (RG) higher than −2 dB at the limit of coverage (LOC) whatever azimuth angle (φ) over a 400 MHz radiation bandwidth (8.0–8.4 GHz) have been obtained except for the angle where the gain is maximum ($\theta = 35°$ instead 65°). However, the antenna feed is a 4-way divider with phase shifter (0, 90°, 180°, and 270°). This solution deteriorates the total efficiency and increases the antenna complexity. In this paper, a new electromagnetic feed is presented. It is made of a uniform circular helix antenna. It is organized as follows. First, Section II presents in simulation a comparison between several feeds and gives the best solution. It also deals with its association with the compact choke horn used in [3] on the 3 U platform. The comparison of measured and theoretical results is presented in Section III before a conclusion in Section IV.

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II. ANTENNA DESCRIPTION

In [3], the global design of a compact choke horn fed with four coaxial probes spatially and temporally-shifted by 90° and placed in the same z-plane has been carried out. This design is based on the one from Brachat [4] and scaled down to operate at 8 GHz. It has been optimized to obtain a good

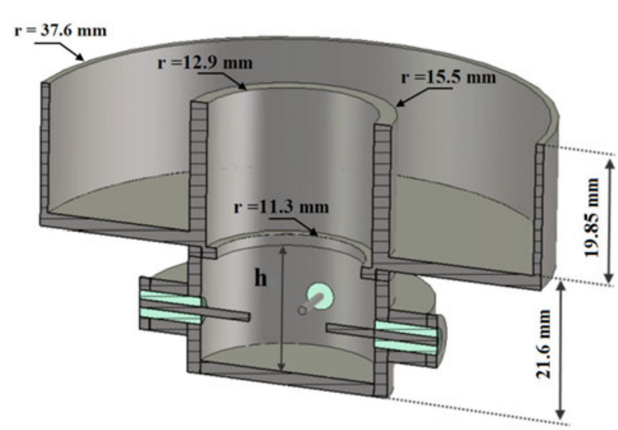

Fig. 1. Design of the compact choke horn.

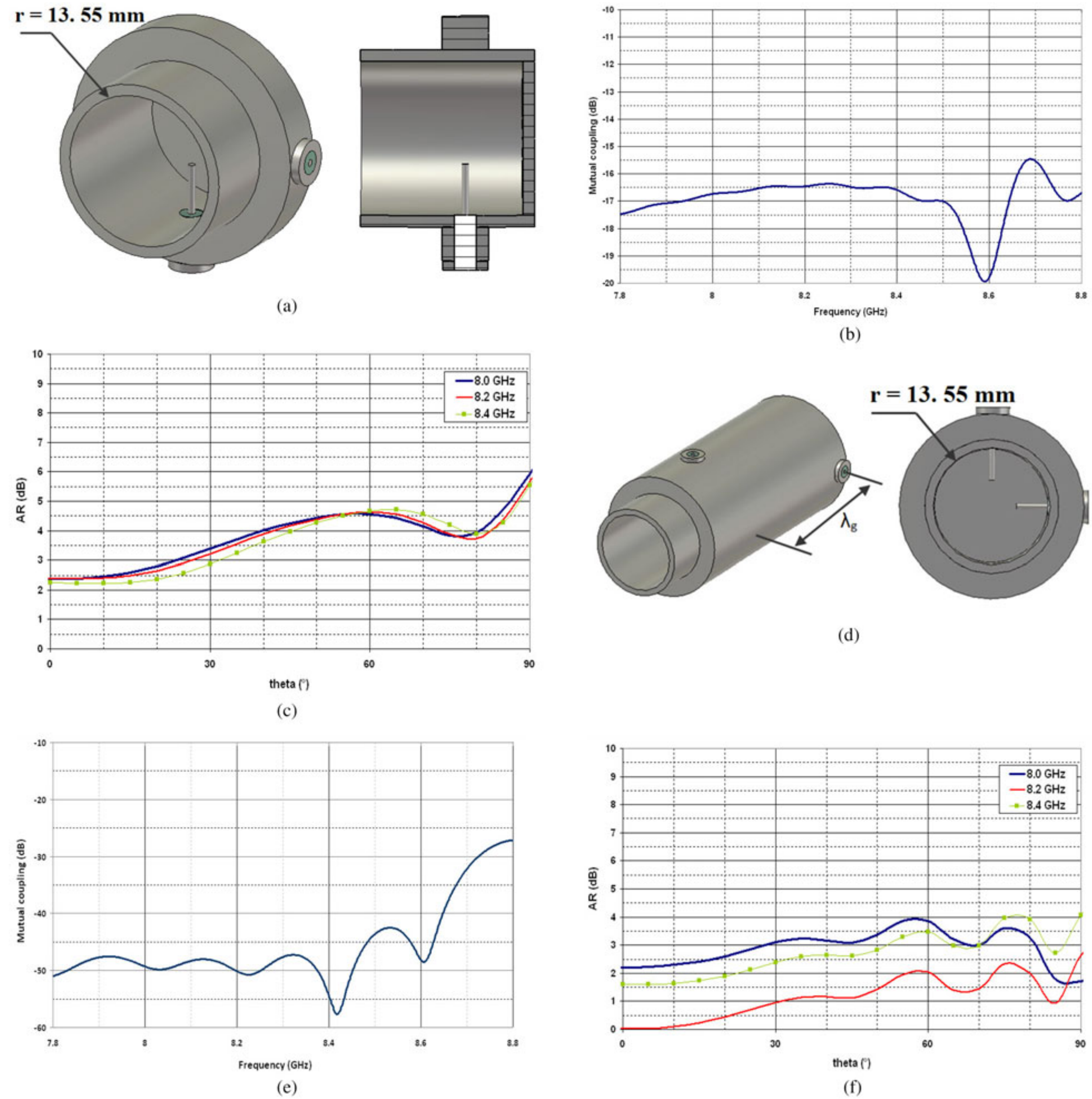

Fig. 2. Case 1: two coaxial probes in the same *z*-plane (a), mutual coupling (b), simulated AR radiation patterns ($\varphi = 0^{\circ}$ plane) (c). Case 2: two coaxial probes in different *z*-planes (d), mutual coupling (e), simulated AR radiation patterns ($\varphi = 0^{\circ}$ plane) (f).

AR respecting the mechanical constraints. Figure 1 shows this antenna design with four coaxial probes but without the 4-way divider with phase shifter (0, 90°, 180°, and 270°). Now we have to replace this complex feed with a simpler one providing lower insertion losses and easier to realize. It is also essential to keep a good AR.

A) Comparison between several antenna feeds

All waveguide polarizers have a metallic or dielectric film in the middle of a waveguide, a sloped or stepped septum that are not suitable for this application because of their size. Three other feeds have been tested using CST Microwave Studio:

– Two coaxial probes
– Ring probe
– Helix antenna

1) TWO COAXIAL PROBES

The simplest configuration is the case 1 which requires two coaxial probes, spatially and temporally-shifted by 90° at the central frequency (8.2 GHz), and placed in the same z-plane (Fig. 2(a)). The waveguide output has been extended by 20 mm for the establishment of the propagation modes. The AR radiation is then obtained. This configuration does not work properly because of the too high coupling between the probes (S21 > -20 dB) (Fig. 2(b)), which increases the AR in the $\varphi = 0^{\circ}$ cut-plane (Fig. 2(c)). This coupling, which can be either constructive or destructive, depends on the phase

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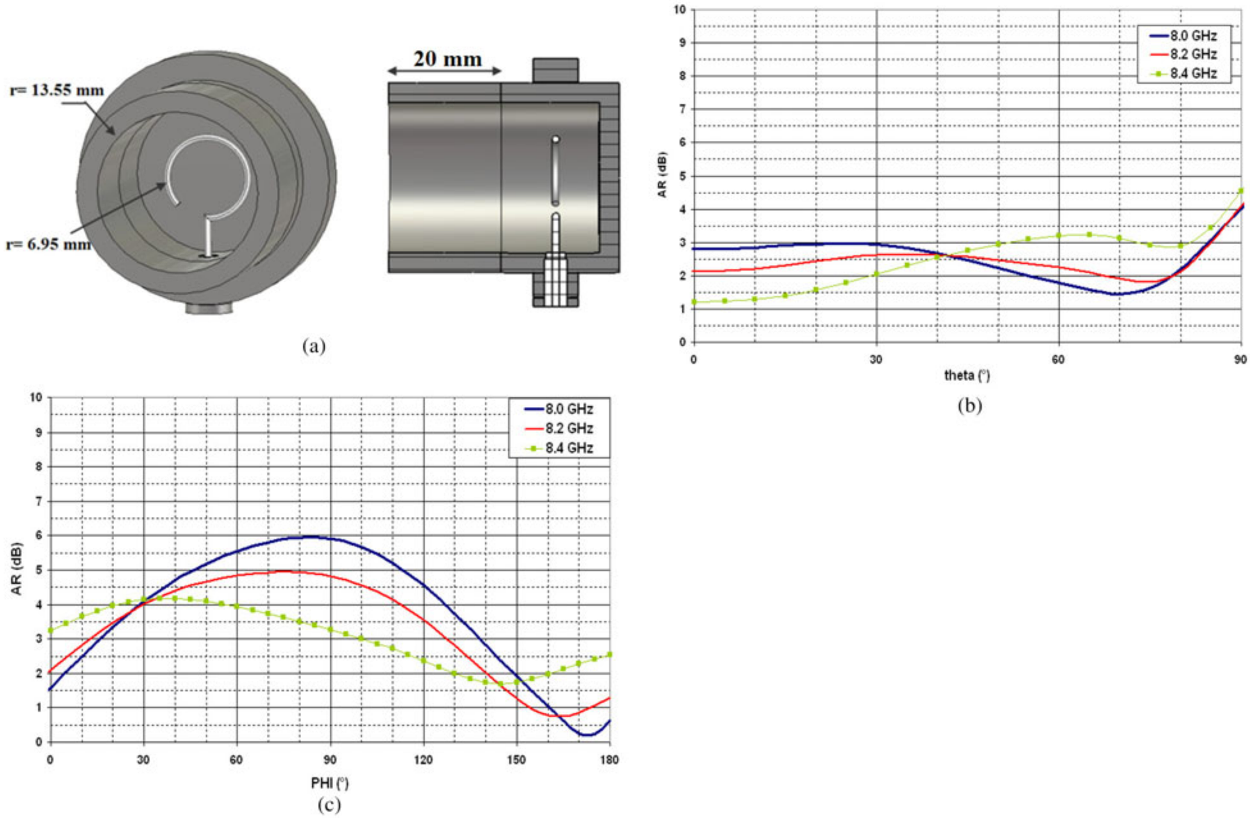

Fig. 3. Design of ring probe (a), simulated AR radiation patterns ($\varphi = 0$ plane) (b), simulated AR at $\theta = 65^{\circ}$ versus azimuth angle (c).

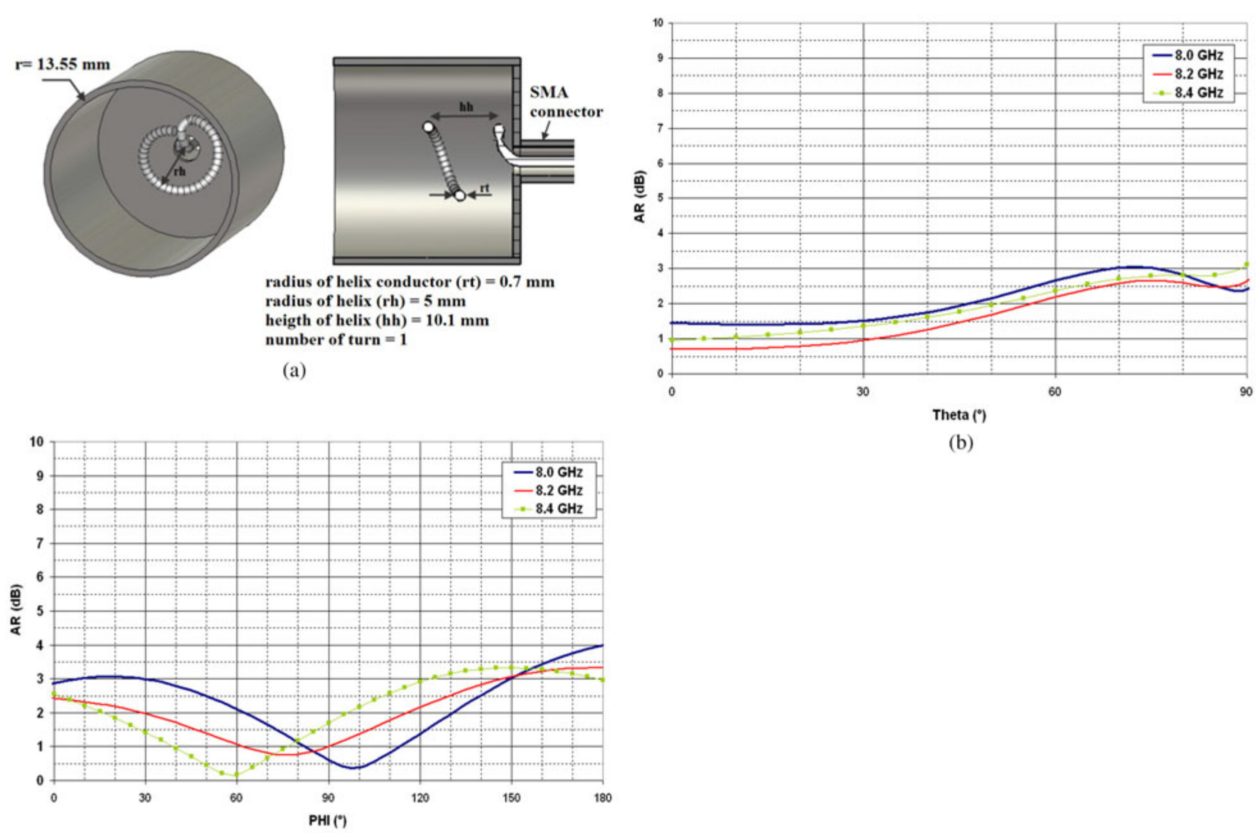

Fig. 4. Design of helix antenna (a), simulated AR radiation patterns ($\varphi = 0^{\circ}$ plane) (b), Simulated AR at $\theta = 65^{\circ}$ versus azimuth angle (c).

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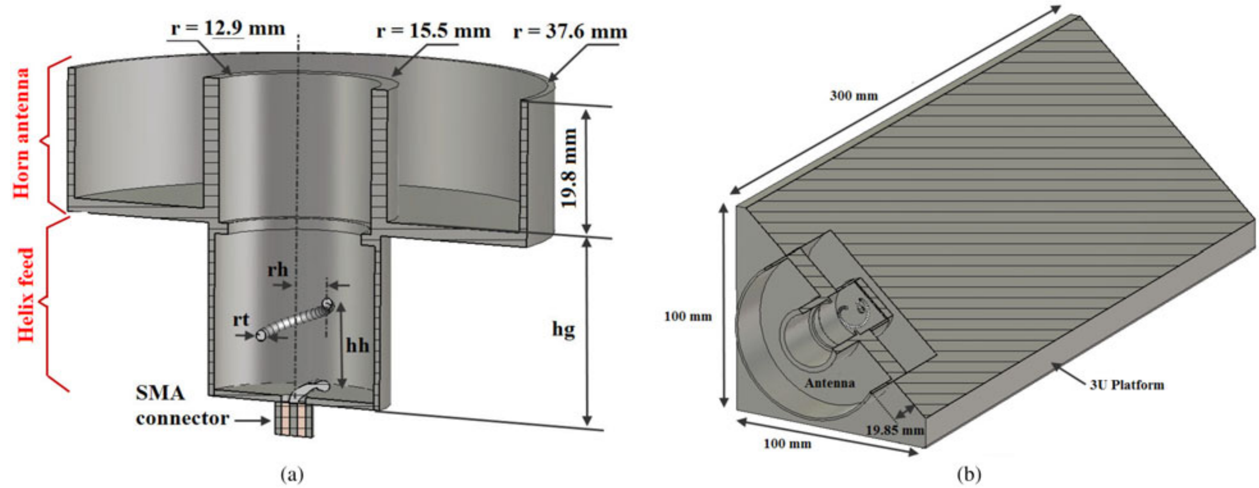

Fig. 5. Simulation of the whole antenna (a), simulation of the whole antenna on the platform 3 U (b).

Table 1. Parameter dimensions.

Parameter	**Dimension in mm**
H_g	27.4
R_t	0.8
R_h	5.7
H_h	12.9

shift between the ports and results in a difference between the E_θ and E_φ electric field amplitudes [5]. It is therefore beneficial to add a guided wavelength (λ_g) between the coaxial probes (Fig. 2(d)) which will decrease the mutual coupling (S21 < -40 dB) (Fig. 2(e)). In this case 2, the AR is acceptable. However, this solution cannot be retained due to its size and its frequency dependence.

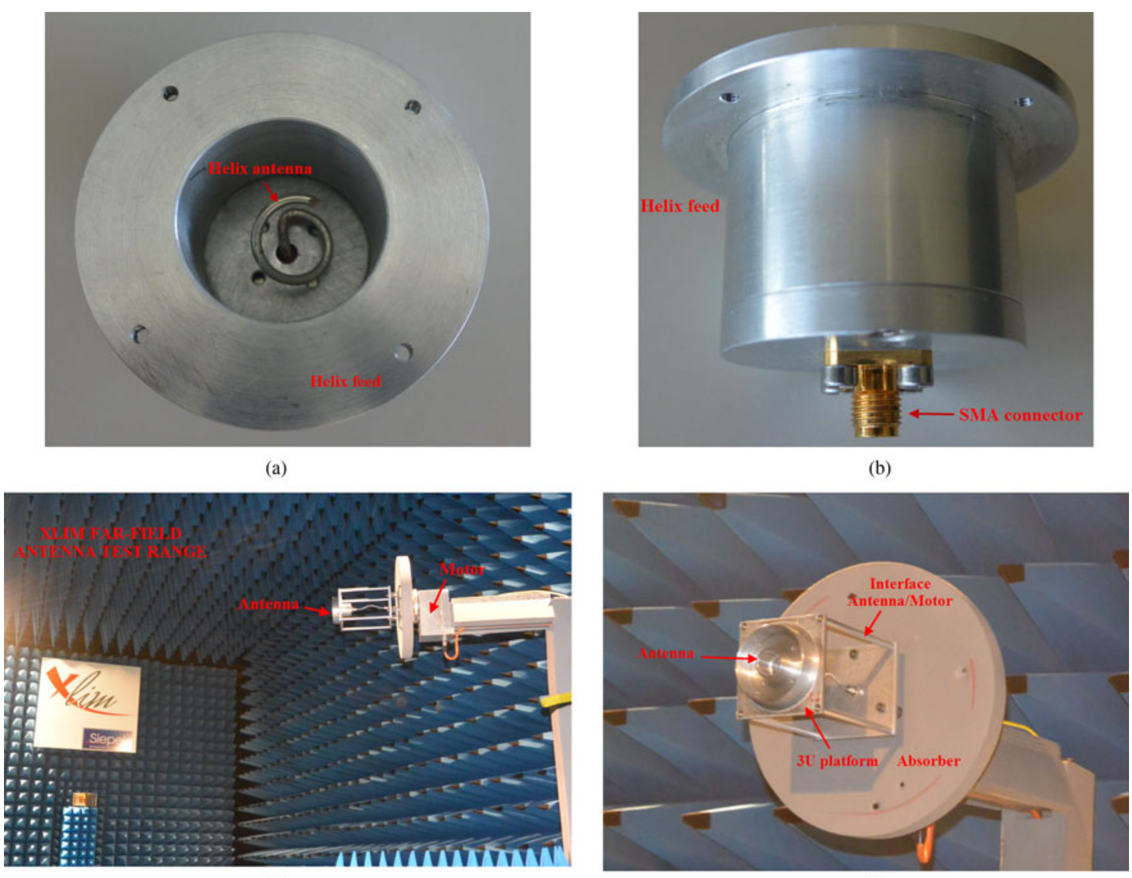

Fig. 6. View of the helix feed (front view) (a), view of the helix feed (bottom view) (b), photography of the manufactured antenna positioned on our antenna test range support (c), photography of the manufactured antenna positioned on our antenna test range support (zoom) (d).

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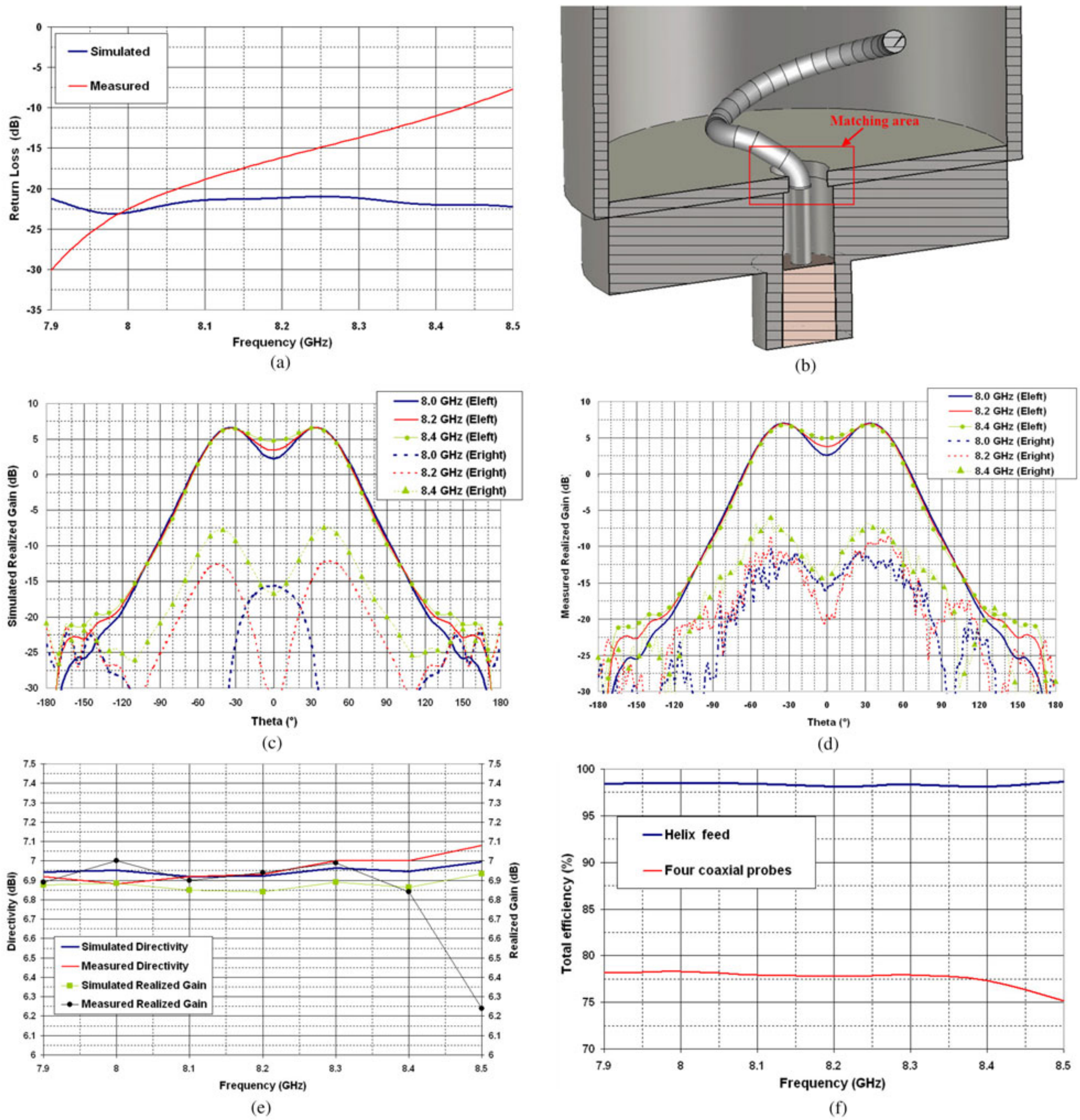

Fig. 7. Return loss (a), matching area (b), simulated RHCP and LHCP radiation patterns ($\varphi = 0^\circ$ plane) (c), measured RHCP and LHCP radiation patterns ($\varphi = 0^\circ$ plane) (d), directivity and maximum RG (e), simulated total efficiency (f), RG at $\theta = 65^\circ$ versus azimuth angle (g), AR radiation patterns ($\varphi = 0^\circ$ plane) (h), AR at $\theta = 65^\circ$ versus azimuth angle (i).

2) RING PROBE

The design is based on the one from Kunpeng Wei [6] and scaled up to operate at 8 GHz (Fig. 3(a)). The waveguide output has been extended by 20 mm for the reasons aforementioned. Figure 3(b) presents the simulated AR radiation patterns ($\varphi = 0^\circ$ plane) and shows that this solution is not efficient. It is too sensitive to the frequency. Moreover, Fig. 3(c) shows the simulated AR patterns at $\theta = 65^\circ$ versus the azimuth angle (φ). They depend highly on this azimuth angle. As a result, this feed cannot be kept for this study.

3) HELIX FEED

The helix antenna has been developed by Kraus in 1947 [7]. Several configurations are possible (uniform, tapered end, continuous taper, non-uniform, etc.) with a single or several metallic conductors. In our case, a uniform circular helix feed has been designed with a single winding and turn to minimize the height (Fig. 4(a)). Figures 4(b)–4(c) show that the feed has correct performances of AR over a 400 MHz radiation bandwidth. This solution is kept for the following study. This feed will be associated with the compact choke horn used in [3] and installed on the 3 U platform simulating a nanosatellite to obtain the final structure.

B) Simulation of the whole antenna

The helix feed is then installed into the horn input (Fig. 5(a)) and the whole antenna obtained on the 3 U platform is shown in

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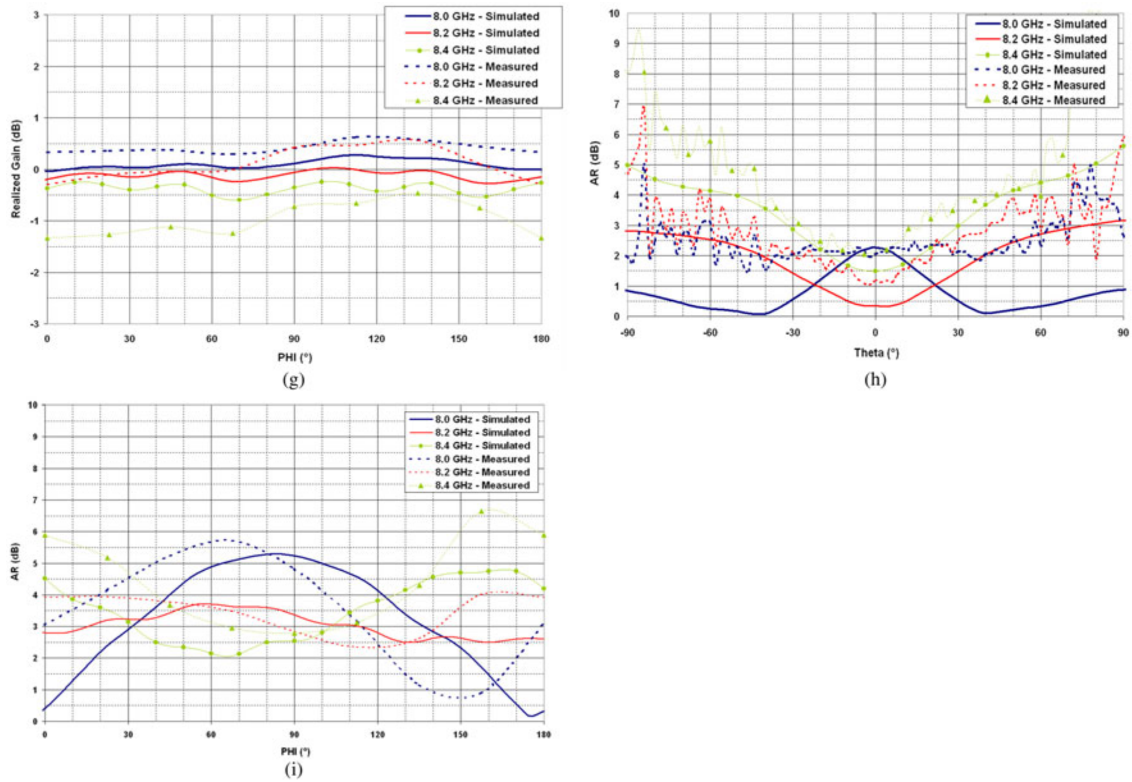

Fig. 7. (continued)

Fig. 5(b). It is not possible to keep the helix parameters when it is associated with horn. Therefore, a new optimization has been made, by changing the value of the waveguide height (H_g), the helix conductor radius (R_t), the helix radius (R_h), and the helix height (H_h). The final dimensions are indicated in Table 1.

III. MEASUREMENT AND SIMULATION VALIDATION

A prototype has been realized and measured in our Far-Field Antenna Test Range (Figs 6(a)–6(d)). Figure 7(a) shows a good matching over the desired radiation bandwidth. However, a difference appears between simulation and measurement. The matching antenna depends greatly on the mechanical accuracy of the helix and its positioning at the waveguide input (Fig. 7(b)). Figures 7(c)–7(d) show the left hand circular polarization (LHCP) and the right hand circular polarization (RHCP) radiation patterns (RG drawn in the $\varphi = 0^\circ$ cut-plane) in simulations and measurements. An isoflux shape over the entire frequency band is obtained but the RG is maximum at the $\theta = 35^\circ$ angle instead of $\theta = 65^\circ$. This is the same for the antenna studied in [3]. The simulated and measured directivity are similar (Fig. 7(e)) in the studied bandwidth. The maximum RG are comparable over a 400 MHz bandwidth with a measurement tolerance of ± 0.8 dB. We can see a real improvement on the total efficiency which is close to 100% (taking into account the measurement tolerance) instead of the 80% previously obtained in [3]. Figure 7(f) shows this comparison of the simulated total efficiency. The simulated RG is almost greater than 0 at the LOC whatever the azimuth angle (φ) instead of -2 dB in [3]. The measured RG is slightly lower than the simulated ones (Fig. 7(g)). On the other side, the horn changes the AR quality of the helix feed (Figs 7(h) and 7(i)). In the frequency band, the maximum AR is approximately 5 dB which is not suitable for such a space mission but for other ones less restrictive. Increasing the number of turns of the helix will improve this characteristic at the detriment of the antenna compactness [7]. The AR measurement results are similar to the simulation up to $\theta = \pm 50^\circ$. Beyond, the mechanical support effects such as the interface "antenna/motor" degrade this parameter.

IV. CONCLUSION

This paper completes previous work on an X-band compact choke horn antenna with circular polarization and isoflux pattern for nanosatellite applications. The feed of this last one was made of four coaxial probes requiring the use of a 4-way divider with phase shifter (0, 90°, 180°, and 270°). The insertion losses of this device degrade the total efficiency and it increases the realization complexity. A new antenna feed using a uniform circular helix antenna has been proposed and applied to the design. Excellent numerical results have been obtained with a total efficiency close to 100% on the 8.0–8.4 GHz frequency band. On the other side, the simulated AR quality is less efficient than the first case, about 5 dB instead of 3 dB on the LOC whatever the azimuth angle (φ). This kind of antenna is suitable for missions less restrictive than the one developed here. A prototype has then been realized to demonstrate the feasibility of such a structure. The measurement results are in excellent agreement with the theoretical ones.

https://doi.org/10.1017/S1759078715001117 Published online by Cambridge University Press

ACKNOWLEDGMENT

The authors would like to thank Centre National d'Etudes Spatiales (CNES) – FRANCE who has financially supported this study.

REFERENCES

[1] Ravanelli, R.; Iannicelli, C.; Baldecchi, N.; Franchini, F.: Multi-objective optimization of an isoflux antenna for LEO satellite down-handling link, in Microwave Radar and Wireless Communications (MIKON), 2010 18th Int. Conf. on, 14–16 June 2010, pp. 1–4.

[2] Jeon, K.-J.; Lee, K.-I.; Son, J.-G.; Lee, T.-K.; Lee, J.-W.; Lee, W.-K.: X-band isoflux pattern antenna for SAR data transmission, in Synthetic Aperture Radar (APSAR), 2011 3rd Int. Asia-Pacific Conf. on, 26–30 September 2011, pp. 1–4.

[3] Arnaud, E.; Duchesne, L.; Elis, K.; Fouany, J.; Monediere, T.; Thevenot, M.: X-band compact choke horn antenna with circular polarization and isoflux pattern for nanosatellite applications. Int. J. Microw. Wireless Technol., available on CJO2015. doi: 10.1017/S1759078715000677.

[4] Brachat, P.: Sectoral pattern synthesis with primary feeds. IEEE Trans. Antennas Propag., **42** (4) (1994), 484–491.

[5] Arnaud, E.; Rodes, E.; Thevenot, M.; Chantalat, R.; Monediere, T.: Achievements on circularly polarized horn-fed metallic electromagnetic band gap antenna design. Int. J. Microw. Wireless Technol., **5** (4) (2013), 507–520.

[6] Wei, K.; Zhang, Z.; Zhao, Y.; Feng, Z.: Design of a ring probe-fed metallic cavity antenna for satellite applications. IEEE Trans. Antennas Propag., **61** (9) (2013), 4836–4839. doi: 10.1109/TAP.2013.2264453.

[7] Volakis, J.L.: Antenna Engineering Handbook, 4th ed. Helical Antennas, Chapter, McGraw-Hill Professional, United States, 2007 1993 1984 1961.

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